TEKNILLINEN TIEDEKUNTA

USED ELECTRIC VEHICLES LITHIUM-ION BATTERIES IN THE CIRCULAR ECONOMY CONTEXT - A SYSTEMATIC LITERATURE REVIEW

Ollimarkus Tiainen

INDUSTRIAL ENGINEERING AND MANAGEMENT

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ABSTRACT

Used electric vehicles lithium-ion batteries in the circular economy context – a systematic literature review

Ollimarkus Tiainen

University of Oulu, Industrial Engineering and Management

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Supervisors at the university: Jukka Majava, Pasi Rönkkö

Countries around the world aim to reduce the greenhouse gas emissions from gasoline powered cars and as a solution to reduce these emissions electric vehicles (EV) have emerged. EVs run on lithium-ion batteries (LIBs) and therefore do not cause greenhouse gas emission due to not using gasoline in their engines. However, when more and more EVs are manufactured the LIBs that give them their power naturally become more and more regular as well and this poses a problem for people and countries of the world as well as to our environment. LIBs hold valuable and scarce materials like cobalt (COB), lithium (LI), graphite (GRA) and manganese (MAN) that can cause harm for the environment if handled incorrectly. Furthermore, after EV LIBs have reached their end-of-life in EVs they still hold enough capacity to be applied to entirely other uses, like buildings. To combat and solve these environmental and potential second life applications for EV LIBS and the materials they hold, CE and its many practices and methods have been proposed as a solution to slow and close the resource loops and offer new second life applications to EV LIBs. The goal of this thesis is to review how EV LIBs second life applications are considered in the CE context currently in the existing literature by performing a systematic literature review (SLR) on the topic. Focus was directed on the current state of the studies on the matter and possible challenges there still are in adopting CE models to EV LIBs. Results show that research to the topic is picking up pace, which is needed because current CE methods in recycling, reusing and repurposing EV LIBs are not efficient enough to be applied on a mass scale across the world due to not being environmentally nor economically feasible as it currently stands.

Keywords: Circular Economy, Electric Vehicles, Lithium-ion Batteries, Second Life, Recycling

TIIVISTELMÄ

Käytettyjen sähköautojen litium-ioni-akkujen kiertotalous – systemaattinen kirjallisuuskatsaus

Ollimarkus Tiainen

Oulun yliopisto Tuotantotalous

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Ohjaajat: Jukka Majava, Pasi Rönkkö

Useat maat ja niiden hallitukset ympäri maailman tähtäävät bensiiniautoista johtuvien kasvihuonekaasupäästöjen vähentämiseen siirtymällä yhä enemmän sähköautotuotantoon saavuttaakseen tavoitteensa päästöjen vähentämisestä. Sähköautot toimivat litium-ioni-akuilla ja näin ne eivät aiheuta bensiinin palamisesta koituvia päästöjä ja niistä koituvia ympäristö- ja ilmakehärasitusta. Kuitenkin, koska sähköautoja valmistetaan yhä enemmän ja enemmän niiden virtalähteenään käyttämät litium-ioni-akut yleistyvät samaa tahtia yhdessä sähköautojen kanssa aiheuttaen haasteita globaalisti ja paikallisesti valtioille, väestölle ja ympäristölle. Sähköautojen akkujen valmistamiseksi on käytetty kallisarvoisia uusiutumattomia materiaaleja, kuten kobolttia, litiumia, grafiittia ja mangaania, jotka aiheuttavat ympäristöllisiä ongelmia, mikäli niitä ei käsitellä oikein virtalähteenä toimisien päätyttyä. Kun litium-ioni-akut eivät ole enää käyttökelpoisia sähköautojen energianlähteenä, niiden sisältämää kapasiteettia voidaan muissa hyödyntää monissa muissa käyttökohteissa, kuten esimerkiksi rakennuksissa. Erilaisten ympäristöongelmien ja tehokkaan uusiokäytön saavuttamiseksi on ehdotettu akkujen sisältämien materiaalien kiertotaloutta, jonka avulla voidaan hidastaa ja sulkea resurssisilmukoita ja edesauttaa akkujen uusiokäyttöä. Tämän tutkimuksen tavoitteena on tutkia systemaattisen kirjallisuuskatsauksen avulla, kuinka käytettyjen sähköautojen akkujen uusiokäyttö on tällä hetkellä mahdollistettu kiertotalouden malleilla ja metodeilla. Tutkimuksessa keskityttiin olemassa olevien tutkimusten nykytilaan ja näkemykseen, sekä mahdollisiin haasteisiin, joita kiertotalouden mallien käyttöönottamisessa on käytettyjen sähköautojen litium-ioni-akkujen suhteen. Systemaattisen kirjallisuuskatsauksen tulokset osoittavat, että tutkimus aiheeseen on yleistymässä, joka on tarpeellista, sillä nykyiset kiertotalouden metodit/toimintatavat eivät ole ympäristöllisesti ja taloudellisesti sillä tasolla, jotta niitä voidaan ottaa käyttöön maailmanlaajuisesti, jolloin litium-ioni-akut niistä voisivat hyötyä.

Avainsanat: Kiertotalous, Sähköautot, Litium akut, Uusiokäyttö, Kierrätys

FOREWORD

This thesis was completed as part of the master's degree program in Industrial Engineering and Management at the University of Oulu. Aim for this thesis is to review the existing literature in order to build a comprehensive picture how used EV LIBs are addressed in the CE context on this day and age. The first steps in starting this thesis were made during February 2022 and the closing touches were made in June 2022 before the midsummer celebrations. The task of writing this thesis was challenging but at the same time an experience I wouldn't change for nothing. I was able gain knowledge into a topic I was personally interested even before choosing the topic for the thesis and in addition to that I learned valuable skills on academic writing.

I would like to thank first and foremost to my supervisors Jukka Majava and Pasi Rönkkö for their instructions, help and understanding during the writing process. Meetings on the progress of the thesis were helpful for me and I got great advice how to improve the thesis every time. Also, I have to express my gratitude for Jaana Suojärvi from Oulu university library who helped me greatly during the information retrieving phase of the thesis.

I would also like to express my gratitude towards my family for supporting me all the way through my studies cultivating in completion of this thesis. Now onwards to a new chapter in life.

TABLE OF CONTENTS

LIST OF ABBREVIATIONS

BM Business Model

CE Circular Economy

COB Cobalt

EV Electric Vehicle

GRA Graphite

LI Lithium

LIB Lithium-ion batteries

LBM Linear Business model

MAN Manganese

NI Nickel

RQ Research Question

SLR Systematic literature review

1 INTRODUCTION

1.1 Background of the study

In countries among European Union almost 75% of the greenhouse gas emissions are caused by traditional road network transportation by passenger cars and transport trucks alike. These emissions caused by transport have been rising rapidly since 2014, despite of the fact there have already been laws and regulations that have been in place since the early 2010s. However, these regulations have not been followed accordingly. During the year 2019 EU put in place a new regulation to whole union which aim to limit emissions for light duty vehicles that (if taken seriously) would see emissions decrease by 15% from 2025 like Albertsen et al. (2021) stated. One invention that will help to achieve this goal are electric vehicles.

Electric vehicles are transportation means that run wholly or partly with lithium-ion batteries and could help to solve greenhouse gas emissions issue on some level (other action is naturally also needed). Moreover, when one issue solves itself a new one emerges.

In the future, when electric vehicles become more common, a growing number of them will retire from active transportation use every year. This causes problems because LIBs are, if left lying around unchecked harmful to environment so they need to be recycled, which is as it currently stands, costly and time consuming. However, after these batteries are retired from electric vehicle use, they still hold enough capacity that can be reused in new EVs as their batteries or for entirely new purpose other than EVs Olsson et al. (2018). Current recycling methods are not however up to date to efficiently separate and further process the reusable materials from the batteries nor are the laws and policies designed in a way that they push corporations towards recycling. These problems lead to a current situation where recycling of LIBs is not either economically or environmentally efficient way to proceed.

CE and its practices and models have been suggested to solve this problem. This thesis was made in order to address how the current literature can answer the issue of reuse/ repurpose and recycling of electric vehicle batteries with the help of circular economy.

1.2 Research objective and questions

The goal of this thesis is to determine the current research situation of how CE currently address and fits used EV LIBs second life use, challenges in reuse and future possibilities. Focus of the research is on reuse, recycling and second life applications and challenges.

In order to investigate the goals of the thesis thoroughly following research questions (RQ) were set for the thesis.

RQ1 How are reuse, recycling and second life applications of EV LIBs addressed in circular economy context currently?

RQ2 What kind of challenges are there when adopting current circular economy models and practices to used EV LIBs?

First question aims to focus on the current state of studies and research on the matter.

Second question addresses the need for further development in CE models and practices for them to help with EV LIBs second life use.

1.3 Research structure

This thesis follows a structure presented below and it is done in two phases:

1. Literature review
2. Analysis, results and discussions

During the literature review previous relevant studies on the topic are presented. Literature review presents topics such as circular economy, circular business models, electric vehicles and lithium-ion batteries and an introduction what is a systematic literature review. In the second phase of the thesis chosen articles are analyzed, discussion on the topic is held and results are presented.

2 LITERATURE REVIEW

Because the topic of this systematic literature review is still in need of further research and clear CE business models (BM) for electric vehicle (EV) LIBs is yet to be laid out, before analyzing the topic of the thesis, CE and the potential of EV LIBs need to be studied in more detail.

In the next few following chapters, we will focus on the main topics of this thesis paper on a conceptual level, in order to understand them so we can in later chapters produce the best possible analysis and discussion of them. These topics that we will be covering are CE and EV LIBs. We look at the historical beginnings of the subjects, their definitions and the links between them by doing a narrative literature review.

2.1 The history of circular economy

The credit of inventing the ideology called circular economy (CE) can not be given to any single person or even a group of scholars, a fact that makes identifying the origins of CE virtually impossible. As a term CE did not even appear until the year 1990, study by Pearce et al. (1990) discussed how every economic and environmental act and process are always linked between each other, this led to the formulation of the term CE. Even before that there have been studies and scholars that influenced the forming of the term and concept of CE greatly. Study by Winans et al. (2017) gives credit to Professor John Lyle, to chemist Michael Braungart and economist Walter Stahel by stating that these researchers highly influenced the forming of CE as its own concept in their respective studies and gives credit also to scholar called Rachel Carson on her work in her thesis called "limits to growth".

Systematic literature review of CE by Merli et al. (2018a) suggests that the concept and study of CE formed overt time across multiple years when researches and scholars studied a branch of science called industrial ecology and gradually over time these studies developed into own branch of studies and ideologies in academic world by drawing from industrial ecology. They also state that the concept of CE was first time introduced back in 1966 by Boulding (2013) in his study. Reason behind for this statement is that Boulding discussed in his work the idea of closed systems. He introduced this idea of closed systems in order to demonstrate how many of the resources we use in products are actually limited and non-renewable even though we use them every day and produce constantly more of them.

As we can see scholars have different views on how the study and even the term CE was first introduced to us. It is hard to pinpoint when the study of CE actually begun because it is a vast field of study with many different focus points and implications to many different fields of study. CE draws from various different fields of study and some of these fields predate it quite significantly. CE has also developed differently in different locations around the globe. This is a result stemming from the many cultures, social and political issues in different parts of the world, so in order to be usable concept and ideology, CE needed to develop differently in some areas to others as stated by Winans et al. (2017). CE is also constantly developing and therefore able to adapt to many different uses, and this is something to keep in mind in regard to this thesis.

