Sustainable business model perspectives for the electric vehicle industry

The case of battery second use

by

Robert Reinhardt

UNIVERSITAT POLITÈCNICA
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A thesis submitted for the award of the degree of Doctor of Philosophy by the Universitat Politècnica de Catalunya (UPC) – BarcelonaTech

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Executive Summary

The purpose of this doctoral research dissertation is to examine sustainable business model (SBM) perspectives for the rapidly developing Battery Second Use (B2U) market within the emerging electric vehicle (EV) industry. Previous research has shown that a global mass market adoption of electric vehicles (EVs) is still hindered by the high costs of lithium-ion batteries (LIBs). Repurposing degraded EV batteries in second use applications holds the potential to reduce first-cost impediments of EVs. The research on new business models is limited. The ones that emerge rapidly within the EV and battery second use (B2U) industries focus mainly on economic aspects without integrating social and environmental dimensions. Simultaneously, the emerging research topic around sustainable business models (SBMs) seem to be able to bridge the environmental management concerns in conjunction with economic and social changes.

This thesis further develops and extends extant literature by addressing this paucity through offering an interdisciplinary approach by drawing upon key perspectives from the emerging sustainable technology of EVs and its underlying B2U market in relation to SBMs. The research entails both, qualitative and quantitative assessments, to examine the correlation between SBMs and B2U. Major results indicate that B2U has led to innovative cross-sectoral multi stakeholder business relationships, particularly relevant for the previously isolated automotive and energy markets that are now investigating the full potential of second life batteries and hence new business opportunities for the first time in history. B2U holds the potential to facilitate current unsustainable practices in the EV industry. This in turn, will lead towards a faster EV market uptake and improvements of overall sustainability performance through SBM perspectives. Therefore, it was discovered that prospective innovative business models for B2U, which take a multi-stakeholder network centric business model design rather than firm-centric one, may prove to be a viable business case for sustainability.

It was further unearthed that B2U leads to shared sustainable value creation mechanism for the EV industry (and newly emerging stakeholders) as part of innovative SBMs. Therefore, this doctoral dissertation proposes a new B2U innovative business model framework that records and explains the stakeholder relationships as an innovative and forming phenomenon, as well as opens new roads for future discussion among researchers and practitioners.

This doctoral dissertation has addressed a paucity and inter-disciplinary literature gap and met an industrial and academic need accordingly. Overall, a new research stream emerges on SBMs for EV B2U and it is hoped that more contributions will follow to increase the impact and value of sustainable waste & resource management and the circular economy.

Keywords

Sustainable business models; sustainable business model innovation; innovation; electric vehicle; battery; lithium-ion battery; battery second use; battery second life; circular economy; sustainable waste management

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Abbreviations

BatPac	Battery Performance and Cost model
B2U	Battery Second Use
BMI	Business Model Innovation
BMS	Battery Management System
BEV	Battery Electric Vehicle
CM	Critical Metal
CSR	Corporate Social Responsibility
DB	Database
DBMS	Database Management System
EEE	Electrical and Electronic Equipment
E-Mobility	Electric Mobility
EOL	End-Of-Life
ER	Entity Relationship
ESS	Energy Storage System
EU	European Union
EV	Electric Vehicle
E-Waste	Electronic Waste
GHG	Greenhouse Gas Emissions
ICEV	Internal Combustion Engine Vehicle
IT	Information Technology
LCA	Life Cycle Assessment
LFP	Lithium Iron Phosphate
LIB	Lithium Ion Battery
LMO	Lithium Manganese Oxide
NCA	Lithium Nickel Cobalt Aluminum Oxide
NMC	Lithium Nickel Manganese Cobalt Oxide
SBM	Sustainable Business Model
SBMI	Sustainable Business Model Innovation
SIBM	Sustainable Innovation Business Model

PHEV	Plug-In Hybrid Electric Vehicle
PV	Photovoltaic
TBL	Triple Bottom Line
TIAX	PHEV Cost Assessment Study
WEEE	Waste Electrical and Electronic Equipment

Chapter 1

Introduction

1.1 Motivation

This chapter presents the introduction to this doctoral dissertation, the research aim and objectives, an overview of the employed research strategies and methods, thesis structure, and related published doctoral research.

1.2 Introduction

In the last few decades, global concerns over climate change as a result of a rising global population and related increasing resource use and environmental impacts have strengthened the need to shift towards holistic approaches that challenge the issues of a more sustainable future. In fact, the transport sector is one of the key contributors to global greenhouse gas (GHG) emissions to the atmosphere due to ever-increasing uses of finite fossil fuels and ongoing dependency on internal combustion engine vehicles (ICEVs) for more than a century, which emphasize that current economic, social, and environmental structures within the automotive industry are unsustainable (Ahmadian et al., 2018; Casals et al., 2017). These concerns alongside an increased focus on sustainable transportation have stimulated a trend within the automotive sector towards electric vehicles (EVs), which are a promising solution to restrict such emissions.

The EV is not new and was subject to tremendous changes from the nineteenth century to the present day. It may come as a surprise for one that EVs were once the top choice for transportation. The first EV models were developed around 1832 – 1839 after achieving a series of breakthroughs, from the battery to the electric motor, and in the late 1800s resulted with the first commercial EV on the road (DOE, 2014). In fact, by 1900 the total value of EVs outsold all other types of cars including internal combustion engine vehicles (ICEVs) but with the arrival of next-generation gasoline cars, such as the appearance of the electric starters, the ICEV received global success and by 1935 EVs were scarce (Thompson, 2015).

There are a variety of EVs that store electricity energy in electric motors such as capacitors, compressed air, fuel cells and batteries. This doctoral dissertation is exclusively dealing with vehicles that only store electricity in rechargeable lithium-ion battery (LIB) packs, commonly referred to as battery electric vehicles (BEVs) or pure EVs, and thus the term EV will solely refer to this kind of vehicle. Further, BEVs are dominating the emerging EV industry over plug-in electric vehicles and hybrid electric vehicles, indicating that this technology will most likely prevail in the future (Rong et al., 2017). However, a global mass market adoption of EVs is still hindered by presently high costs of lithium-ion battery (LIB) packs, which translate into highly priced vehicles (Bonges and Lusk, 2016).

Among other possible solutions to make EVs more affordable, the concept of battery second use (B2U) has been identified as one promising value creation mechanism that could feed back some revenue to EV manufacturers that may lead to lower vehicle selling prices, and thus making EVs more competitive (Jiao and Evans, 2016a). Once degraded, the second use of EV batteries in less demanding applications such as stationary energy storage systems (ESS) presents a cost effective option that can contribute to building smart grid technologies (Podias et al., 2018; Neubauer and Pesaran, 2011). In this second life, the batteries can be procured at low cost, indicating new businesses opportunities (Figure 1).

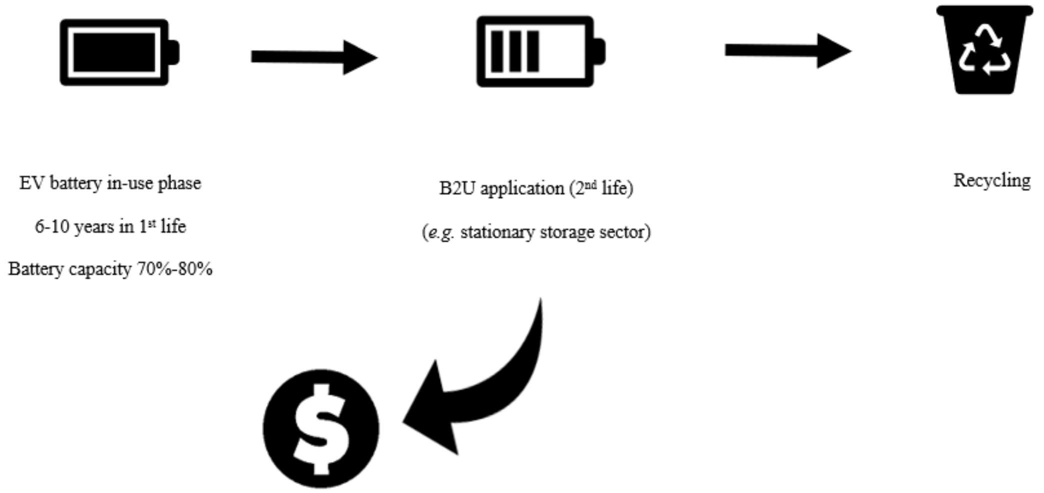

Figure 1 The concept of Battery Second Use

Through remanufacturing and reuse, the concept of B2U slows down the resource cycle by prolonging the battery's total service life and partially closes the resource loop as the recycling phase is delayed substantially, leading towards improved sustainable resource management. Therefore, it is line with the principles and different interpretations of the circular economy, which all have in common that resource life extending strategies are the most essential element (Antikainen et al., 2016). Given the concept of B2U, it must be highlighted that product life extending strategies are crucial to decrease negative impacts on the environment and to contribute towards the circular economy. However, it is still unclear how a firm might translate such strategies into innovative business models (Bocken et al., 2016). In this regard, Boons and Lüdeke-Freund (2013) argue that sustainable business models (SBMs) can significantly contribute to solving economic, ecological and social problems simultaneously (Boons and Lüdeke-Freund, 2013). Consequently, this review follows the argument that the emerging B2U industry can deliver not only economic value but also social and environmental values as part of SBM approaches.

However, it seems that neither theoretical nor empirical research has yet answered the question what these business models entail and how they will develop in the future. According to Yang et al. (2017) current research efforts in the field of SBMs is not yet mature, stating that there is "…a lack of agreed concepts of sustainable business models and the ways to achieve this being poorly addressed in literature" (p1796). Rana et al. (2017) also relates to this lack of research and existing works on SBMs and modelling approaches, stating that current frameworks tend to be limited in their research scope and a more holistic view of the three metrics of sustainability, the environment, society, and the economy, is needed. SBM research is slowly gaining a foothold but the concept itself still lacks clarification in practice, particularly the development of SBM theory is still in its infancy (Dentchev et al., 2018). In a recent analysis on developments in SBM scholarship and practice, Lüdeke-Freund and Dembek (2017) have assessed whether SBM research is an emergent field or a subfield of already established theories and concepts, concluding and confirming that in fact SBM research is an emerging field lacking more research.

With prospective increased global EV market share, a growing number of retired EV batteries will become available at low cost that could provide valuable services in stationary ESS. For this reason, end-of-life (EOL) EV batteries may represent a disruptive technology that will change the current nature of the automotive and energy industries as the electricity markets presently lack cost-effective ESS as well as that B2U may represent much cheaper electricity storage from renewable than is available today. Consequently, there is the opportunity of an attractive market not only for original equipment manufacturers (OEMs) but also for new market participants such as electricity producers, grid operators, recycling companies, service providers and final costumers, which all will be part of innovative evolving value chains. Thus, potential B2U strategies are dependent on many factors, particularly on the interests of the different stakeholders involved, which underlines that articulating effective business models will be difficult. Recently, the concept of B2U is a much-debated issue within the automotive industry (Jiao and Evans, 2018) and nearly all of the major car companies have participated in pilot and demonstration projects as part of joint ventures with other stakeholders to gain a better understanding about the feasibility and the capabilities of B2U and development of viable innovative business models (Table 1).

Table 1 Selected Battery Second Use projects

OEM	B2U partner/service provider	EV model	Capacity	B2U application	Country	Reference
Daimler	GETEC, The Mobility House, Remondis	Smart	13 MWh	Renewable energy	Germany	(Daimler, 2016)
GM	ABB	Volt	50 kWh / 25 kW	Power supply	USA	(ABB, 2012)
GM	ABB	Volt	n/a	Renewable energy	USA	(General Motors, 2015)
Renault	Eco2Charge	Kangoo ZE	66 kWh	Renewable energy	France	(Eco2Charge, 2014)
Nissan	Eaton	Leaf	4.2 kWh	Residential energy storage	UK	(Nissan, 2017a)
Nissan	Eaton & The Mobility House	Leaf	4 MWh / 4 MW	Peak shaving, Backup power	Netherlands	(Nissan, 2016)
Nissan	Sumitomo	Leaf	400 kWh/600 kW	Renewable energy	Japan	(St.John, 2015)
Mitsubishi & PSA	EDF & Forsee Power	Peugeot Ion, C-zero & iMiev	n/a	Renewable energy	France	(Green Car Congress, 2015)
BMW	UC San Diego	Mini-E	160 kWh / 100 kW	Renewable energy	USA	(California Energy Commission, 2012)
BMW	Vattenfall & Bosch	ActiveE & i3	2.8 MWh / 2 MW	Renewable energy	Germany	(Lambert, 2016)
BMW	Vattenfall	i3	12 kWh / 50 kW	Fast charging	Germany	(BMW, 2014)
Renault	Connected Energy	Zoe	50 kWh / 50 kW	Fast charging	UK	(Renault, 2017a)

It is evident that there is a growing investment, experimentation, and interest on the topic of B2U, indicating the creation of a secondary market for retired EV batteries including newly forming stakeholder relationships and hence new market opportunities. However, most of these projects have served as demonstration and pilot projects due to low availability of degraded EV batteries (i.e. slow EV market uptake) as well as uncertainties on quantifying the true economic value of these batteries. Thus, developments in the nascent B2U industry are speculative at this point as companies entering into this evolving market are still evaluating if B2U is a profitable business or not. Hence, potential B2U market forms, economic properties or identified stakeholders involved through the establishment of mature (sustainable) business models is far from becoming a reality (Bräuer, 2016). Furthermore, very few studies have assessed B2U from a business model perspective and consequently follow-up studies are in demand that evaluate the increased value of reusing EV batteries (Jiao and Evans, 2017).

1.3 Aim of the research

The necessity for this doctoral dissertation arose from the limited ability of current (sustainable) business model approaches to quantify the full scope of the emerging B2U industry within the rapidly developing EV industry as part of prospective more and new SBM perspectives. This has led to the following research aim of this doctoral dissertation:

To explore the electric vehicle battery end-of-life strategy of battery second use from a sustainable business model perspective

For this reason, this dissertation has also identified a sub-set of research objectives to facilitate in answering the research aim:

1. Investigate the creation of a sustainable business model for the EV industry with an emphasis on B2U
2. Unearth and record the intercorrelation between the EV sector and emerging B2U market, considering SBM perspectives
3. Explore how the B2U market and prospective (sustainable) business models will develop from a stakeholder perspective to capture the full value of EV waste batteries

1.4 Thesis structure

This thesis is organized into 9 chapters and attempts to take both, academia and practitioners' point of view into account (Table 2).

Chapter 1 aims to familiarise the reader with the research topic, comprehend the research gap and resulting primary research focus and related doctoral publications and scientific contributions at international conferences.

Chapter 2 delivers a comprehensive critical review on SBM perspectives for EV B2U in order to highlight that there is a paucity and knowledge gap on SBM perspective for the emerging EV B2U market and resulting urgent need for further empirical analyses. This chapter is based on the comprehensive review article 'Towards sustainable business models for electric vehicle battery second use: a critical review' published in the Journal of Environmental Management as well as related conference abstract & poster entitled 'A critical review of sustainable business models for the end-of-life strategy of electric vehicle battery second use', presented at the 2019 International Conference on Resource Sustainability - Cities (icRS Cities 2019), Adelaide, Australia.

Chapter 3 and Chapter 4 represent major preliminary results from the ongoing extensive literature review on SBM perspectives for EV B2U. Accordingly, Chapter 3 discusses the EV B2U macro-environment through undertaking an external analysis of political, economic, social, technological, environmental and legal (PESTEL) uncontrollable factors that will impact the emerging B2U market as whole. Continuously, Chapter 4 highlights that the EV B2U related EU regulatory framework in place is not of a proactive nature as emerging technologies of EV batteries (including the emerging concept of B2U) and energy storage technologies as they arrive at the market are not in alignment with evolved legislations at EU level. These chapters are based on the conference papers titled 'Macro environmental analysis of the electric vehicle battery second use market' & 'Critical evaluation of European Union legislation on the second use of degraded traction batteries', presented at the 13th & 14th International Conference on the European Energy Markets (EEM), Porto (Portugal) and Dresden (Germany).