2.2 Circular economy and its many names

Now that we have looked at the historical development of CE, it is time for us now, before tackling CE in regards of this thesis, to look at what it actually means. We will do this by looking at how the most cited and read papers define CE and try and come to a conclusion ourselves. This is all done in order try and find some definition by looking through multiple research papers and books.

During the 21st century circular economy has attracted more and more interest from both authorities and scholars alike. However, this has not led to a unified definition or understanding of CE as a term, instead CE is defined differently by many scholars in their studies and means different things to every other people as pointed out by Kirchherr et al. (2017). We will look at the most relevant definitions in regards of this thesis in the ensuing chapter.

In their research Kirchherr et al. (2017) aimed to shed light on to how CE is defined amongst scholars nowadays. They accomplished the results of their study by means of collecting 114 definitions of CE and then coding them on 17 dimensions. This method of research yielded a following definition to CE. Researchers were able to determine that for most people in most cases CE means combination of processes related to recycle and reuse. One important finding was also that in most definitions of CE it is not clearly or alarmingly at all stated that in order to benefit and even get CE activities to work, a systematic change is needed. This systematic change refers to laws, regulations and social aspects within countries. This finding is extremely important in regards of this thesis, because CE practices in regards of EV batteries are not currently up to date and some of the blame can be put on to inability to recognize the importance of systematic change.

In their research Murray et al. (2017) find similar result as Kirchherr et al. (2017) in theirs in regards of material and resource recycling as well as the fact that processes need to be revamped to fit CE, but also add that these points their findings that when CE is used on corporations the use of it might in some cases lead to limitations and tensions because of the fact that CE as concept and ideology is missing social dimensions which if added would help with this problem Murray et al. (2017) propose entirely new definition for CE as "economic model wherein planning, resourcing, procurement, production and reprocessing are designed and managed, as both process and output." This would in their view maximize human wellbeing and ensure the best possible function/ operating of our ecosystem.

Korhonen et al. (2018) study tries to define and develop the many different definitions of CE amongst researchers. They find that CE definitions can be divided into two subgroups by where they get the inspiration to their definition. The first group cites or uses the definition of Ellen MacArthur Foundation. EAMFs definition of CE can be summarized as follows. CE at its core level is a business strategy. It has many different ideas and methodologies by which using corporations and governments can change their linear systems into circular ones. These systems range from manufacturing activities all the way to consumption

The other CE definitions group that Korhonen et al. (2018) propose in their research is one where writers of article on CE base their definitions on their own, or others previous research and definitions. There are many different definitions in this group, but a general summary definition is that CE is a model/ a way of thinking that can be used to achieve economic development which lead to better environment. Similarly, as with the historical origins of CE, the definition of it is debated. From these definitions we can conclude that CE does not have a clear definition, indeed it has a multitude of different ones. This can be because of various stakeholders, such as law and policymakers, businesses, researchers, consumers, etc. are very much interested in it. In fact, one universal definition would be close to impossible to achieve because of the various different interested stakeholders and should not even be attempted. If done it would always- no matter how wide of a definition- exclude some parties specific interests and views. Moreover, this universal definition could interrupt and therefore derail the constant development of CE ideology as currently it is gaining more and more interest and evolving constantly. This would be harmful for the future applications of CE and furthermore to our world as CE as an ideology and a way of thinking can be important in future economic growth for corporations and governments and environmental stability all around the globe as Korhonen, Nuur, et al. (2018). This lack of universal definition should not be taken as a sign to not develop CE as a concept and try and adapt new policies and practices.

Even though Murray et al. (2017) in their research suggest a new definition to CE, perhaps the view that there should not be any clear definition of CE at all like Korhonen, Nuur, et.al (2018) stated is the best definition to CE at its current state. Regarding this thesis this is the definition we keep in mind as CE need to evolve and be developed into something more in order for it to work with EV battery reuse purposes. When we remember that we can take comfort from the fact that lack of clear definition is in fact a richness in case of circular economy.

2.3 CE business models closing and slowing loops

Now that we have looked at the complex history of CE and the difficulties in establishing an unified definition of CE as a term it is time for us to explore CE business models and their applications. This is vital part of the thesis as without understanding the current CE models it is impossible to see their potential and limitations in regards of EV LIB second life usage. This part is established by presenting the most used and popular CE business models by other scholars.

The traditional linear business model (LBM) can be summarized as follows: take materials-make products with these materials-use the products produced-dispose the used products in landfills. Production with LBMs depends traditionally greatly on the use of fossil fuels as an energy source and materials produced with LBMs on the other hand are used once and after they are used to their maximum utility they are disposed and never thought of again without even considering recycling or reuse possibilities. Circular business models are different in many regards from these traditional LBMs. This is because of (according to research by) N.M.P. Bocken et al. (2016a) CE business models (BMs) aim by different means and actions regarding production, product design and waste management to close these LBMs into a loop where materials, resources and products can continuously be reused and recycled and therefore are circular. This enables a second life for resources used in production and products produced. Also, renewable resources and energy sources are favored over fossil fuels and non-renewable materials. These renewable resources are utilized whenever and where-ever possible in this closed loop systems and should be taken into account already in the product design phase in order to enable their use. Furthermore, this fact is emphasized in research by Bocken & Ritala (2022) where they state that with CE BMs the way manufacturers and product designers use resources in production and plan/design products can greatly be improved by CE BMs so the use and designing becomes more economically and environmentally beneficial. These are the core fundamental ideas of CE and its BMs.

In their research of CE BMs N.M.P. Bocken et al. (2016a) distinguish two different main categories for CE BM. The first of these two is called “Slowing resource loops” and the second “Closing loops”. Slowing loops basically means that the aim of the BMs that fit in this category is to drag out/slow down the initial usage and reuse of materials and resources over their lifetime for as long as possible thus reducing the need to produce new product and use new resources in their production. This is achieved by designing new “long life goods” and majorly growing the life of every product produced under this BM. Ellen MacArthur Foundation (2015) adds to this by suggesting that reuse through technical life and proper well-designed maintenance are also vital in slowing resource loops.

In closing loops CE BM category, the focus and aim is to try to reuse every material, resource and product through recycling procedures designed to enable maximum reusability for resources embedded in products during their initial production. Fehrer & Wieland (2021) point out how communication amongst all the stakeholder is vital in order to close the loops. This is because communication ensures that all parties that are within the value-chain are informed on the necessary steps to close the loops.

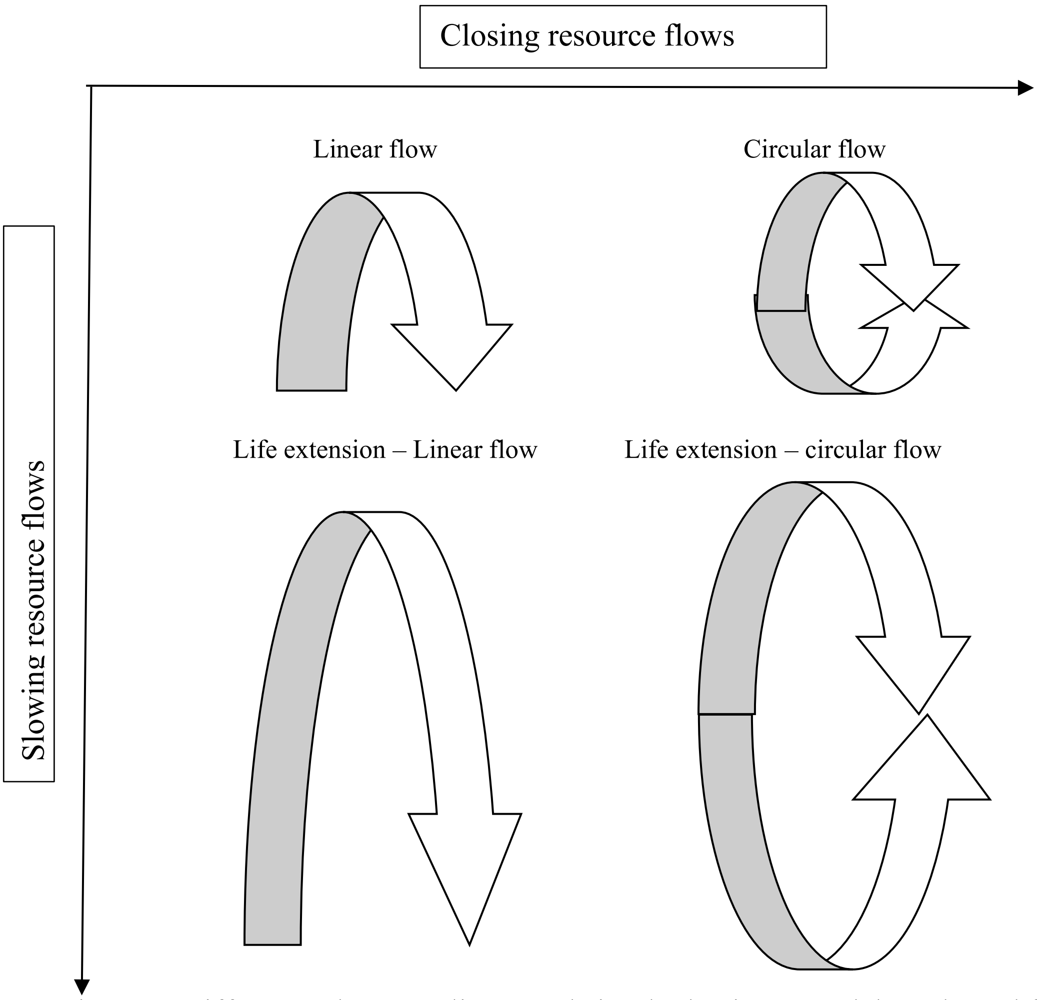

Figure 1. Differences between linear and circular business models. Adopted from Bocken et al. (2016a)

When companies manage to extend the periods that their products can be used (Slowing resource loops BM) it can have major positive results in reducing the need to obtain new materials and thus great monetary gains and benefits for corporations and therefore giving them competitive advantage against their competitors when money save from not purchasing new resources can be invested elsewhere. Important business strategies to enforce this are for example according to N.M.P. Bocken et al. (2016a) designing the products in a way that they are reliable and durable in every environment (don't break under ideal conditions and rough use). They are designed in a way that maintenance is easy to conduct, so this does not take long labor times and maintenance does not require the use of new resources. Any of the parts used in products should also be designed accordingly to enable easy replaceability and repair. Also, as time goes it is important to design products in a way that possible upgrades to older generation products can be installed as naturally product designers design new products and upgrades to older ones, and earlier products are designed in a way that new “ideas” can be directly adapted to them. With these strategies companies should be able to extend the life of their products and gain competitive edge towards their competitors.

In regards of closing resource loops Bocken et al. (2016a) first state that there are ultimately only two possible outcomes for materials and resources. Resources are either recycled and the reused in some capacity or they cannot be reused or even recycled in any way. It is vital for corporations to be able to secure a continuous flow of resources in a loop rather than a linear flow of materials for multiple reasons. Used products and waste resources should be recycled into (new) materials in a way that they can be used in a same way as the “original” materials used in products. N.M.P. Bocken et al. (2016a) also suggested BMs for product and resource development and planning phases in order to close the resource loops. First and foremost, of these BM is “design for technological cycle”. This technological cycle design basically means that products are designed in a way that the materials used to produce them can be safely and easily harvested, recycled and then reused in new products. Other BM suggested is “design for a biological cycle”. In this strategy products should be designed to consume safe and healthy materials (materials that produce food for natural systems). This strategy is designed for products that cannot be recycled so when they are discarded they are used as food. When product designers design products using this BM these products do not pollute environment but actually help it function in a natural way.