Chapter 5 presents a quantitative environmental and economic assessment of the importance of the cathode material selection within LIB technology based EVs. As a result of a growing global EV market and related energy storage markets, there will be a substantial increase in (critical) raw material demand. Thus, this Chapter aims to emphasize the significance of alternative innovative battery material recovery, reuse/second use strategies, such as the emerging concept of B2U. This chapter is based on the conference paper and related poster titled, 'A critical evaluation of cathode materials for lithium-ion electric vehicle batteries', presented at the International Congress on Project Management and Engineering 2016, Cartagena, Spain. The conference paper was selected to be part of the Springer lecture notes book series Project Management and Engineering Research, Lecture Notes in Management and Industrial Engineering.

Chapter 6 builds upon key findings from Chapter 5 and proposes a sustainable innovative recovery database management system (DBMS) to support the material supply of European industries while addressing key sustainability concerns. As the global EV B2U market is still in its infancy (i.e. large volumes of EV batteries will not become available before 2025-2030), this chapter focuses on experiences made and lessons learnt in the global consumer electronics industry. This industry is currently facing the major 21st century sustainability management problem of electronic waste (e-waste) and linked serious harm to the environment and human health. It is noteworthy that this chapter is the result of successfully attending the 1st Global Spring School of the European Network for innovative recovery strategies of rare earth and other critical metals from electrical and electronic waste (ReCreew) (COST Action ES1407, EU Framework Programme Horizon 2020), Hamburg, Germany. Our scientific team, which consisted of 3 PhD candidates, was awarded the 1st ReCreew Award for best paper presentation on innovative solutions for critical WEEE recycling and metal recovery within the global electronics industry. This chapter is based on the resulting conference paper titled 'Challenges and Perspectives on a Database Management System for the Sustainable Recovery of Critical Metals from Waste Electrical and Electronic Equipment', which was presented at the 15th International Conference on Environmental Science and Technology (CEST), Rhodes, Greece. The conference paper was selected to be part of the linked conference special journal issue in Global Nest Journal, title 'Conceptual Design for Data Flow for a Database Management System for the Sustainable Recovery of Critical Metals from Waste Electrical and Electronic Equipment'.

Chapter 7 attempts to identify key opportunities and threats of a prospective B2U industry through reporting evidences from selected EV B2U cross-sectoral stakeholder sustainability related business activities, which led to a refreshing conceptualisation of an SBM framework for the EV B2U industry. This chapter is based on the entitled manuscript 'Proposing a conceptual sustainable business model for the electric vehicle battery second use industry: opportunities and threats', submitted to the Journal of Environmental Management.

Chapter 8 examines the inevitability of developing sustainable business models (SBMs) for the rapidly developing battery second use (B2U) market within the emerging electric vehicle (EV) industry. With the help of rich industry case data, the conceptual sustainable innovation business model (SIBM) framework is proposed. This chapter is based on the conference short paper titled ‘Sustainable business model archetypes for the electric vehicle battery second use industry: towards a conceptual framework’, presented at the 3rd International Conference on New Business Models (NBM 2019), ESCP Europe, Berlin, Germany. Relatedly, and building upon scientific feedback from NBM 2019, an original research article manuscript entitled ‘Sustainable business model archetypes for the electric vehicle battery second use industry: towards a conceptual framework’, has been submitted to the Journal of Cleaner Production and is currently ‘under revision’.

Chapter 9 presents overall conclusions of this doctoral dissertation including key contributions and recommendations for future research works.

Table 2 Thesis structure

Chapter	**This chapter will enable the reader to…**
Chapter 1	…become familiar with the research topic, identified research gap, research aim and objectives, research strategy & methods and with the overall structure and layout of the thesis
Chapter 2	…comprehend the paucity and knowledge gap on SBM perspective for the emerging EV B2U market and urgent need for further empirical analyses
Chapter 3	… realise uncontrollable external macro factors that will impact the developing EV B2U market now and in the future
Chapter 4	… appreciate the importance of implementing pro-active EU legislation related to the concept of B2U
Chapter 5	… grasp the importance of cathode material selection in LIB technology based EVs and resulting significance of alternative innovative material reuse/second use strategies
Chapter 6	… understand alternative innovative conceptual (critical) raw material recovery strategies
Chapter 7	… comprehend key opportunities and threats of a prospective EV B2U market
Chapter 8	… accept the necessity of developing a SBM for the EV B2U followed by comprehending the presented conceptual sustainable innovations business model (SIBM) framework
Chapter 9	… perceive overall thesis results, contributions and recommendations for future research

1.5 Publications & International Conferences

Journals (peer reviewed)

Reinhardt, R., Christodoulou, I., Amante García, B., Gassó-Domingo, S. (2019). Towards sustainable business models for electric vehicle battery second use: a critical review. Journal of Environmental Management, **245**, 432-446. DOI: https://doi.org/10.1016/j.jenvman.2019.05.095

Penaherrera, F., Reinhardt, R., Kousati, A. (2018). Conceptual Design for Data Flow for a Database Management System for the Sustainable Recovery of Critical Metals from Waste Electrical and Electronic Equipment. Global Nest Journal, **20** (3), 700-705.
DOI: https://doi.org/10.30955/gnj.002581

International conferences (peer-reviewed)

Reinhardt, R., Amante García, B., Christodoulou, I., Gassó-Domingo, S. (2019). Sustainable business model archetypes for the electric vehicle battery second use industry: towards a conceptual framework. Paper presented at the 4th International Conference on New Business Models, ESCP Europe, Berlin, Germany, 1st – 3rd July 2019.

Reinhardt, R., Amante García, B., Gassó-Domingo, S., Christodoulou, I. (2019). A critical review of sustainable business models for the end-of-life strategy of electric vehicle battery second use. Accepted Abstract & Poster Presentation. Poster presented at the 2019 International Conference on Resource Sustainability - Cities (icRS Cities 2019), Adelaide, Australia, 1st – 3rd July 2019.

Reinhardt, R., Amante García, B., Gassó-Domingo, S., Christodoulou, I. (2017). Macro environmental analysis of the electric vehicle battery second use market. In: 14th International Conference on the European Energy Market – EEM 2017, Dresden, Germany, 6th – 9th June 2017. 1-6, IEEE. https://doi.org/10.1109/EEM.2017.7982031

Penaherrera, F., Kousati, A., Reinhardt, R. (2017). Challenges and Perspectives on a Database Management System for the Sustainable Recovery of Critical Metals from Waste Electrical and Electronic Equipment: Paper presented at the 15th International Conference on Environmental Science and Technology (CEST), Rhodes, Greece, 31st August – 2nd September 2017.

Reinhardt, R., Amante García, B., Casals, L.C., Gassó-Domingo, S. (2016). Critical analysis on European Union legislations and policies with regards to the second use of degraded electric vehicle traction batteries. In: 13th International Conference on the European Energy Market 2016, Porto, Portugal, 6th – 9th June 2016. 1-5, IEEE. https://doi.org/10.1109/EEM.2016.7521207

Reinhardt, R., Amante García, B., Casals, L.C., Gassó-Domingo, S. (2016). A critical evaluation of cathode materials for lithium-ion electric vehicle batteries. Poster presented at the International Congress on Project Management and Engineering 2016, Cartagena, Spain, 13th – 15th July 2016.

Book chapter (peer reviewed)

Reinhardt, R., Amante García, B., Casals, L.C., Gassó-Domingo, S. (2019). A critical evaluation of cathode materials for lithium-ion electric vehicle batteries. In: Ayuso Muñoz J., Yagüe Blanco J., Capuz-Rizo S. (eds). Project Management and Engineering Research. Lecture Notes in Management and Industrial Engineering. Springer, Cham, 99-110. https://doi.org/10.1007/978-3-319-92273-7_7

State-of-the-Art

2.1 Motivation

This chapter presents the state-of-the-art on the interdisciplinary relationship of the two major emerging research streams of sustainable business models (SBMs) and electric vehicle (EV) battery second use (B2U).

2.2 The concept of electric vehicle battery second use

The lifecycle of EV batteries conceptually begins with the extraction of raw materials (including mining and processing) to battery manufacturing, the primary use in the EV (1st life), followed by end-of-life disposal (Neubauer et al., 2015; Neubauer and Pesaran, 2011; Reid and Julve, 2016; Richter et al., 2016; Ahmadi et al., 2014b). Considering the integration of the concept of B2U, an additional loop has been added including battery refurbishment and second life application in grid storage, which substantially extends the battery lifecycle in comparison to a more linear approach and is thus in line with the cornerstones of the circular economy (Figure 2).