Last BM for closing resource loops suggested by N.M.P. Bocken et al. (2016a) is called “design for disassembly and reassembly”. This BM aims to combine both design for technological and biological cycle. Products are therefore designed in a way that they are easily disassembled into parts and can be then reassembled into smaller units which saves space and resources. Moreover, this strategy also helps user to easily distinguish materials from each other and therefore these materials can easily in disassembly phase be separated into their own piles.

2.4 Current understanding of CE amongst scholars

As we have already discussed earlier in this thesis the current linear flow of materials and resources in our world is not sustainable and we will eventually run out of non-renewable materials and resources, like cobalt, nickel and lithium which are all used in EV LIBs. This is the issue discussed further by Korhonen, Honkasalo et al. (2018) in their research where they aimed to conclude the current situation and vision of CE. They conducted their research by going through extensively the earlier research into CE and produced valuable conclusion on the current state and limitations of CE and how it fights to reorganize the linear flow of resource and products into a circular one at this current day.

In their research, they came to a conclusion that indeed CE is the way forward in the future. Korhonen, Honkasalo et al. (2018) that CE with its BMs and strategies is in some cases able to turn earlier mentioned linear flows in reverse circular flows and so doing get resources and materials (recycled) used to produce products into reuse in new products. They also produced a figure that perhaps is the best in explaining how CE turns linear flows into circular ones.

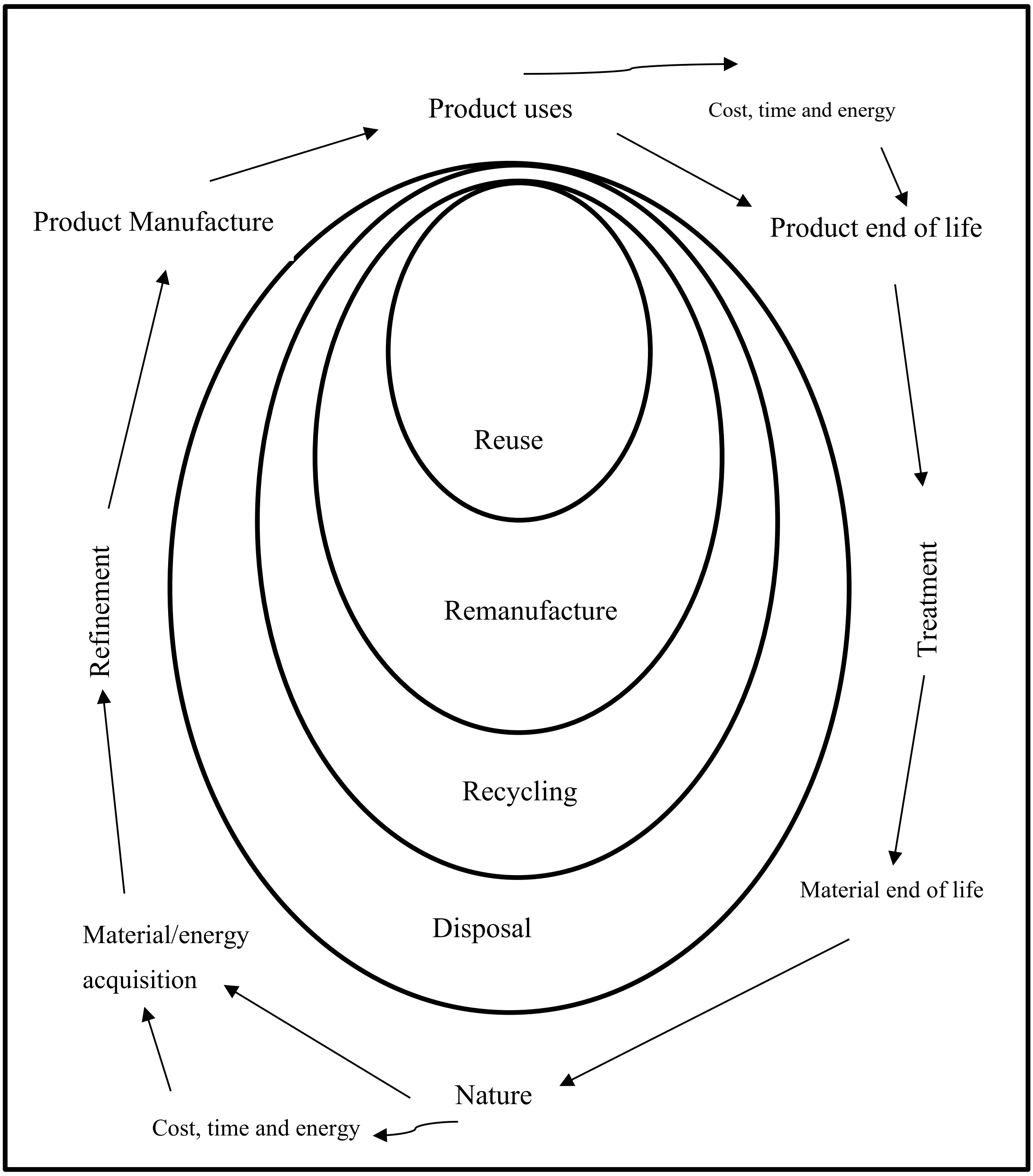

Figure 2. The current ideology of circular economy Adopted from Korhonen et al. (2018)

In figure 2 we can see the current situation of CE define by Korhonen, Honkasalo et al. (2018). In this picture the deeper you go into the circles (from outer circles to inner) the less resources and energy are needed to complete these tasks that the circles represent. The inner circles are also more economical when compared to outer circles, so to operate within inner circles requires less money. This is the reason why timeframe that resources and materials spend in the inner circles should be maximized, as this is more economic for all stakeholders and therefore yields savings and ability to invest elsewhere. In that way more economical gain will be achieved across the whole value-chain.

Figure 2 describes a model (current comprehensive situation of CE) that works as follows (from inner circles to outwards). Materials that have reached the end of their useful life must be at first collected from usage and after that separated from waste for possible reuse, refurbishment or repair (CE activities). When this first step is completed, and all materials are collected after that, one can move to the next circle where products are remanufactured (via different methods) and only after that should raw material be utilized. This way of thinking has been the idea with traditional recycling methods. When following CE principles and recycling practices the act of burning through energy should be second to last option for manufacturers and the last option these corporations should think would be the act of disposing resources/materials. When corporations follow this CE ideology of resource/material use, products that corporations produce can then reach the greatest possible value chain, life cycle and quality for as long as possible (circles enable this). CE model is also more energy efficient and monetarily appealing than the traditional linear one as stated by Korhonen, Honkasalo et al. (2018).

When companies purchase raw materials, they first need to process them before they can be used in production, and this naturally costs money so companies should prefer to use value already produced (products/services) that are in inner CE circles as long as possible. This way economic benefits can be achieved. Environmental benefits via CE use arise from waste and end of life usage via CE methods like recycling, waste is not disposed to nature. CE models also develop traditional recycling where in most cases the recycling is done when most of the value in recycled products is already lost and cannot be reused according to Korhonen, Honkasalo et al. (2018).

2.5 How CE links different stakeholders together

CE BMs and strategies combine, link and benefit many different stakeholders and interested parties in environment and economical world. In their study Lieder & Rashid (2016) conducted a framework that explains how CE BMs link resource scarcity, environmental impact and economic benefits together.

Every business and company aims to achieve monetary profits and advantage towards their competitors. CE BMs can help companies achieve economical benefits/monetary gain in larger quantities compared to LBMs. However, to achieve this with CE according to Lieder & Rashid (2016) companies are required to adopt “an integrative approach towards business models, product design, supply chain design and choice of materials.” The condition of our environment, whether it is unwell or well, affects everything on this planet and depends on scarce and non-renewable resources that we use in production, energy etc. Therefore, reuse of these resources and materials is vital goal of CE BMs and for our world. CE addresses with its BMs the circularity of resources, material circularity and volatility Lieder & Rashid (2016). In figure 3 Lieder & Rashid (2016) show how CE addresses and links these previously mentioned aspects of our world.

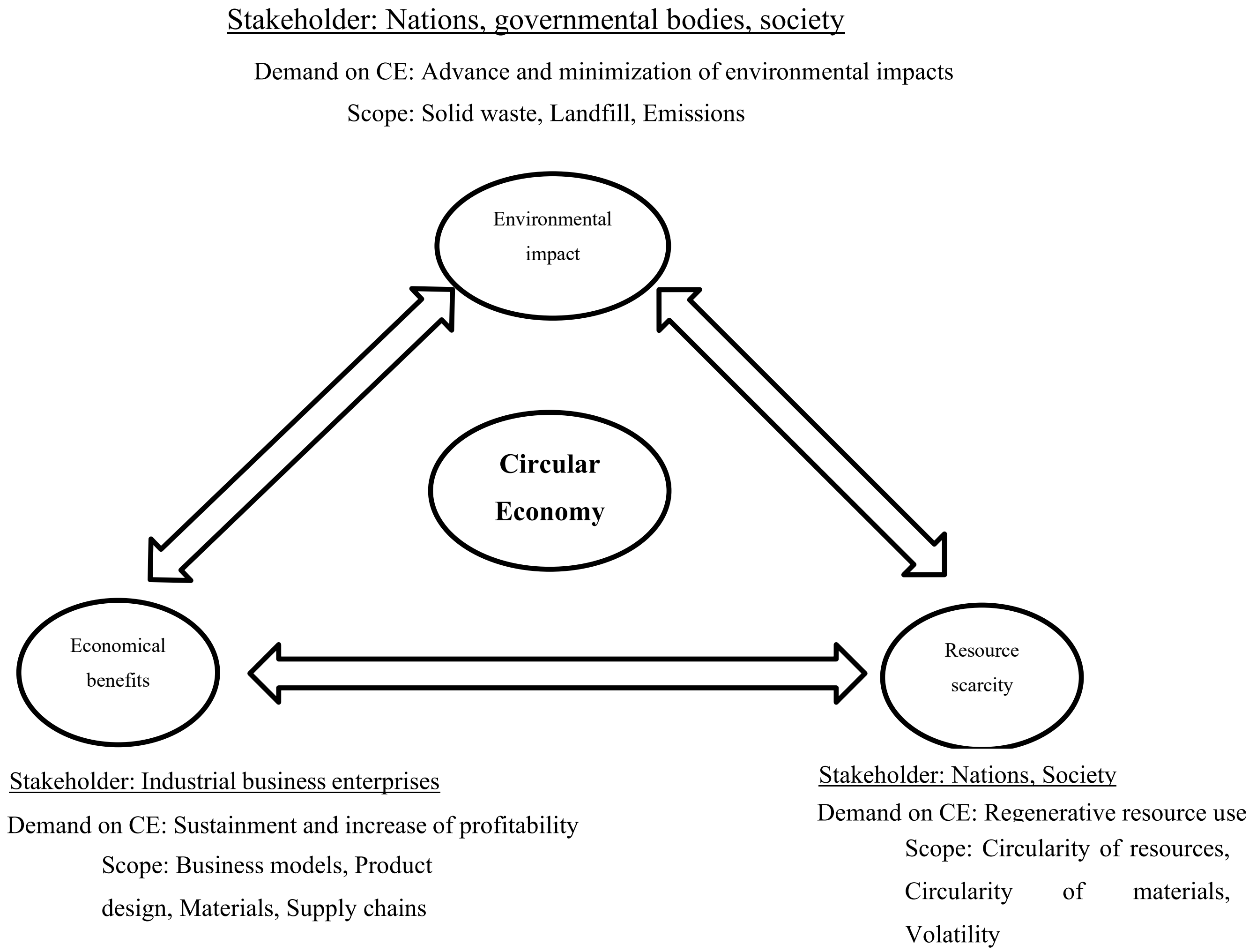

Figure 3. Comprehensive CE framework. Adopted from Lieder & Rashid (2016)

In this CE framework by Lieder & Rashid (2016) resource scarcity, environmental aspect and economic gains are all linked together, and all include both short-term and long-term objectives. As firms aim to achieve economic gains through production and other daily operations these activities greatly affect the environment in many ways both good and bad. When corporations have been practicing traditional linear BMs and operating with them, they tend to generate waste in great quantities. However, when firms look at the end-of-life products with CE eyes, they can be seen as resources for new products rather than disposable waste (like when using linear models). In order to do this firms need to practice resource value management in everyday business operations. This resource value management is a CE practice and is different to the traditional linear waste management. In this practice firms do not separate waste and resources from each other and by practicing this nonseparation the waste can be seen as a possible resource for production Lieder & Rashid (2016).

Our world is currently dominated by linear systems in business operations context and it is because of this linear mind-set that implementation of CE practices and concept is hard. Other major obstacle to adopt CE practices is that environmental gains (when using CE models) are easy to understand but on the other hand the economic benefits are harder to grasp. For firms to successfully adopt CE business models into their operations, major changes and commitment is needed by businesses high management. Ghisellini et al. (2016) go a step deeper in their research and state how the implementation of CE needs to be handled in corporations on micro, meso and macro levels. Each of these three levels within corporation structure should have their own distinctive strategies to follow circularity

In their research Lieder & Rashid (2016) also proposed a practical way in their research which companies and public institutions can follow when wanting to switch from linear to circular model. In this model (figure 4) public organizations operate from top-down and private industries from bottom-up.

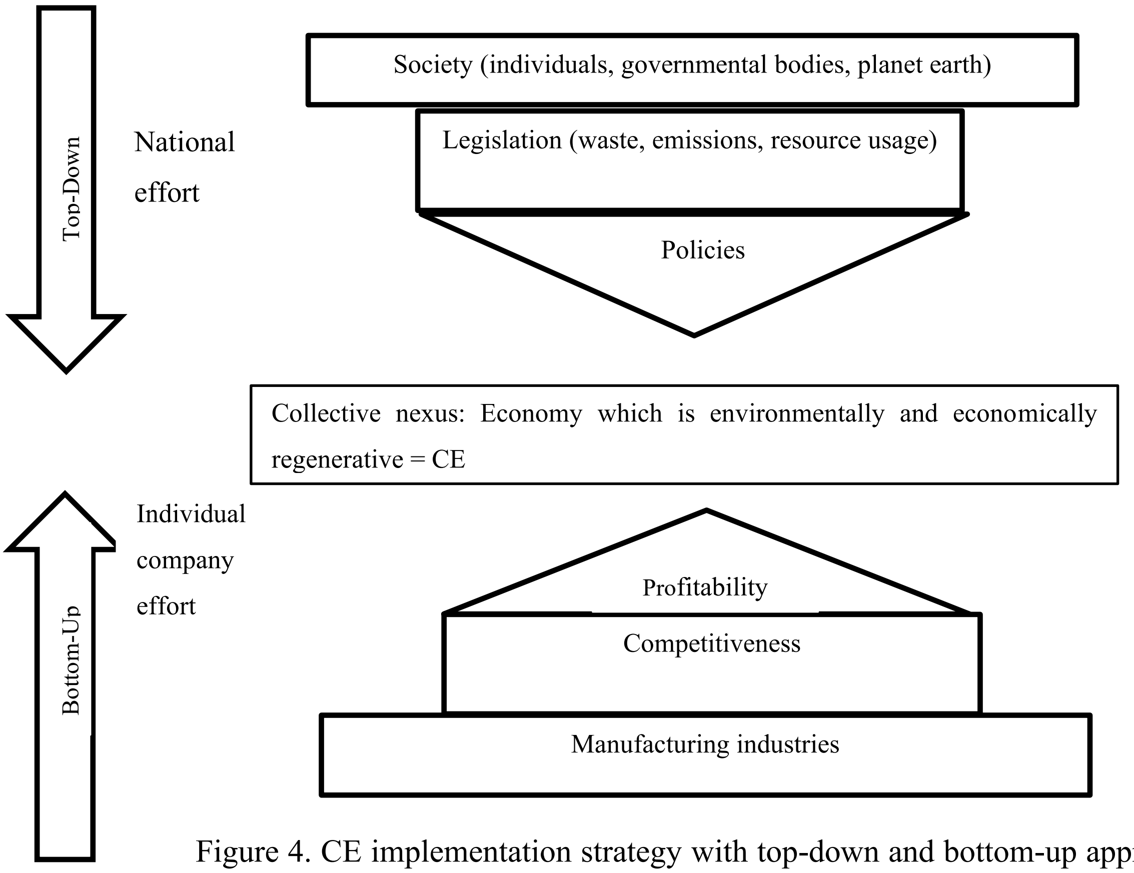

Figure 4. CE implementation strategy with top-down and bottom-up approach. Adopted from Lieder & Rashid (2016).

CE transitions need to be supported on all levels described in figure 4. However currently the support for CE implementation is still missing from governmental point of view. There is a clear lack in legislations and benefits that hinder CE implementations even though benefits from using CE are clear for most industries (at least from the environmental point of view) Lieder & Rashid (2016). Some of these benefits are tackling the issue of resource scarcity by circling resources with reuse, environmental benefits and also more future jobs and more competitive position compared to competitors.

Furthermore, tax benefits have been researched and suggested in the context of CE. In his research Stahel (2013) stated that a clear shift in taxation is needed in order to get companies to move from traditional LBMs to circular BMs. This shift should be made more desirable by removing taxation from renewable resources and focusing on heavily taxing non-renewable resources so no loss of tax revenue would happen. This would greatly push corporations and other stakeholders to move towards CE as they naturally want to be more profitable. There are also other economic benefits suggested for corporations that practice CE. These include specific tax benefits and reductions for products that have been produced by CE practices and therefore can be reused. In addition to this tax reductions and benefits in maintenance, repair, recycling and other "recovery activities" has been suggested by scholars. This would increase the willingness of managers of corporations to practice these processes and therefore help corporations' willingness to move towards and implement CE strategies to their operations Lieder & Rashid (2016).

Companies that base their operations on manufacturing, require continuous development of their practices and BMs in order for their business models to fit and change into circular ones. Also, new partnerships need to be evaluated in order to achieve new collaborative BMs. Basically, this means that manufacturing firms start to shift their main focus onto economically beneficial operations like remanufacturing that are currently done "on the side" but not really focused on when firms practice linear BMs. When corporations start new partnerships with CE in mind they can gain new ideas on resources, management and BMs from their partners Lieder & Rashid (2016).

Like N.M.P. Bocken et al. (2016a) state in their article the product design for CE is closely connected to CE BMs and in their research Lieder & Rashid (2016) also discuss this. They conclude that product design and in addition to this forward and reverse supply chains are vital when CE is considered, and these should be kept in mind and developed when implementing CE practices. When products are designed with CE in mind materials can be recovered, recaptured and reused in different processes in many different stages in product life cycle.

2.6 Limitations of CE

Circular economy is a great concept and perhaps it is the one that all companies and governments should aim towards in the future, in order to save resources, money and environment. However currently CE and its many applications and methods offer many challenges to its practitioners. These challenges can arise for example in the transition phase when firms take steps to transition from linear models to circular ones N.M.P. Bocken et al. (2016b) for multiple reasons, from insufficient or currently limited research to the field that one wishes to implement CE Winans et al. (2017) or from the simple fact that the research on the CE concept is currently limited and has not been practiced for long at this time and further research is desperately needed Korhonen, Honkasalo et al. (2018) in this chapter we will look at the most worrying limitations of CE currently, as this look into limited CE will become important when we later on in this thesis discuss CE in regards of reuse of EV LIB. Furthermore, this part of the literature review is mainly done in order to make the reader of this thesis aware that CE needs to be researched further as there are many questions in regards of it that need to be solved in order for it to work in all situations. Aim of this chapter is not to scare reader away from CE but rather emphasis how widely it can be used if all questions are answered.

The research for CE and its potentiality for us is just beginning and more research needs to be conducted on a regular basis Korhonen, Honkasalo et al. (2018). Some questions that urgently need answering are for example "the nature of self- organized complex social-ecological systems" in where CE is a member Chertow & Ehrenfeld (2012).

One other major issue identified by scholars are material flows and a call for further research in regards of them has already been made, as scholars anticipate that they will become far more complex in the future as a result from bending linear flows into circular ones Korhonen, Honkasalo et al. (2018).

Korhonen, Honkasalo et al. (2018) in their study listed six main challenges for CE as of today. These are presented in a Table 1 below:

Challenge description

Table 1. Limitations of CE adopted from Korhonen, Honkasalo et al. (2018)

Thermodynamic limitations	- CE methods use energy
System boundary limitations	- Problems are displaced across product lifecycle

Limits posed by physical scale of the economy	- "Rebound effect, Jevons's paradox, boomerang effect Limits posed by path-dependency and lock-in"
Limits of governance and management	- Those in charge of governing organizations are not able or willing to enforce change
Limits of social and cultural definitions	- Cultural changes are hard to impose - Waste management and therefore recycling methods are greatly affected by social and cultural norms
Limits posed by path-dependency and lock in	- First technologies retain their market position despite of in-efficiency

Thermodynamic limitations mean that even though CE itself reduces energy consumption and new resource use by its practices in many cases, its operations and methods like recycling, reuse and remanufacturing all use energy (although some is saved due to CE actions).

Spatial system boundary limitations happen when problems of CE are misplaced due to cross organizational and geographical lines in material flows and costs. In addition, management across country lines causes misplacement.

Limits that arise from the physical scale of the economy can be concluded with Jevons's paradox and boomerang effects. This paradox can be explained as follows: whilst CE practices increase production and simultaneously affect positively production costs and prices of the products which leads to higher consumption levels by buyers of the products as they are more affordable as a result of CE. This causes greater economic gains than the environmental ones which is harmful as people are naturally geared towards caring more about economical gains than environmental benefits.

Limitations from path dependencies and lock in limitations happen when new CE products, models or innovations are pushed to organizations operations, production facilities or products without first getting rid of the already existing ones. These new CE methods and practices then need to compete with existing linear ones which causes ineffective use for both.

Governance and management limitations happen when managers that govern organizations are not willing or able to enforce CE change. When an organization wants to impose new BMs that are part of CE, they need to have a strong management that has the right mindset to impose new models, innovations and ideas. It will not be easy to get things rolling from the get-go and if an organization wants to change it linear flows to circular ones it needs management and governance to them that enables the change.

Perhaps the most challenging limitation to CE implementations are barriers that arise from cultural and social practices. Societies are the ones as a whole that have and will choose the way of material and resource use and thus far, they have chosen the linear way. Cultural and social mindsets, laws and regulations need to change in order for CE flows and ideas to flourish.

2.7 Circular economy as a solution for electric vehicles batteries second life use

More and more people in our world pay more focus and show growing interest in the development of EVs and an ever-growing number of people buy them every year. This naturally leads to a growing number of EV batteries that near their usefulness as a transportation means enablers as they run out of needed levels of capacity after a time that is needed to power EVs. This has caused authorities, governments and scholars to focus on the issue of how to handle the recycling or the reuse of the batteries, as they still in most cases hold sufficient capacity that can be used in many different second life purposes as discussed in study by Olsson et al. (2018). However, despite the growing interest on behalf of authorities and scholars most of the existing literature points out that CE in regards of EV batteries reuse and recycling is not likely to work as a ready-made model as the recycling of LIBs is challenging and not efficient enough with the current methods and therefore further development is needed as stated by Ahuja et al. (2020)

Also, the current volumes of LIBs are not high enough for the current recycling methods to be effective and economically feasible to get desired results from it (monetary gain or environmental benefits).