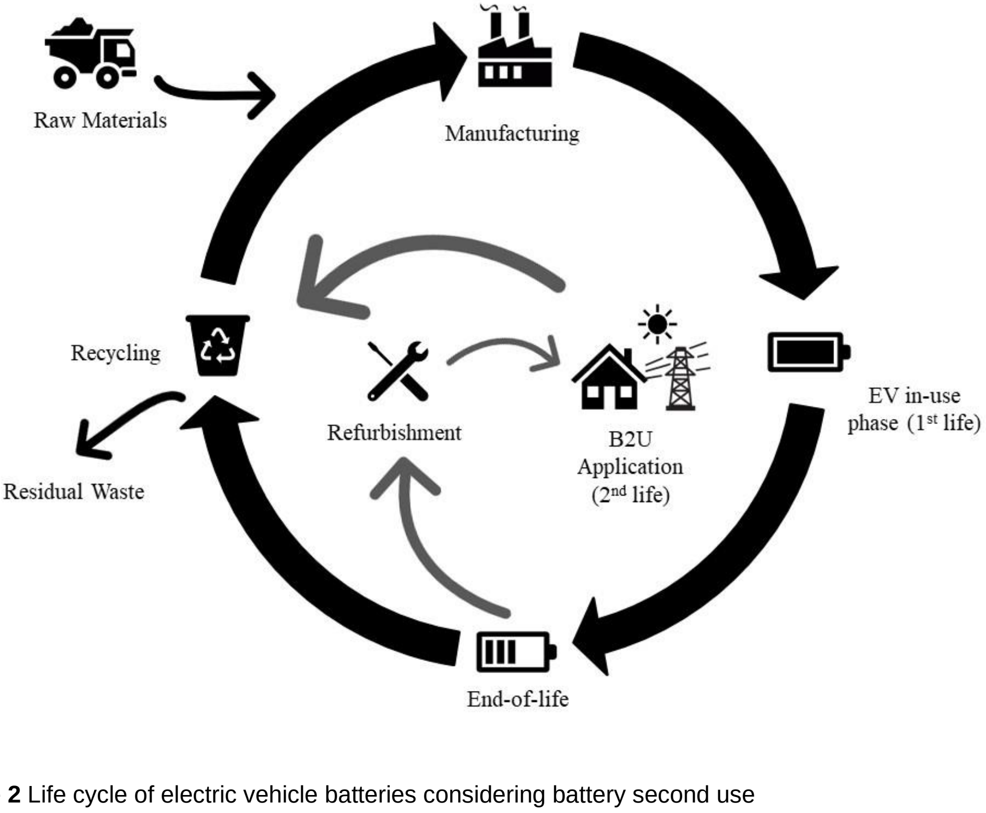

Figure 2 Life cycle of electric vehicle batteries considering battery second use

A lithium-ion battery (LIB) pack's first life includes the manufacturing of the battery and its effective and low carbon operation in an EV whereby the battery provides electrical operating power for the motor and auxiliary units whenever needed (Rehme et al., 2016). An EV battery's first life in an automotive application is characterised by different driving patterns, operating temperatures and charging rates, which makes each battery age individually and it is therefore difficult to predict a battery's aging behaviour (Knowles and Morris, 2014).

Furthermore, in the EV's first life, the vehicle can act as a distribute energy storage device and can offer many service such as through EV charging (vehicle-to-grid), the vehicle's rechargeable battery provides power to the grid that can help to balance loads by e.g. charging at nigh time when demand is low (so-called 'valley filling') or send power back to the grid when demand is high (so-called 'peak shaving') (Yong et al., 2015). These grid operation and management potentials have received increased attention from the electricity markets, particularly with regards to effectively balancing the grid. This is a direct result of growing policy pressures on decarbonising the electricity generation through integrating increased volumes of renewable energies. As a result, EV companies such as Nissan and Tesla have entered the stationary storage market for residential and commercial uses by installing their own stationary storage solutions that facilitates in learning about this technology while generating some revenue (Reid and Julve, 2016).

However, the integration and storage of intermittent renewables in large-scale ESS still lacks cost-effective solutions due to expensive LIB packs (Heymans et al., 2014). This is confirmed by Casals et al. (2019), stating that LIB pack prices would need to be below 220 dollar per kilowatt-hour ($/kWh) to result in substantial revenues as part of stationary ESS. B2U solutions in the stationary storage market can therefore perform the same services at substantially lower cost and may unlock the potential to feedback revenue to EV companies that will in turn lead to lower vehicle prices (Jiao and Evans, 2016b). However, it must also be underlined that with ongoing battery price reductions, the concept of B2U may face strong competition from new, cheaper, and specifically for ESS purposes designed batteries.

An EV battery reaches its EOL when it can no longer meet the requirements of the vehicle operation (reduced maximum range and decreased acceleration) and typically customers bring their EVs to the dealership when the vehicle is performing below the customer's expectation (Cready et al., 2003). An EV battery is considered not useful for traction purposes and has degraded after losing around 20%-30% of its capacity or after around 4,000 charge cycles or 120.000 km of driving (Sathre et al., 2015; Ahmadi et al., 2015; Neubauer, Smith, et al., 2015). As these batteries still retain around 70%-80% capacity, researchers have found that instead of recycling these EOL batteries immediately after their first use in an EV, repurposing degraded EV batteries in a second life in less demanding stationary ESS is still possible and feasible form a techno-economic and environmental perspective (Cready et al, 2003; Wolfs, 2010; Gaines and Sullivan, 2010; Neubauer and Pesaran, 2011; Ramoni and Hong-Chao Zhang, 2013; Manzetti and Mariasiu, 2015).

The refurbishment process usually entails costly reengineering of an EV battery for a non-vehicle stationary storage application through battery disassembly, testing degradation and failure rates, repairing any damages, removal and replacement of substandard cells, reassembly of the module and pack, packaging for B2U application and adding electrical hardware, control and safety system (Derousseau et al. 2017; Standridge & Hasan 2015; Foster et al. 2014; Ahmadi et al. 2014; Cready et al. 2003). Today, EV batteries consist of many components such as lithium-ion cells, battery management systems, sensors and cooling systems, which in principle can all be re-used in B2U concepts (Fischhaber et al., 2016). However each degraded EV battery has its own individual state of health depending on the previous exposure and treatment during their first-life and therefore costly manual disassembly processes are presently the norm as each battery must be cleaned, inspected and replaced to reach like new condition (Ramoni and Zhang, 2013). Therefore, a standard testing procedure is urgently needed so that degraded batteries can be safely used in B2U applications. Further, it must be underlined that today there exists no widely accepted standard for B2U at the initial battery design stage (‘design for B2U’) or once the battery has reached its first EOL. Therefore researchers are calling for increased battery quality standards and certification protocols to ensure safe and effective functioning in B2U applications as well as underline the importance of collaborations between EV companies and battery makers i.e. original equipment manufacturers (OEMs), in order to develop standardised battery components and models to ensure cross-manufacturer compatibility (Hu et al., 2017).

After the batteries have been repurposed, they are ready for use in a B2U application. Today, across the literature the most prominent B2U strategy has been identified to be the battery repurposing and further use in non-automobile stationary ESS (Derousseau et al., 2017; Beverungen et al., 2016; Bräuer et al., 2016; Jiao and Evans, 2016b; Standridge and Corneal, 2014; Foster et al., 2014; Ahmadi, Fowler, et al., 2014; Ambrose et al., 2014; Neubauer and Pesaran, 2011; Narula et al., 2011; Williams and Lipman, 2010). Applying second life batteries to battery storage technologies can provide a variety of different services and benefits to stakeholders involved (Figure 3).