Development in CE business models, practices and recycling processes is vitally needed as the research article of Dunn et al. (2021) states that after the year 2040 if development and research have been done in a timely manner there is a real chance that up to 60% of COB (cobalt), 57% of MAN (manganese), 53% of LI (lithium) and 53 % of NI (nickel) needed globally and regionally can be retrieved with CE practices from used LIBs. These are significant numbers as these materials are used in all sections of global and regional economics, and really, they highlight the need for further research for the topic. Also, because a growing number of LIBs begin to reach the end of their useful life in EVs there would be severe environmental and even health effects if the research is not carried further.

2.8 Electric vehicles and lithium-ion batteries

As this thesis aims to build a comprehensive view on current state of research on how EV LIB second life is enabled with CE practices, we naturally need to discuss EVs LIBs and what kind of resources and materials can be reused and recovered from the batteries. Discussion on possible further research and limitations of current state of the research will be held in the discussion part of the thesis.

In today's world one of the key goals and challenges for governments is to explore different options on how to reduce and ultimately completely eliminate the use of petroleum in transportation vehicles Tromboni et al. (2017). This is vital since oil is a nonrenewable resource and in addition to that harmful for our environment when used as an energy source. EVs are automobiles that use electric motors as their primary power source and these electric motors are powered by batteries and more specifically lithium-ion batteries. EVs are one key component in realizing this petrol free future but some might be surprised by the fact that they have been around for a quite long time and have been developed since 1834. Naturally only in recent history they have become a viable option for petrol powered cars stated by Bansal (2005)

Key component for EVs are LIBs. LIBs are vital in making this dream of EVs surpassing petrol vehicles become a reality as they are used in today's EVs as the main energy source researched by Chalk & Miller (2006). Since as early as the 1990s industry specializing in building and designing cars have studied, tested and built an increasing number of EVs that work with LIBs Tromboni et al. (2017) and when the production and sales of these EVs increase gradually it will inevitably mean that the amount of EV LIBs that reach the end of their useful life also increase at same rate Olsson et al. (2018)

As EVs have developed over the years, so have batteries and the currently most used and developed battery is LIB. This willingness and indeed a need to develop batteries stems from a fact that batteries need to be reliable and safe to use, perform on high acceptable levels in all conditions and they also need to have a long lifespan to be economically feasible Li et al. (2018) EVs use LIBs as their power. LIBs are a very effective source of energy for EVs as they hold much energy and are light when comparing to the weight of the battery, offer an easy use (due to their light design) to different types of vehicles and a much longer lifespan than other batteries. All these abilities are needed in EVs, and this is why LIBs are used in them rather than other types of Tarascon & Armand (2001).

Every LIB is made out of four key components that together form a working battery. In LIBs are cathodes which are designed and used in LIBs to be the component that sets the capacity and the voltage of the battery. Secondary but equally important use of cathodes is that they are the source for lithium-ions needed. Anode is the part of the battery that makes it possible for the electric current to move through an external circuit. Furthermore, regarding anodes, lithium-ions are stored in anodes when battery is full. Electrolyte is an integral part of the battery as it acts as conduit for the lithium-ions and is made out of salts, solvents and additives. Final key component of LIB is the physical barrier that is designed to separate cathode and anode Yoshido et al. (2009)

2.9 Reusable, recyclable resources in lithium-ion batteries

In research conducted by Dunn et all. (2021) they stated that from retired LIBs much of the resources used to produce them can be reused in various different second life applications. LIBs contain many non-renewable and scarce materials, such as cobalt, lithium, manganese and nickel. Furthermore, they concluded that with CE methods in the future up to 50-60 % of resources needed globally and regionally could be reused from LIBs via CE methods, that have reached the end of their lives.

COB disregarding some extremely rare situations can only be retrieved as a byproduct of mining some other metal Hawkins (2021). This is one major factor why reuse of COB from LIBs is vital to develop into a possibility as COB is not easily attainable as itself. COB is used in many applications such as automobile, catalyst and many other applications in the chemical industry. COB is an important resource in our world and CE practices can help us with the acquisition of it greatly as the demand for COB raises gradually.

LI is a key material for many different products produced on a mass scale. These include for example many industrial products and of course batteries. As the uses of LI have increased gradually over the recent years so has the demand of it as well. In research by Talens Peiró et al. (2013) states that demand for LI will actually increase from 30 to 60 % by 2020. This naturally means that recycling and reusing LI is already a current issue in our economy.

MAN is a nonrenewable material that can be found from the nature in rocks, soil and water. MAN is used in iron production, batteries and other uses in our economy. And as with COB and LI the demand of MAN has grown and will continue to do so as our economy keeps developing Howe et al. (2004).

NI is metal that can resists corrosion and its most used application therefore is to plate and protect other metals from corrosion. This use can be seen all around us from bikes to doorhandles. Also, NI is used to manufacture alloys like stainless steel stated by Sudagar et al. (2013). Because of these uses NI is highly demanded material and therefore CE applications to reuse it from LIBs are vital to ensure continuous flow of NI the future.

3 METHODOLOGY

3.1 Literature review

In every research, whether it is a journal article, master's degree work or any other academic research, in all these instances a well-done literature review is vital for the outcome of the work. Without a thorough literature review it is an impossible job for author to acquire a level of understanding of the topic that is necessary to continue previous research further or dive into what type of research has already been made. When made accordingly literature review gives its author knowledge on what type of research methods have previously been used by previous authors on the topic of the research. Furthermore, with well-made literature review author is able to identify possible issues and challenges in the topic at question Yin (1998).

In a research conducted by Knopf (2006) he states that every literature review conducted should have two main objectives. The first is to find and present the main findings of previous relevant research done on the subject on hand. This gives the author of every research on every topic the best possible and relevant information of the topic that gives the tools to write a well-made research on the matter and further the knowledge of the field. Secondly when made accordingly, main objective for every literature review that Knopf (2006) sets is the way literature review is presented. What he means by this is that literature review in every field of study must provide its reader an understanding on the subject at hand its rights, possible wrongs and inconclusive situation at the moment that the author is writing their research. This helps both the author and the reader to gain early insight on the subjects possible problems and develop possible solutions and further research questions in their mind.

Ultimately the benefits that arise from a well-made literature review should never be underestimated as they act as an important source for future research as well as a base for the research the author is going to write Heyvaert et al. (2016). In their book they also point out the fact that to write the highest quality systematic literature review has always been an extremely challenging tasks and continues to be so. The next part of this thesis focuses on introducing what is systematic literature review and after that we move on to conducting one on the subject of this thesis.

3.2 How systematic literature review differs from traditional narrative literature review

The chosen study methodology for this thesis is systematic literature review (SLR). SLR is a type of "secondary study" that aims by it means to identify, analyze and explain all the currently finished and relevant studies on a research, research topic, question or phenomenon Kitcharoen (2004).

Paré et al. (2015) add to this definition that with SLR researchers are able to widen and provide deeper understanding of already existing research while it is also a great tool to identify possible gaps in current literature. With a thorough and persistent analyzes and well-made summaries of relevant literatures, researches and books to the topic at hand scholars and authors are able to test their own hypothesis, answer their research questions and even build entirely new theories on the topic of SLR. Furthermore, they conclude that when scholars perform a SLR on certain topic they can with the results derived from it analyze the existing literature and by doing so point out the weaknesses and any possible contradictions within the existing work.

The other main type of methodology used in all types of research articles across the world is called narrative literature review. Narrative literature review is used in scientific articles with the aim of discussing and defining the current state of research done on a chosen topic with a more theoretical point of view. Narrative literature review is however different to SLR because it does not list the databases used or even the methodology that is chosen to produce the results of the study. Furthermore, it also neglects to inform the reader on the criteria on what the articles chosen and cited during the literature review were chosen. This type of literature review is commonly used by students in their bachelors/master's thesis work and this type of narrative literature review was also used during chapter 2 of this thesis. However, it is important to this thesis to distinguish the differences between SLR and narrative literature review and this is done below.

Table 2. Main differences between systematic literature review and narrative literature review adopted from Rother (2007)

Fetures	Narrative literature review	Systematic literature review
Question	Tend to be wide and non-specific	Questions need to be specific in order for the work to achieve is goals
Source	Sources can be biased and very nonspecific	Sources cover all aspects of the topic at hand and search strings etc are clearly presented
Selection	Selection is not specific and has bias	Selection of the sources is based on specified criteria
Evaluation	Nonspecific	Tightly monitored evaluation
Synthesis	Qualitative	Quantitative
Inferences	Sometimes evidence-based	Usually evidence-based

The differences of the two main types of literature reviews can be seen above in table 2. When answering the research question narrative literature review (NLR) is broader whilst SLR is specific with its answers. Sources of the literature reviews differ also as NLR uses unspecified and potentially biased sources when SLR has greatly more comprehensive sources and clear approach to search types (search strings and constant methods). Selection of the articles presented in these literature reviews also differs. NLR does not specify what database or search words were used whilst SLR has clear criteria for sources and search type is uniformly applied across different databases. When the evaluation is in question NLR is variable when SLR is quite harsh and even critical in its evaluations. Synthesis are with NLR qualitative and with SLR quantitative. The inferences also differ as NLRs inferences only sometimes are based on clear evidence as SLR inferences are almost always based in clear evidence Rother (2007).

3.3 Systematic literature review framework

There are many frameworks proposed by different scholars on how to produce a great and thorough SLR. From these different authors we can piece together the main checkpoints that every SLR should follow and complete in order to thoroughly do SLR on a selected topic Merli et al. (2108b)

Table 3. The steps to provide a comprehensive systematic literature by Tranfield et al. (2003)

1. Research questions	Writer/ writers of SLR set up research questions that match the topic
2. Material collection	Specifying to the reader what type of material is collected
3. Descriptive analysis	From collected materials applicable and needed aspects are analyzed with quantitative methods
4. Category selection	Category selection is performed in order to organize materials collected in a presentable and understandable way
5. Material evaluation	Collected material is evaluated and results of the SLR are presented

This is the framework/checklist followed in this thesis while conducting the SLR. This was selected among the many possible frameworks as it fits the aim of the study, yields the kind of data, helps to answer the research question and leads to a comprehensive and clear conclusion on the current state of CE business models used in EV LIBs second life applications.

3.4 Material collection

As already stated in this thesis the study is composed with the means of systematic literature review (SLR). The steps and phases of this study can be found in Figure 8. When deciding the goal for this thesis (finding the answers for the research questions that we set at the beginning of this thesis) appropriate and accurate keywords were chosen. This was done with the help of the University of Oulu's information retrieval professional from the university library in order to get the best and most accurate search results. As the thesis has two distinguishable categories CE and EV LIBs and the aim of the study was to find out how CE methodologies are currently used to enable EV LIBs second life applications, naturally the keywords represent both these sides and are tied together with search operators. These keywords are presented in Figure 5. For Circular economy side keywords that were chosen with the help of information retrieval professional were: circular economy and circular business model, Electric vehicle and lithium-ion battery side was covered with: electric car, e-car, electric vehicle, e-vehicle, electric mobility, battery, batteries, energy storage, electric storage. Also reuse, recycling, remanufacture were included in the first searches but these searches included results in the region of thousands, so it was decided to exclude them from keywords. The database used in this thesis was Scopus (abstract and citation database where all studies are reviewed in order to maintain high quality amongst them) and this selection amongst databases was done with the instructor of the thesis.