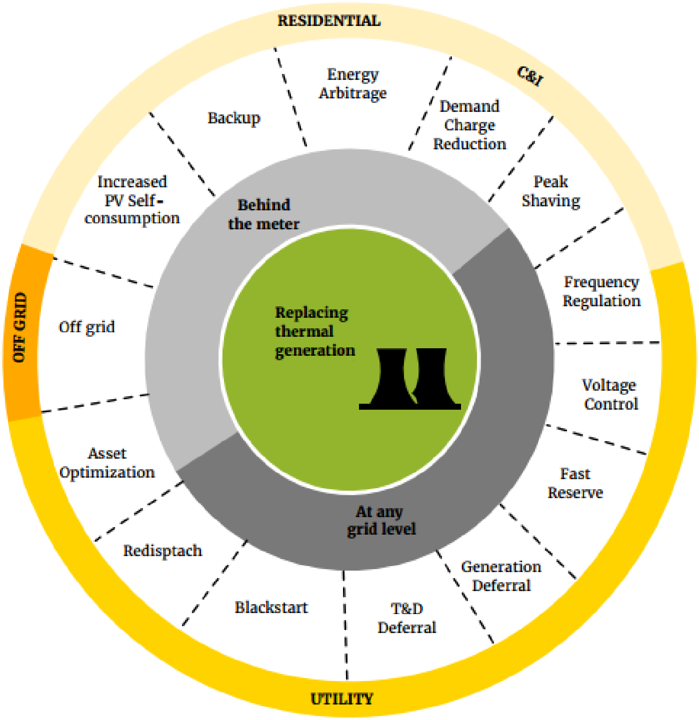

Figure 3 Benefits of battery energy storage technologies (Reid & Julve 2016)

Previous research in the field concluded that the most environmentally and economically beneficial B2U application markets for EV traction batteries lay within industrial and residential uses including current and emerging grid-related applications (Standridge and Corneal, 2014; Neubauer and Pesaran, 2011; Gaines and Sullivan, 2010). According to Burke (2009) the most efficient B2U applications are within the residential sector (e.g. buffer for renewable energy) in contrast to large-scale storage system as the refitting process requires more efforts and costs. Williams & Lipman (2011) and Narula et al. (2011) on the other hand, estimate that the most economic use is the application in large-scale stationary ESS. Ambrose et al. (2014) demonstrated that applying second life EV batteries to micro-grid systems in developing countries in contrast to using lead-acid batteries has shown several economic and environmental benefits, which has been confirmed in studies by Neubauer et al. (2012) and Neubauer & Pesaran (2011).

According to Rehme & Richter (2016), with regards to the ESS's degree of mobility, B2U application cases can be classified in stationary (e.g. home storage from PV panels), semi-stationary (e.g. power for construction sites), or mobile (e.g. reuse in scooters or golf cars). Törkler (2014) on the other hand, identified three possible B2U applications depending on the needed energy that are energy related and industrial applications, commercial applications, and residence related applications. Consequently, the battery management system needs to be adjusted to the specific

B2U stationary storage application to increase overall lifetime and economic benefits (Reid and Julve, 2016). In that context, it must be underlined that there is pressing need for regulation, especially within the European Union (EU) legal context, to address the emerging technologies and relationships between EVs (including B2U) and energy storage technologies as they arrive at the markets in a more proactive manner. According to Reinhardt et al. (2016) EU automotive and energy binding legislations have to work for a more harmonised policy framework, ultimately leading to provide a level playing field for an e-mobility transition within the European economy. It appears that the European Commission has comprehended the need to overcome such regulatory barriers to innovation as of March 2018, an innovation deal with eight partners from national authorities and innovators has been signed, which aims to clarify the regulatory landscape regarding of EV battery EOL solutions (including B2U and recycling) and stationary ESS applications (European Commission, 2018).

The concept of B2U has the potential to delay the battery recycling process by 10-20 years, which is usually implying additional costs for OEMs and entails potential waste and environmental pollution. The industry presently lacks proper environmental sound and economic feasible recycling framework for automotive LIBs on a large scale as well as that it has been claimed that recycling is often motivated by economic revenues (Yun et al., 2018; Sonoc et al., 2015; Gaines et al., 2011). This raises a major sustainability concern on the possible unregulated disposal of EOL EV batteries that can have significant negative effects on the environment and human health (e.g. risk of fires during battery transportation/storage) as it was found to be the case by the unchecked disposal of consumer electronic waste (e-waste) in the past (Richa et al. 2014; Widmer et al. 2005). From an economic perspective, battery recycling facilities require high fixed costs and thus need high utilisation (large volumes of batteries) to become economically feasible (Rohr et al., 2017). In recent years, much research has focused on recycling waste LIBs while simultaneously battery recycling industry infrastructure remains insufficient with only few companies such as Umicore, Sony and Accurec having exploited technologies to recycle spent EV batteries on a large commercial scale (Heelan et al., 2016; Sonoc et al., 2015).

Overall, the concept of B2U delays recycling efforts and may lead to higher residual value of the battery that could improve overall economic efficiency of EVs. Therefore, previously considered as a waste and recycling issue, reusing spent LIBs as part of B2U solutions may now lead into profitable innovative business models towards sustainability that is yet to be fully unearthed for researchers, industry and policy makers.

2.3 Business models

The term ‘business model’ has not been widely discussed across the literature until the 1990s with the introduction of the dotcom age but then reached a relatively good conceptual understanding but due to its complexity no single definition of the term exists. The existing key literature presents various perspectives in a static approach on what business models entail whereby the focus is on how a firm creates and captures value within a value network (Bocken et al., 2014; Zott et al., 2011; Teece, 2010; Zott and Amit, 2008; Osterwalder et al., 2005; Chesbrough and Rosenbloom, 2002 Osterwalder and Pigneur, 2002). This view reflects common agreements among other strategy-oriented business model scholars that creating and delivering customer value lies at the centre of any business model and thus its central element is the customer value proposition (Chesbrough, 2010; Johnson, 2010; Zott and Amit, 2010; Teece, 2010). Further, the literature conceives a business model as firm-specific whereby different components of the business model interact with each other to address change and focus on innovation (Demil and Lecocq, 2010). Thus, researchers have investigated how a business’s activities as part of a business model are interlinked to provide value that may lead into a competitive advantage.

In that regard, one widely accepted tool is the business model canvas, which determines nine elements of any business model that make up the whole system that are value proposition, customer segments, customer relationships, channels, key resources, key activities, partners, costs and revenues (Osterwalder et al., 2005; Osterwalder et al., 2010). Based on a wide range of literature, Richardson (2008) proposes a widely accepted framework for business models, which contain the value proposition, value creation and delivery and value capture. Boons & Lüdeke-Freund (2013) combine approaches by various authors and distinguish the following elements of a generic business model concept, which are value proposition (the value embedded in the products/services offered by the firm); supply chain (the relationships with suppliers); customer interface (the relationships with customers); and financial model (cost and benefits, and their distribution across the stakeholders). Based on these concepts, across the literature three core interrelated characteristics of business models have emerged and can be summarized as: the value proposition, value creation and delivery and value capture (Figure 4).

To keep competitive advantages, firms need to continuously innovate their business models. In searching such innovative ways, business model innovation (BMI) has been acknowledged as a source of competitive advantage as it has the strategic potential to identify new sources of value creation through innovating the different elements (and their interactions) of the business model

(Amit and Zott, 2012; Bocken et al., 2014). BMI is defined as "…the search for new logics of the firm and new ways to create and capture value for its stakeholders" (Casadesus-Masanell & Zhu 2013, p464). As the topic of sustainable development is increasingly identified as a new source of competitive advantage, the concept of BMI is seen as one of the key tools to make strategic use of sustainability in organisations (Zhang et al., 2018; Abdelkafi and Täuscher, 2016; Boons and Lüdeke-Freund, 2013). Since the release of the Brundtland Report in 1987, which defines sustainable development as "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs", the concept has been playing an increasingly critical aspect in agendas of policy makers and strategies of businesses (WCED, 1987, p43). Particularly relevant to the term sustainable development is the 'triple bottom line' (TBL), which aims to a balanced integration of the environment (planet), society (people) and economy (profit) (Elkington, 1997).