In the search string specific search operators were used to get the results. Operator OR was used for both categories CE and EV LIBs to link their keywords together in their own category. Operator AND was used to link these two categories together. Asterisk (*) was added in order for the search string to check through all the possible spellings of keywords to which asterisk was added. Search was made in a way, so it focused on article title, abstract and keywords. Search was carried out March 15, 2022. Only restriction to results was that only studies using English as their language were looked at.

The following search string was used in material collection in scopus database:

(TITLE-ABS-KEY ("electric* car" OR e-car OR "electric* vehicle" OR e-vehicle* OR "electric* mobility") AND TITLE-ABS-KEY (battery OR batteries OR "energy storag*" OR "electric* storag*") AND TITLE-ABS-KEY ("circular economy" OR "circular business model*"))

Circular Economy

- Circular economy
- Circular business models

Electric vehicles and lithium-ion batteries

- Electric car
- E-car
- Electric vehicle
- E-vehicle
- Electric mobility
- Battery
- Batteries
- Energy storage
- Electric storage

Figure 5. Keywords used when finding the material (articles) for thesis

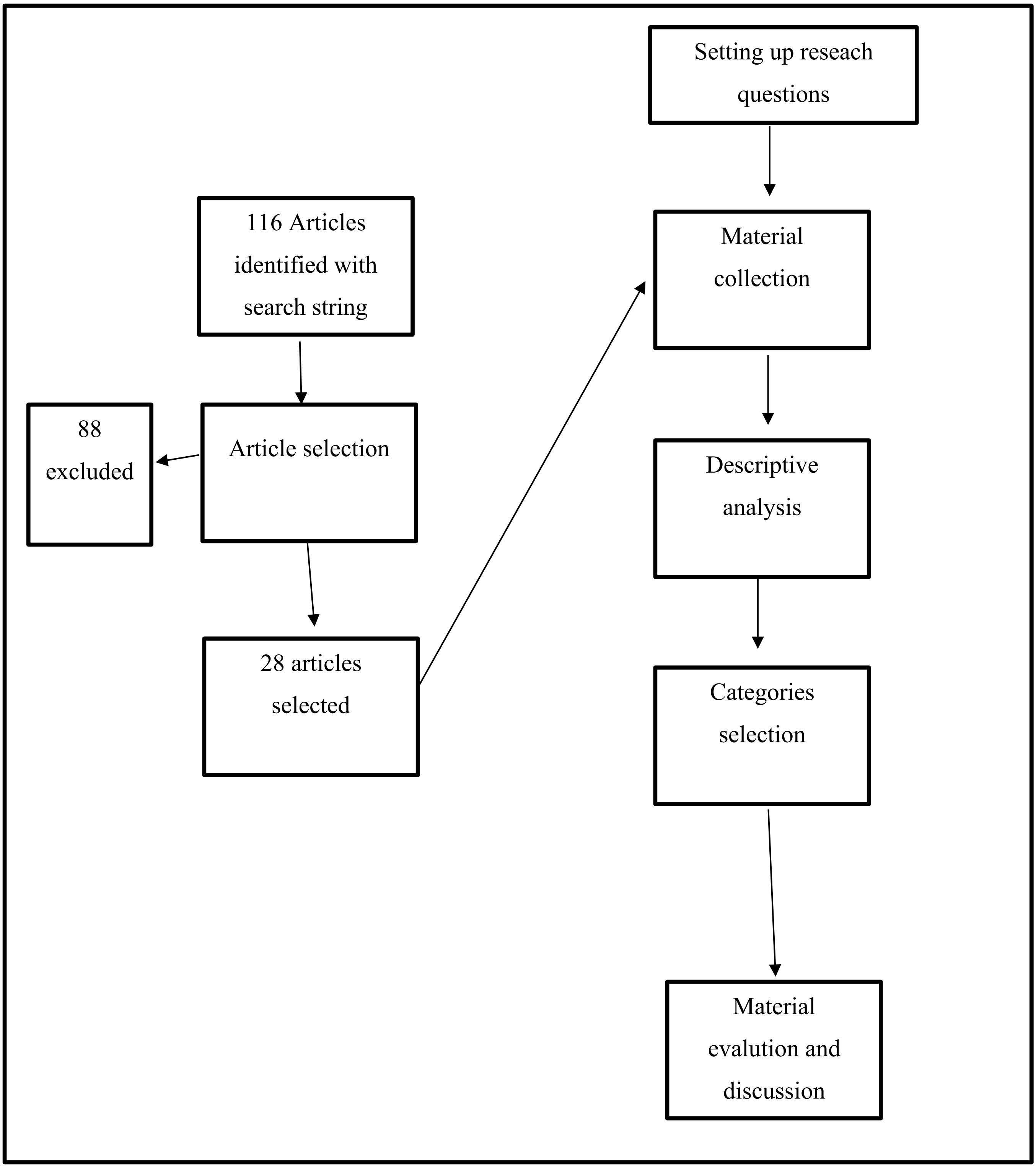

Figure 6. Summary of the phases of the review process

All in all the search string returned 116 articles and all of these were screened by the writer of this thesis (title abstract and keywords were used as a base for the search). While doing this material collection and screening the aim was to identify the articles (28) amongst the search results (116) that discussed the topic of this thesis and were helpful in answering the research questions. From the 116 articles screened 88 did not discuss and link both CE methods and EV LIB reuse so they were excluded. 28 articles discussed, linked them together or were otherwise relevant when answering the research questions so they were selected to further analysis in this systematic review. Furthermore, category selection was performed for these 28 articles.

Table 4. 28 articles that were selected for systematic review, their journal information and a brief summary of the article

N	Author(s)	Article Title	Journal/Conference	Brief description of the article
1	Wrålsen, et al., (2021)	Circular business models for lithium-ion batteries - Stakeholders, barriers, and drivers	Journal of Cleaner Production	Article that studies CE business models and all things related to them in regards of LIBs
2	Albertsen et al., (2021)	Circular business models for electric vehicle lithium-ion batteries: An analysis of current practices of vehicle manufacturers and policies in the EU	Resources, Conservation and Recycling	Article that discusses CE business models for EV LIBs. Bases its discussion current policies in EU
3	Olsson et al., (2018)	Circular business models for extended EV battery life	Batteries	Article where research focuses on CE business models that enable EV battery second life

4	Vu et al., (2020)	Exploring Second Life Applications for Electric Vehicle Batteries	Advances in Transdisciplinary Engineering	Conference paper on economically feasible second life applications for EV LIBs
5	Moore et al., (2020)	Spatial modeling of a second-use strategy for electric vehicle batteries to improve disaster resilience and circular economy	Resources, Conservation and Recycling	Study analyzes CE models for LIBs
6	Ahuja et al., (2020)	A circular economy for electric vehicle batteries: driving the change	Journal of Property, Planning and Environmental Law	Study points out the need for new policies that enable appropriate management of EV LIBs
7	Garrido-Hidalgo et al., (2020)	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 Management	Paper discusses the need for new way of thinking whilst the amount of e-waste grows in our world
8	Cusenza et al., (2019)	Reuse of electric vehicle batteries in buildings: An integrated load match analysis and life cycle assessment approach	Energy and Buildings	Addresses the possible second life use of EV LIBs
9	Richa et al., (2017)	Eco-Efficiency Analysis of a Lithium-Ion Battery Waste	Journal of Industrial Ecology	Paper discusses proposed CE inspired

		Hierarchy Inspired by Circular Economy		waste management for EV LIBs
10	Dunn et al., (2021)	Circularity of Lithium-Ion Battery Materials in Electric Vehicles	Environmental Science and Technology	Studies the potential that batteries have in reducing greenhouse gas emissions when using CE strategies
11	Canalas Caslas et al., (2019)	Reused second life batteries for aggregated demand response services	Journal of Cleaner Production	Study analyzes the possibility for EV LIBs second life use in buildings
12	Groenewald et al., (2017)	Testing of Commercial Electric Vehicle Battery Modules for Circular Economy Applications	SAE International Journal of Materials and Manufacturing	Research discusses the capacity and energy remaining in EV LIBs and furthermore the second life applications for LIBs
13	Mossali et al., (2020)	Methodology and Application of Electric Vehicles Battery Packs Redesign for Circular Economy	Procedia CIRP	In this book authors discuss how LI-Ion packs hold great amount of critical resources and materials and discusses CE applications/ strategies to use in order to subtract them for reuse
14	Baars et al., (2021)	Circular economy strategies for electric vehicle batteries reduce reliance on raw materials	Nature Sustainability	Article discusses when CE strategies are implemented in EV LIBs materials reuse the need for

				new raw materials can be reused
15	Cusenza et all., (2019)	Energy and environmental benefits of circular economy strategies: The case study of reusing used batteries from electric vehicles	Journal of Energy Storage	Article researches and discusses the benefits of CE methods using EV LIBs as case study
16	Bobba et al., (2018)	Life Cycle Assessment of repurposed electric vehicle batteries: an adapted method based on modelling energy flows	Journal of Energy Storage	Article discusses how second life applications of EV LIBs are in line with CE principles
17	Norgren et al., (2020)	Design for Recycling Principles Applicable to Selected Clean Energy Technologies: Crystalline-Silicon Photovoltaic Modules, Electric Vehicle Batteries, and Wind Turbine Blades	Journal of Sustainable Metallurgy	In this journal article researches study how the amount of materials used in LIBs will grow in the near future and how these could be recycled and reused
18	Chan et al., (2021)	Closed-Loop Recycling of Lithium, Cobalt, Nickel, and Manganese from Waste Lithium-Ion Batteries of Electric Vehicles	ACS Sustainable Chemistry and Engineering	Study tries to find ways to recover and reuse materials used in EV LIBs
19	Blömeke et al., (2020)	Recycling 4.0: An Integrated Approach towards an Advanced Circular Economy	ACM International Conference Proceeding Series	Conference paper that discusses how recycling 4.0 drives towards digitalization of processes whilst

				keeping in mind the end of life stage of products. This is discussed with EV LIBs second life uses
20	Kintscher et al., (2020)	Recycling 4.0-digitalization as a key for the advanced circular economy	Journal of Communications	Journal article discusses how the importance of recycling will dawn on us more and more in the future and how industry 4.0 can be one of the key answers to this growing need. EV LIBs are used as an example in this research
21	Yildizbasi et al., (2022)	Key Challenges of Lithium-Ion Battery Recycling Process in Circular Economy Environment: Pythagorean Fuzzy AHP Approach	Part of the lecture notes in Networks and Systems book series (LNNS, volume 308)	Discussion on how materials used in LIBs are rare and expensive and how with CE perspective the needed materials could be recycled from used LIBs
22	Rajaeifar et al., (2022)	Challenges and recent developments in supply and value chains of electric vehicle batteries: A sustainability perspective	Resources, Conservation and Recycling	Article reviews analyzes challenges related to EV LIBs across their useful life
23	Roldan-Ruiz et al., (2020	Highly Efficient p-Toluenesulfonic Acid-Based Deep-Eutectic	ACS Sustainable Chemistry and Engineering	Article addresses the issue: When EVs become more popular

		Solvents for Cathode Recycling of Li-Ion Batteries		the materials in their LIBs become more scarce so reuse and recycling methods need to be developed
24	Roy et al., (2021)	Green Recycling Methods to Treat Lithium-Ion Batteries E-Waste: A Circular Approach to Sustainability	Advanced Materials	Research discusses the increasing amount of LIBs and how new recycling methods are needed. CE point of view
25	Velazquez-Martinez et al., (2019)	A critical review of lithium-ion battery recycling processes from a circular economy perspective	Batteries	Journal paper discusses the LIBs recycling from the perspective of CE
26	Grey et al., (2016)	Sustainability and in situ monitoring in battery development	Nature Materials	Journal article on how LIBs materials need to be integrated into CE methods in order to have a sustainable future for them
27	Sommerville et al., (2020)	A review of physical processes used in the safe recycling of lithium ion batteries	Sustainable Materials and Technologies	Journal article on the separating methods used in EV LIBs. Furthermore discussion on how to better LIBs recycling
28	Deveci et al., (2021)	Remanufacturing facility location for automotive Lithium-ion batteries: An integrated	Journal of Cleaner Production	Journal article discusses how a proper handling of used LIBs is a key

		neutrosophic decision-making		issue amongst EV manufacturers

4. DESCRIPTIVE AND CONTENT ANALYSIS

In descriptive analysis the 28 articles that were listed during material collection phase of this thesis are analyzed with quantitative methods. These include analysis on in where the chosen literature is published, on what year was every research published and frequency of the keywords in abstracts.

4.1 Number of articles per journal

In Figure 7 number of articles per journal is presented and we can tell from it that Journal of Cleaner production has published the most articles/ researches on EV LIBs second life applications with the help of CE methods. From the 28 researches that are analyzed in this thesis Journal of Cleaner production published 3 articles whilst Resources, Conservation and recycling, Batteries, Journal of energy storage and ACS Sustainable chemistry and engineering all published 2 researches.

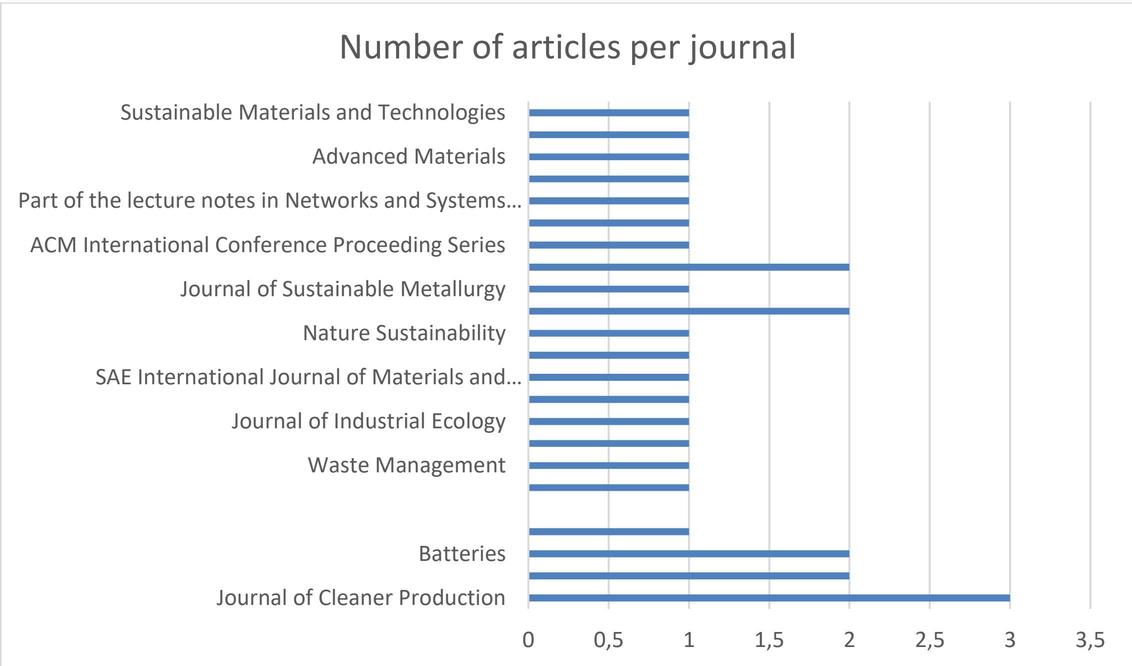

Figure 7. Number of articles per journal

4.2 The publication years of chosen articles

Analysis on the publication year of the articles shows that research papers into the topic of EV LIBs second life applications with CE methods are a growing topic of research.

Especially during the 2020s research in the topic has been growing rapidly. Year 2020 was the year most researches were published (10) followed closely by 20221 with 7 publications. Figure 8 illustrates this development of publications

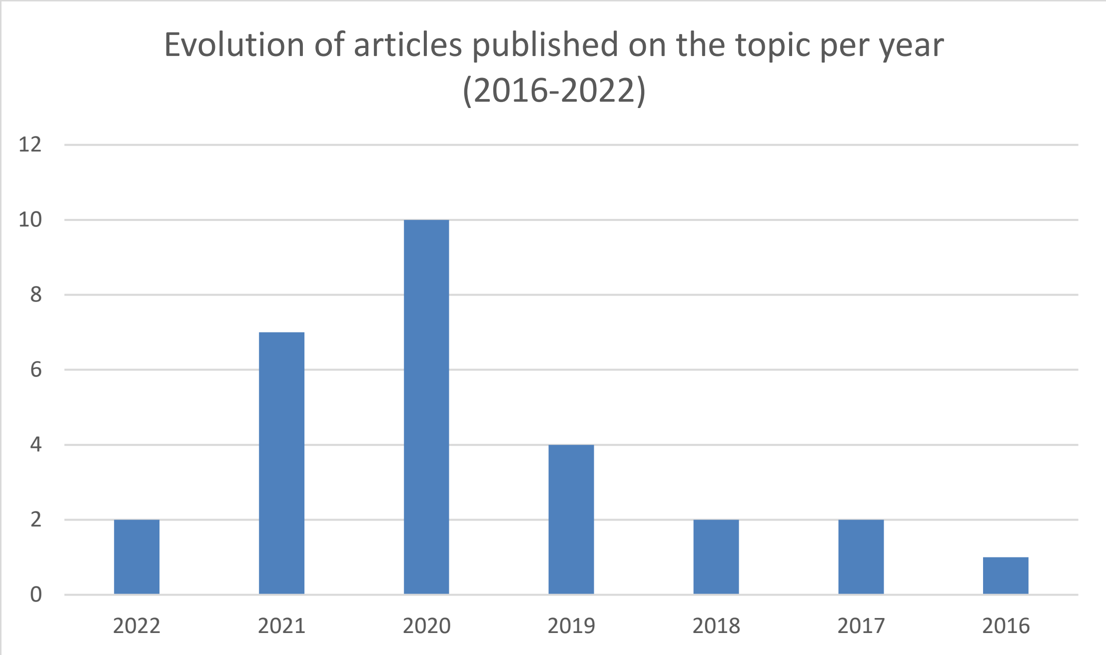

Figure 8. Evolution of the publications per year related to the topic of EV LIBs second life applications with CE methods

4.3 Keywords frequency in abstracts

Figure 9 presents the most used words in the abstracts o the articles chosen for SLR. Most frequent keyword was lithium-ion batteries (LIBS) / Batteries that was used in 93% of the articles. Second most frequent word was electric vehicles (EVs) which was found in 86% of the articles abstracts. Third most frequent word in abstracts was circular economy (CE) which made an appearance in 68% of the articles. Other frequent keywords include remanufacturing, sustainability, sustainable development, recycling, reuse, repurpose, remanufacturing, waste management, business model, closed loops and second life. Words representing EVs and LIBs were as frequent as CE related words. This indicates that correct article selection was made.

Table 5. Most frequent keywords in abstracts of the 28 articles

Lithium-ion battery	26/28	93%
Electric vehicle	24/28	86%
Circular economy	19/28	68%

Remanufacturing	Susystainability	Sustainable development
Recycling	Reuse	Reuse
Repurpose	Closed loops	Second life
Sustainability	Waste management	Business model

Figure 9. Other keywords from the abstracts of the 28 chosen articles

4.4 Category selection

This chapter discusses the different categories chosen 28 articles can be divided. Four main categories within chosen articles were “new methods for EV recycling”, “second life application for used EV LIBs”, “CE and LIB” and articles that fall in other categories but not in mass numbers, o they will be referred as “others”. This type of category selection ensures that the author is able to answer research questions of the study comprehensively and with a wide background into different categories of the topic. Furthermore, this ensures a fair and thorough evaluation of the current situation of the research into the topic at hand. This type of selection helps to analyze a wider range of dimensions in the researches and yields more comprehensive results for the discussion and results parts of the thesis, which would not have been possible without the type of category selection concluded.

4.5 Recycling of used EV LIBs – new methods proposed

Velázquez-Martínez et al. (2019) state in their research how LIBs have become the most important energy source for EVs. Furthermore, they point out the worrying fact that many more LIBs are manufactured than recycled every year and this leads to many of these LIBs being discarded in landfills or even to the nature which is a worrying fact. They conclude in their research how current recycling methods and processes for LIBs are not sufficient enough and tend to focus on components within LIBs that hold high economic value. Components like Cobalt can be counted as a high value component. In their research they analyzed recycling methods and practices with CE point of view and conclude that CE recycling methods can offer more effective results in recycling both increasing the rate of recycling while simultaneously target a wider range of components within LIBs Velázquez-Martínez et al. (2019).

Roy et al. (2021) like Velázquez-Martínez et al. (2019) discusses how current recycling methods of LIBs, which include pyrometallurgy and hydrometallurgy, are not efficient enough and actually produce many unwanted environmental side effects. This is why they address the need for new green recycling processes for LIBs that enable their recycling without these environmental side-effects. These methods might include processes like bioleaching, waste for waste approach and electrodeposition. They state that CE as a concept and goal can be achieved (when speaking about used LIBs) with closed loop recycling which in turn is achieved with green recycling processes.

Roldán-Ruiz et al. (2020) researched how efficiently COB and LI can be recovered (recycled) from EV LIBs with a process where deep eutectic solvents are used. When they compared their results to existing recycling methods and their results, they found that their process (used LIB recycling process with deep eutectic solvents) was able to achieve 94% recovery efficiency with COB. Also, economic and environmental benefits were found because method researched by (Roldán-Ruiz et al., 2020) had a much lower solute to solvent ratio, that is necessary when aiming towards Cob dissolution, compared to currently used recycling methods.

Chan et al. (2021) looked at more theoretical and experimental recycling processes that could help in retrieving Li, Cob, Nic and Mang from LIBs. They were able to determine (for these theoretical and experimental methods) the best leachant to use and even set the optimal conditions for the whole process but once again stress the fact that further research is needed.

Yildizbasi et al. (2022) proposed a completely new analytical recycling process of LIBs with CE principles in mind and were able to prioritize the main barriers in LIB CE recycling processes in environment, cultural and monetary contexts.

4.6 Second life applications for used EV LIBs

Bobba et al. (2018) tell in their study that when EV LIBs reach their usefulness as an energy source for EVs they still hold significant amount of capacity that can be used in different applications. Furthermore, they point out the worrying fact that this reuse, or repurpose of used EV LIBs is still unfortunately quite a small market and needs further development urgently. According to the research the second life applications of EV LIBs should take advantage of CE principles and methods and this second life use will yield great environmental and economic benefits. These benefits arise from the fact that new materials are not needed because they can be retrieved from used LIBs with CE and recycling methods (closing loops).

Cusenza et al. (2019) studied a theory that EV LIBs could be used in stationary applications before they are recycled at all. This theory stems from the fact that these LIBs still hold capacity in them that could be utilized in stationary applications that more often than not are less demanding on the performance of the batteries. They studied this theory by looking at the possibility to use used EV LIBs in residential buildings and they found that using LIBs in stationary storage systems (in buildings) is able to improve the environmental sustainability and in numbers this means reduction from around -4% to -17% which is quite significant reduction in environmental impacts.