Value Proposition	Value Creation & Delivery	Value Capture
• Product/Service offering • Target customer differentiation	• Key activities • Key resources & capabilities • Position in the value network • Value chain	• Cost structure • Revenue model/streams • Competitive strategy

Figure 4 Business model framework (adapted from Bocken et al. 2014; Richardson 2008; Osterwalder & Pigneur 2005)

The recent global financial and economic crisis alongside a rising global population that is consuming ever-increasing volumes of resources, has further led to important questions on the impact of existing corporate business models on the sustainability of the global economy and society (Schaltegger et al., 2016). Scholars have thus argued that if companies are to fully contribute to sustainable development, they need to rethink their business models and fundamentally shift their business activities and innovation practices to achieve deeper incorporation of environmental and social issues and needs as part of a future sustainable economy (Bocken et al., 2014; Boons and Lüdeke-Freund, 2013; Lüdeke-Freund, 2010; Stubbs and Cocklin, 2008). This is why the concept of BMI is increasingly recognised as a mechanism that enables to identify greater social and environmental sustainability in the industrial system (Lüdeke- Freund, 2010).

Scholars and experts are increasingly exploring whether adapted or completely innovative business models can boost economic revenues by either drastically diminishing negative influences or developing positive impacts for the environment and society (Boons and Lüdeke-Freund, 2013; Schaltegger et al., 2012; Stubbs and Cocklin, 2008). Major beliefs among scholars is that the normative concepts of sustainable development with the help of BMI should guide the development and implementation of more sustainable business models, which has been identified as the 'well-rooted foundational idea' in order to contribute solving economic, environmental and social problems (Lüdeke-Freund and Dembek, 2017). This fundamental change will require a holistic approach that can tackle the challenges of a sustainable future through bringing responses to environmental changes in conjunction with economic and social changes, ultimately leading to more sustainable business models (SBMs) (Bocken et al., 2014).

2.4 Sustainable business models

The concept of sustainable business models (SBMs), or also referred to as business models towards sustainability, has emerged within the last decade with works by Stubbs & Cocklin (2008) evaluating organisational and cultural preconditions of business models that contribute positively to environmental and social development (Lüdeke-Freund and Dembek, 2017). In the following years, the interest of academia in SBMs research has increased with the publication of special issues such as in Organization and Environment (Volume 29, March 2016), Journal of Cleaner Production (Volume 45, April 2013) and Sustainability (Volume 8, 2016) along review articles (Geissdoerfer et al., 2018b; Evans et al., 2017b; Schaltegger et al., 2016 Bocken et al., 2014; Boons and Lüdeke-Freund, 2013), which all provide excellent overviews and different perspectives on the topic.

Early works on the topic by Stubbs & Cocklin (2008) state that SBMs use both a systems and firm-level perspective, based on the triple bottom line approach, to define the businesses' purpose and measure performance, include a wider range of stakeholders, and consider the environment and society as stakeholder. The main objective of SBMs is to go beyond creating merely economic value but to achieve a harmony of all stakeholders' interest to create positive sustainable value creation by considering the environment and society as key stakeholders (Bocken et al., 2013).

Lüdeke-Freund (2010) defines SBMs as "…a business model that creates competitive advantage through superior customer value and contribute to a sustainable development of the company and society" (p21). This study further advances towards conceptual models for SBMs underlining that sustainability practices arise through the connection of ecological development and business development (e.g. efficiency and consistency). Recently, Schaltegger et al. (2016) provided a more accurate definition in combining the findings from different scholars, stating that a SBM "…helps describing, analysing, managing, and communicating (i) a company's sustainable value proposition to its customers, and all other stakeholders, (ii) how it creates and delivers this value, (iii) and how it captures economic value while maintaining or regenerating natural, social, and economic capital beyond its organizational boundaries" (p3).

Therefore, the concept of SBMs are defined by integrating the cornerstones of sustainable development into the core of the conventional business model and modifying it by creating economic, social and environmental value through more pro-active collaboration with all stakeholders (Geissdoerfer et al. 2017; Geissdoerfer et al. 2016). To successfully include sustainability into business models, companies must not only consider economic value, which is usually comprehended in monetary measures, but also the benefits of society and the environment, commonly referred to as sustainable value (Evans et al. 2017). Further, according to Geissdoerfer et al. (2018a), sustainable value along pro-active multi-stakeholder engagement and long-term perspective are the three key parameters that will …"utilise the sustainable business model's analytical, strategic and communicational potential to integrate sustainability considerations on the organisational level" (p713). Additionally, there are some practical tools for sustainable value creation available among the literature. Despite the complexity around SBMs, practical tool development efforts amongst researchers are increasingly in demand but still very rare (Geissdoerfer et al., 2016; Evans et al., 2014). First developments in the SBM tools area have been made by some authors such as the introduction of the value mapping tool (Bocken et al., 2013), sustainable value analysis tool (Miying Yang et al., 2017; Yang et al., 2014; Yang et al., 2013), the flourishing canvas (Upward and Jones, 2016) and the triple layered business model canvas (Joyce and Paquin, 2016). Even though these tools and approaches are rare among current literature, they have a tendency to focus only on distinct phases of the innovation process (Geissdoerfer et al., 2016). This is further supported by Lüdeke-Freund & Dembek (2017) who found that tools and other forms of practical guidance are in demand to convert SBM concepts into business model designs that as a consequence will lead to organisational development and operational activities in practice.

Moreover, the literature discusses a variety of generic strategies, subcategories and archetypes for SBMs such as circular business models, product-service systems, social enterprises and base of the pyramid (Tukker, 2015; Bocken et al., 2014;). For instance, according to Geissdoerfer et al. (2018b) circular business models do not only create sustainable value, support pro-active multi-stakeholder management and long-term perspective but also close, slow and narrow resource loops (Bocken, de

Pauw, et al., 2016). But as a result of the different features as well as previously discussed characteristics that classify a SBM, there may be cases where merely a sub-category is fulfilled without meeting the characteristics of a ‘true’ SBM (Figure 5) (Geissdoerfer, Vladimirova, et al., 2018). These sub-categories and strategies were reviewed by Bocken et al. (2014) and synthesised as generic SBM strategies, the so-called SBM archetypes, which aim to accelerate the development of SBMs in theory and practice and advance towards a unifying research agenda. The archetypes provide major orientations of diffusion of new and clean technologies, social innovations and organisational solutions that could contribute to building up the business model for sustainability (Bocken et al., 2014).

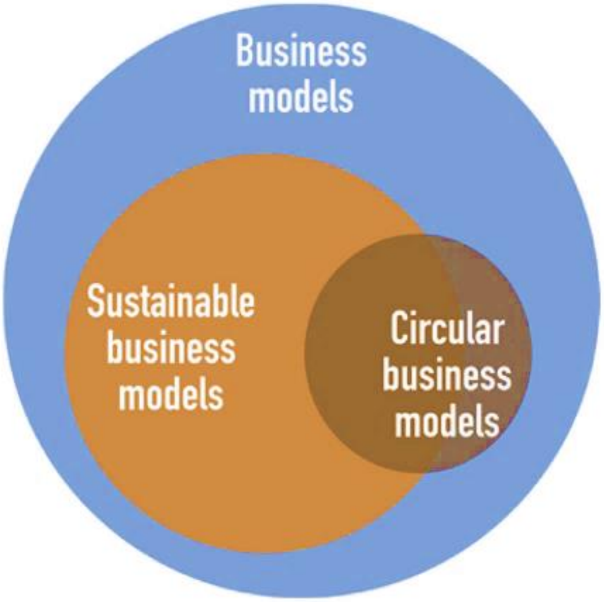

Figure 5 Overlap of the sustainable business model concept and its subcategories (Geissdoerfer et al., 2018)

Recently, the archetypes have been further developed by Bocken et al. (2016b) and Lüdeke-Freund et al. (2016) to include nine archetypes distributed to environmental, social and economic categories as the major innovation types derived from the concepts of sustainable development and the TBL approach (Figure 6) (Ritala et al., 2018; Elkington, 1997). These archetypes are considered as extremely important amongst fellow researchers since they represent typical examples of solutions that contribute to establish SBMs in theory and practice. However, despite their momentous potential with emerging innovative solutions as it might be the case with EV B2U, and a noticeable call for action to tackle pressing issues such as pollution and resource scarcity, the generic SBM strategies have not been accepted by industry yet (Despeisse et al., 2017).

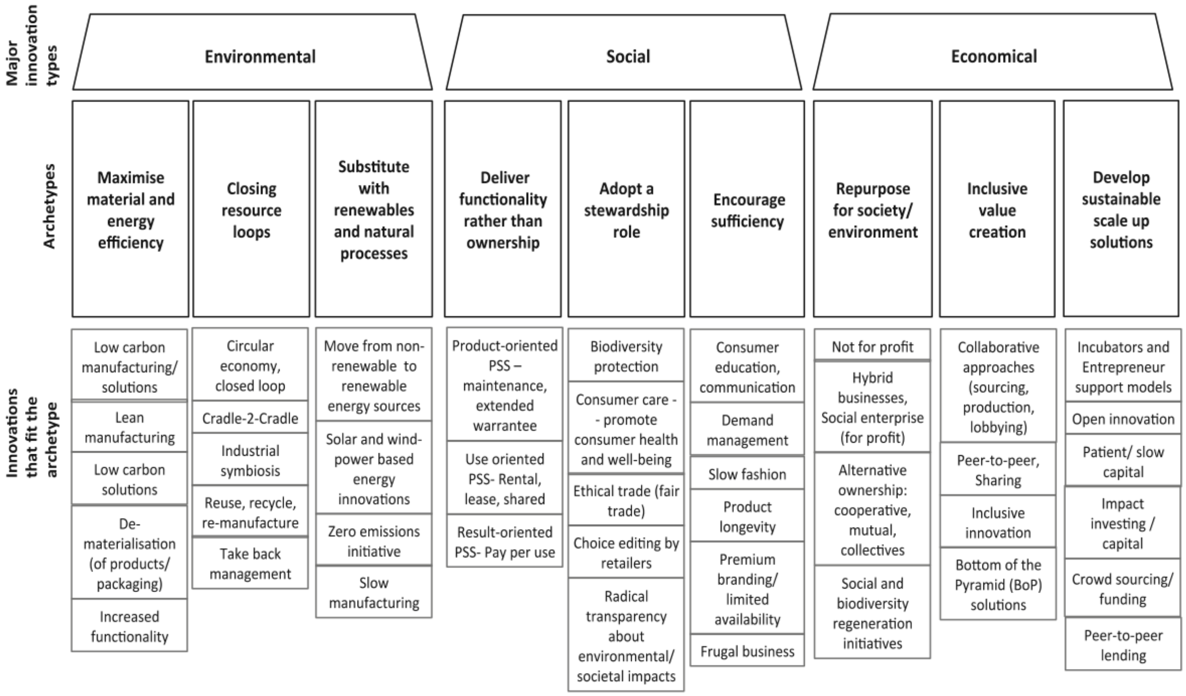

Figure 6 Sustainable business model archetypes (Ritala et al., 2018; Bocken et al., 2016b, 2014; Lüdeke-Freund et al., 2016)

2.5 Methodology

An important first realisation stands out for theorists through a preliminary theoretical investigation. It seems that an investigation of the interdisciplinary relationship between the two emerging research topics of B2U and SBM perspectives has not been previously attempted in such a broad context and overarching content. Given the exploratory research context where little or no information is available along the identified research questions, this review follows an analytical inductive reasoning (Goddard and Melville, 2004). Therefore, a structured review or meta-analysis on the topic was not possible because of non-comparable research results across the literature. Rather, the authors decided to apply a review process in the form of qualitative content analysis through an extensive annual search across the literature, interpretation of the content of text data through systematic classification processes of cording and identifying themes and summarizing relevant findings. Therefore, the primary research focus is on the previously discussed research questions, the identification and analysis of sustainable business model (SBM) perspectives for the emerging concept of electric vehicle (EV) battery second use (B2U).

Data were collected from reputable sources, mainly peer reviewed literature, but also to some extent from grey literature (e.g. company releases) and news and press releases due to the nascent stages of both evolving major research streams. Further, a variety of inclusion and exclusion criteria for the literature and document search was identified and applied (Table 3).

Table 3 Inclusion and exclusion criteria for literature search

Included	**Excluded**
Qualitative studies with an emphasis on: - innovative sustainable business model theory, tools, frameworks and case studies - electric vehicle battery second use innovative business model perspectives	Quantitative studies with an emphasis on: - electric vehicle battery second use environmental and techno-economic assessments with no implications for (sustainable) business model evolution in the electric vehicle sector and underlying B2U market Research studies on sustainable business model sub-categories and themes (e.g. circular economy, closed loop system, remanufacturing)
Type of study: peer reviewed journal articles, conference papers and book chapters Non-peer reviewed: grey literature coupled with news/press releases on recent innovative B2U industry activities	Type of study: non-peer reviewed journal articles, theses/dissertations

Therefore, it was crucial to conduct an interdisciplinary review of both business and science databases to meet the review scope. We searched academic databases (e.g. Science Direct, Scopus, JSTOR, ProQuest, Web of Science, Social Science Citation Index, SpringerLink), Web search engines (e.g. Google and Google Scholar), and available catalogues on grey literature (e.g. British Library Catalogue) and to some extent news/press releases. The inserted keyword search included a combination of “electric vehicle battery second use”, “electric vehicle battery reuse”, “business model innovation electric vehicles”, “sustainable business models”, “business models for sustainability”, and “sustainable business model innovation”. These terms were reassessed through an ongoing iterative process until data saturation was reached as well as the application of the snowball sampling method in order to recognise relevant literature from the reviewed research. The coding, synthesis and analysis of data was undertaken manually and in accordance with the identified research questions along the applied inclusion and exclusion criteria. Results are not intended to provide concrete answers to the new research field but rather identify first patterns and lessons in both emerging research fields.

This screening process confirmed the necessity of this interdisciplinary review article as through evaluating existing research on the topic it became evident that most research in the context of B2U has been delivered mainly in the form of quantitative studies on the techno-economic (Table 4)and environmental feasibilities (Table 5).

Table 4 Battery second use techno-economic studies and findings

Findings	Reference
Increase of EV LIB lifetime and subsidy to the business case as high initial cost of batteries is decreased	(Narula et al. 2011; Neubauer and Pesaran, 2011; Neubauer et al. 2012)
B2U in stationary ESS (e.g. intermittent renewable storage) offers revenue at low cost for the energy markets and enhances utility operation (e.g. relieve the public grid)	(Beer et al. 2012; Lih et al. 2012; Neubauer et al. 2012; Gaines and Sullivan, 2010; Williams and Lipman, 2010; Cready et al. 2003)
Enormous economic potential as B2U in stationary ESS is price competitive to current costs for ESS with 'newly' fabricated batteries	(Rohr et al. 2017; Gaines and Cuenca, 2000)
Highlight the significance of a favourable regulatory framework	(Heymans et al. 2014; Wolfs, 2010)

Table 5 Battery second use environmental studies and findings

Findings	Reference
EV in-use phase represents most critical phase with regards to emitted GHG (unsustainable charging sources 'green washing') Studies are limited to the EV battery production and use phase	(Ellingsen et al. 2014; Hawkins et al. 2013; Notter et al. 2010; Majeau-Bettez et al. 2011)
EV battery production represents 30% - 50% of EV total lifetime GHG emissions B2U decreases demand for material production, which causes the environmental pollution	(Dunn et al. 2012; Gaines et al. 2011; Gaines and Sullivan, 2010; Zackrisson et al. 2010)
B2U can achieve substantial net reductions in CO_2 emissions because of the potential to be applied in stationary ESS	(Ahmadi et al. 2014b; Cicconi et al. 2012; Genikomsakis et al. 2013)
B2U in stationary ESS connected with renewable energy sources present most environmental benefits (specific benefits depending on specific use case, respective electricity mix and presence of competing technologies	(Casals et al. 2016, 2015; Faria et al. 2014; Sathre et al. 2015)

Further, these studies concluded that no major technical barriers were identified but increased research efforts on the feasibility of effective (sustainable) business models should be further studied in practice (Elkind, 2014; Foster et al. 2014; Heymans et al. 2014b; Beer et al. 2012; Neubauer et al. 2012; Lih et al. 2012; Narula et al. 2011; Wolfs, 2010; Williams and Lipman, 2010; Gaines and Sullivan, 2010; Cready et al. 2003; Gaines and Cuenca, 2000). Moreover, a comprehensive study by Jiao & Evans (2017) found that these studies are quantitative, require detailed breakdowns of the technical, economic or environmental parameters and are limited in their boundary conditions due to the uncertainties of the parameters (no or limited data available) in the emerging stage of the B2U industry and therefore call for a substantial increase on B2U research efforts from a (sustainable) business model perspective. Bocken et al. (2015) supports this view, concluding that tools such as LCA have the tendency "…to be narrowly used on a limited range of parameters such as energy and carbon, rather than offering a holistic perspective for analysis embracing all stakeholder considerations, and particularly social dimensions" (p69). This is further underlined by Patala et al. (2016), relating to previous research efforts excessively concentrating on environmental impacts, stating that this may delay "…a promotion of ecologically beneficial offerings, and emphasizing the economic benefits of the offering might facilitate their more widespread business acceptance" (p147).