Canals Casals et al. (2019) also studied the possibility to use EV LIBs in buildings after they have reached their useful life in EVs as they still hold up to 80% of their useful capacity. Their results point out that the repurpose and in this case reuse of LIBs in buildings might not be monetarily appealing enough even if the useful life of the LIBs is extended by 4 years. However, if LIBs are simultaneously able to take part in secondary electricity markets in addition to being used in buildings, in this case according to Canals Casals et al. (2019) the business as a result stemming from this two-part use is economically feasible enough to be implemented. Moore et al. (2020) back these statements of reuse by suggesting stationary second life applications like buildings in their research on second life applications for EV LIBs.

Vu et al. (2020) wanted to research second life applications for EV LIBs that are more easily economically achievable. They conducted their study by doing a case study with a corporation specializing in industrial vehicle manufacturing. And with this quantitative and qualitative methodology they were able to find three new second life applications for this corporation.

4.7 CE and LIBs

Electric mobility is the key in reducing pollution from gasoline vehicles and therefore EVs will become more and more regular in the future. This naturally increases the number of LIBs as EVs use them as their source of power. These LIBs hold precious and scarce resources, materials and capacity that can be used further or again Ahuja et al. (2020) suggest in their research that with CE goals and methods this kind of repurpose and reuse can be achieved as CE demands and guides towards this kind of behavior.

Baars et al. (2021) studied CE business models in EV LIB context Wrålsen et al. (2020) did same kind of study but furthermore looked at all the factors contributing to effective implementation of CE for LIBs and found key issues and factors that have a major effect on successful CE implementation. The main drivers of CE business models include national and global laws and regulations that enable and guide companies towards CE business models The main obstacle of CE implementation was found to be the financial viability. This is why new models and practices are needed and constantly developed. Olsson et al. (2018) back these findings in their paper.

Albertsen et al. (2021) similarly to other articles in this category analyze currently used practices of CE for EV LIBs in the EU area. They conducted their study by analyzing companies homepages and conducting interviews on the management of these companies analyzed. They find that some improvements have been made into the right direction, but state that much more in-depth research is needed.

4.8 Other topics analyzed in the articles

Naturally out of 28 articles not all fit into the three main categories and the other article topics are introduced in the following chapter.

Garrido-Hidalgo et al. (2020) studied and suggested internet of things as an enabler for EV LIBs second life applications, reuse or repurpose. With the findings of their study, they strongly suggest that internet of things will in the future help with right selection of CE BMs and recycling and other CE activities.

Dunn et al. (2021) looked into how EV LIBs can help in reducing greenhouse gas emissions due to their possible circularity with the help of CE. They found that CE can help achieve needed levels of circularity for EV LIBs that makes the recycling of them economically feasible.

Groenewald et al. (2017) studied and tested in their research the features of EV LIBs and tried to determine if they could somehow be optimized thus yielding longer life (longer loops) and enabling second life applications for them. They find that in some cases the energy capacity and resistance of LIBs can be altered thus offering new possible applications for LIBs. Test were carried out for commercial EV LIBs.

Mossali et al. (2020) studied the possibility of design EV LIBs in a way that they are more easily recycled and therefore their materials more easily reused in new LIBs or other applications that need those resources. They were able to identify qualities which could be altered and therefore would help with recycling of LIBs.

Norgren et al. (2020) stress out the fact that LIBs are not currently designed in away that their recycling or disassembly is easy. They take a look at design for recycling principles and try and envelope them with going through academic research papers and interviewing experts on the matter.

Blömeke et al. (2020) and Kintsscher et al. (2020) aimed to tackle the environmental and economical challenges arising from LIB use and from the scarcity of their materials by looking at recycling 4.0 which aims to revolutionize recycling processes by making them completely digital. This digitalization of recycling would speed up the process and make it more effective as recycling 4.0 draws from different branches of science like chemistry and computer engineering and so doing makes great strides towards the betterment of CE concepts.

Rajaeifar et al. (2022) researched excessively the challenges currently existing in EV LIBs supply chains and were able make valuable findings grouping challenges in supply chains to five subgroups and identifying new important research topics.

Grey & Tarascon (2016) addressed the importance of sustainability development and design in EV LIBs. They discuss how EV energy source (their batteries) should be built from renewable materials that do not cause harm, to our environment as they currently do.

Sommerville et al. (2020) looked through and addressed currently used recycling processes and methods for EV LIBs and identified four different main strategies amongst them. They ranked each of these four categories by their strengths and weaknesses. The main finding of their study is the urgent need for further development amongst all these recycling methods in order to answer the need of EV LIB recycling with CE methods.

Deveci et al. (2021) researched the needs and challenges in deciding a location for EV LIBs remanufacturing facilities and when setting up supply chains for them.

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5. DISCUSSION AND CONCLUSION

5.1 Circular economy and electric vehicle lithium-ion batteries

Circular economy frameworks, business models and processes can help in the task of giving second life for used EV LIBs as scholars like Baars et al. (2021) and Wrålsen et al. (2021) stated in their studies. With CE practices reuse, repurpose and recycling of materials and resources that used LIBs hold can be achieved in the future. Understanding the possibilities that implementation of CE and furthermore what CE actually is vital first step in adaptation of CE models and like Ghisellini et al. (2016) pointed out, the understanding of the possibilities and responsibilities need to happen on every level of the organization and amongst stakeholders. This understanding of CE does not just mean that corporations need to understand it, also politicians, governments and law makers need to be aware of the possibilities and the structure of CE models in order for it to work at all on any level. This need for law, regulations and tax reform is backed by scholars in their studies Olsson et al. (2018), Kirchherr et al. (2017) and Murray et al. 2017). In addition to second life applications, future CE practices and business models improve nations environmental issues by reducing the need of finding and processing new materials, manufacturing new products and bringing down emissions caused by traditional transportation and from transportation of resources and materials and like Tromboni et al. (2017) stress this is vital for our environment now and in the future. The amazing fact that CE offers to solve the issue of used LIBs is that they do not even necessarily have to be recycled at first like Bobba et al. (2018) pointed out in their research. In this thesis we have reviewed research papers like Cusenza et al. (2019) and Canals Casals et al. (2019) in stationary applications and Vu et al. (2020) who developed applications at more general level focusing on monetary gains in applications. However, all these amazing opportunities are only possible if a systematic change in the whole structure of our governments and corporations thinking is performed.

Already corporations recycle some of the used EV LIBs but the scale of manufacturing to recycling is worryingly low due to the fact that the amount of EV LIBs that reach the end of their useful life in EVs will rise rapidly in the near future and this fact was addressed in the study by Ahuja et al. (2020). Therefore, the possibilities CE models offer are important to implement as quickly as possible. However, this is concern currently amongst scholars like Dunn et al. (2021) who point that more research is needed into the matter. The current recycling methods are not efficient enough to be economically feasible for corporations to implement so the necessary will power to drive the change amongst corporations is not where it should be yet. This willpower to drive the change could be helped with tax reforms as stated by Stahel (2013). Olsson et al. (2018) instead suggests law reforms, but author of this thesis thinks that both are needed and necessary. The same kind of issue of lack of willpower touches governments and lawmakers. Even if the environmental benefits are clear to see when the economic gains are not at an acceptable level or even as Lieder & Rashid (2016) pointed out, not understated by lawmakers and government bodies, governments and lawmakers are therefore not willing to issue laws, policies and even tax reforms in support of CE.

Another problem currently for CE use in EV LIBs is that it simply has not been researched enough as of today. Almost in every article chosen for this SLR authors point out the fact that further research into the topic is needed, and urgently. Most of the research currently focuses on same kind of second life applications like Cusenza et al. (2019) and Canals Casals et al. (2019) their researches into EV LIB second life application in buildings. Author of this thesis would like to see more innovative second life application studies, a bit like Vu et al. (2020) but even more outside of the box thinking is needed as current research seems to follow mainstream trends. This is actually quite odd since the whole concept of CE was developed not as a mainstream study but rather as a byproduct of similar studies in many different branches of science. We do not have that much time to waste before the LIB problem blows out of control. Luckily as shown in this thesis research articles into the issue have been increasing steadily year by year and after the article selection to this thesis was performed number of new interesting research have already been published this year.

In order to tackle these inefficiencies these issues need to be addressed now before the LIB problem becomes too much to handle. Research needs to be carried out on all levels into the CE implementation into used EV LIBs and possible second life applications of these batteries.

5.2 Key findings of the study

This thesis was written with an intention to research and address the current state of research into how circular economy models and practices are applied to used electric vehicles lithium-ion batteries and their second life applications. With this in mind, effort was made to analyze articles that discuss the relationship (or potentiality of a relationship) with circular economy models and used EV LIBs.

The following research questions were set in chapter 1

RQ1 How are reuse, recycling and second life applications of EV LIB batteries addressed in circular economy context currently?

RQ2 What kind of challenges are there when adopting current circular economy models and practices to used EV LIBs?

When analyzing the existing literature clear connections are found between CE and used EV LIBs second life applications, recycling, repurpose and reuse. This is great news because CE is ever developing field of study and new models and practices are constantly developed by scholars. On the other hand, the current policies within CE are not efficient enough for corporations or governments to enforce on a systematic and nationwide level yet and this is pointed out in most of the articles chosen for this thesis. So, more research needs to be carried out into the topic and new recycling and reuse methods and applications need to be tested. Luckily, CE has gained more and more attention by researches in recent years and so has CE use in EV LIBs. This is important for the future of EV LIBs when EVs become more regular and therefore the amount of used LIBs will rise as well and with CE methods the problem of inefficient recycling to manufacturing rates can be addressed, also reuse and repurpose applications need to be researched further in order to get the full use out of used EV LIBs as when they reach their useful end in EVs they still hold capacity that can be used in other applications. Furthermore, there are challenges in convincing corporations, lawmakers, tax makers and governments to perform a systematic change in order to get full benefits from CE in regards of used EV LIBs.

5.3 Limitations and recommendations for further research

This thesis was conducted by reviewing research articles so it is theoretical review on the topic. This poses some limitations. Firstly, the second life applications for used EV LIBs could have been backed by actual test and interviews on their effectiveness from the industries they touched. This is an issue because the reuse and recycling processes are only tested by the researches and the voice of the people that these new approaches actually touches is not heard. Second limitation arises from the fact that only Scopus was used as a search engine and even though it is wide and appreciated database this might have excluded some researches from the review. Thirdly, only 28 articles were used as a sample for this SLR so the sample size and inclusion rate is on the smaller side. Furthermore, regarding article selection the authors own views and preferences might have affected the selection. So, bias in the article selection can be seen as a limitation in regards of the thesis

For future research topics author suggests further research into second life applications with testing by the industries these applications affect. Also, more innovative second life applications need to be developed in order to answer the challenge of finding these applications for the growing number of LIBs that retire each year. Other needed research topics are the types of challenges and limitations CE currently has on EV LIBs context. These need to be addressed on government and corporation level in order to ease the needed systematic change that is needed in order for CE to work for EV LIBs. Also, more answers need to be found via research into how to get all relevant stakeholders on the topic to perform the needed systematic change. Are tax reforms, laws and regulation changes the way or perhaps there is some not previously seen way to help with this issue. Something not discussed and therefore not researched amongst the articles chosen for this thesis and its SLR is the question are LIBs even the most effective tool to power EVs if they yield such an environmental and economic problems for governments and corporations. Perhaps EV LIBs are not the way to move forward and some other energy source consisting of renewable materials and resources that already or more easily fits into CE contexts and its practices needs to be developed to replace LIBs as the source of energy for EVs.

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