Therefore, this study extends this understanding and underline the interconnectivity of business models to the managerial fields of social, environmental, and economic relevance through an empirical investigation of B2U and the interaction with SBM perspectives and emerged concepts. Another major contribution to professionals and practitioners will be the identification of the process of how prospective SBM perspectives in the context of B2U can ease or even solve current unsustainable practices in the overarching EV industry. A recent study by Lüdeke-Freund and Dembek (2017) emphasizes that inter- and transdisciplinary research efforts are required to better comprehend changes of businesses towards sustainability as part of SBM approaches and the authors conclude that as a result "…a series of critical reviews could be a starting point for such an endeavour" (p1168). This is in conjunction with recent research efforts in the global business research community, which underline that the identity and legitimacy of international business (IB) as a field is at stake due to the increasing interconnectedness of the world along ongoing evolution of industries and technologies (e.g. industrial revolution 4.0). A recent study by Poulis and Poulis (2017) deliver an ontological perspective on the disciplinary tautology of IB and the authors demonstrate that a lack of ontological clarity undermines IB's sustainability. The authors argue that to redraw legitimate knowledge boundaries for IB an ontological shift is required, which may be achieved through turning to other fields for illumination by skilfully applying interdisciplinary research efforts that in turn can lead to a standing element of IB scholars' analytical skills (Poulis and Poulis, 2017). Therefore, given the nature of this interdisciplinary review, it also contributes to opening a major discussion on the identification of the boundary identification in the field of IB.

2.6 Results

2.6.1 The rise of electric vehicles: a pressing need for innovative business models

The global automotive industry is on the tip of an automotive revolution towards electric mobility, with recent studies predicting that 54% of new car sales and 33% of the global car fleet will be electric by 2040 (BNEF, 2017). It is estimated that by 2020 the total ownership costs for most EVs will be lower than that of ICEVs, resulting in consumer savings as the lifetime price of purchasing an EV including costs for fuel and maintenance will be lower than that of ICEVs (Renewable Energy Association, 2017). Due to finite available resources, the inevitable shift from ICEVs towards EVs requires new forms of business as the value propositions of e-mobility are more complex (Laurischkat & Viertelhausen, 2017). Furthermore, recent trends such as the sharing economy, moving from owning cars (products) towards using cars (services), will call for increased holistic mobility solutions alongside the inclusion of new stakeholders and their complex interactions that will disrupt current value structures and underline that the whole ecosystem must be re-considered (Kley et al., 2011)**.**

The rise of the sustainable technology of EVs as a potential viable alternative to ICEVs has been accompanied by an expectation that it will bring drastic changes in auto mobility and in new business models, which EV manufacturers and others would need to adapt to enter this market (Wells & Nieuwenhuis, 2015). Researchers argue that a radical shift towards sustainable technologies requires changes to exiting business models, products and social systems and that if companies fail to analyse the whole environment and system of sustainable technologies, it will result in the development of inadequate business models and the loss of competitive advantage (Budde Christensen et al., 2012; Kley et al., 2011).

Further, the sustainable technology of EVs challenges prevailing business models in the presently unsustainable automotive industry, which are heavily dependent on the use of fossil fuels (Bohnsack et al., 2014). This is further supported by Budde Christensen et al. (2012) stating, "…it might be that innovative technologies that have the potential to meet key sustainability targets are not easily introduced by existing business models within a sector, and that only by changes to the business model would such technologies become commercially viable" (p499). Therefore, this would include a reconsideration of the traditional business model concept (value proposition, value creation & delivery and value capture).

A suitable business model can grow the market appeal of a technology such as EVs, improve the value capture of this innovation and finally lead to increased competitive advantage (Chesbrough, 2010). However, in the context of emerging industries and sustainable technologies such as EVs, the right business model is not yet apparent. Bohnsack et al. (2014) emphasizes this stating, "…the emergence of EVs … is a useful context to analyse business model evolution, because this industry is still in the process of discovering a business model that attracts large numbers of customers" (p287). The concept of BMI that puts sustainability at its core is critical for a market uptake of EVs as well as for sources of value creation towards customers that compensates for the higher initial investment cost compared to ICEVs. The mobility concept of B2U could lead to such value creation mechanism through BMI by addressing current unsustainable issues in the EV sector, ultimately making the technology affordable and competitive to ICEVs.

2.6.2 Unsustainable practices in the electric vehicle industry

Critical issues for a prospective market uptake of EV have emerged. It seems that as a result of highly priced EVs (i.e. high costs of installed LIB packs), there is a heavy burden on the market potential (Bonges and Lusk, 2016). A study by Jiao and Evans (2016a) identified current EV practices and market uptake barriers as unsustainable from the economic, social and environmental perspective (Figure 7).

Economy High Price	Society Inconvenient	Environment Pollution
• High vehicle (battery) cost • High battery replacement cost	• Limited driving range ('range anxiety') • Long charging times • Limited charging infrastructure	• Unsustainable charging source "green washing" • Unsustainable EOL disposal mechanisms

Figure 7 Unsustainable issues in the EV industry (adapted from Jiao & Evans 2016a)

From the economic perspective, the high price of EVs because of expensive LIB packs is the key barrier for a faster global market adoption. Today, LIB packs in EVs can make up to 30%-50% of total vehicle cost. EVs as a disruptive technology has already been developed but it is insufficient to enter the mass market, which demands low cost vehicles i.e. low cost batteries (Lorentz et al., 2015). According to a systematic review study that analysed over 80 different EV LIB pack estimates reported between 2007-2014, EV LIB technology has improved significantly in the last decade with battery costs dropping by approximately 14% annually from above $1000/kWh to around $410/kWh (Nykvist and Nilsson, 2015a). A study by the U.S. Department of Energy (2017) estimates LIB pack cost between \$250/kWh - \$300/kWh in 2016. Findings by Bloomberg New Energy Finance (BNEF) found the price of LIB packs at \$273/kWh in 2016 and in the case study of a battery production plant in Korea, a price drop to \$162/kWh in 2017 and \$74/kWh in 2030 is forecasted (Curry, 2017).

Consequently it must be underlined that the EV industry is still in its infancy stage and to accelerate mass market adoption, the EV market desires an augmentation of capacity and power, increase in the battery's lifetime and most importantly, dramatically reduced battery pack costs to make EVs competitive to ICEVs. Besides available research on present LIB pack costs, there are also a number of recent cost forecasts available for EV batteries in 2020 (Berckmans et al., 2017; P3 Consulting Group, 2016; Pillot, 2015), whereby estimates vary between 250 \$/kWh – 131 \$/kWh. These are crucial to understand EV LIB market price developments as battery costs need to reach 150 \$/kWh, which has been generally comprehended to be the tipping point whereby EV (i.e. battery) technology has become mature and will reach global market penetration (Nykvist and Nilsson, 2015a).

EV manufacturers are currently facing trade-offs between final vehicle selling price (price impact of selected battery materials) and desired driving ranges (overall performance of selected battery materials) (Reinhardt et al., 2019). Once the battery is no longer useful for traction purposes and needs to be replaced, customers currently pay high battery replacements cost that represents another economic barrier (Bohnsack, 2013). To tackle these issues, EV companies such as Nissan for its Leaf model and Renault for its Zoe model have started to offer their customers financing options such as to lease only the battery (including warranty and replacement costs) while purchasing the rest of the vehicle (Renault, 2017a; Nissan, 2017a). This can be identified as first indicators of BMI within the EV industry as companies are moving towards product-service systems.

In terms of societal perspective, EVs are still seen as inconvenient and have caused so-called 'range anxieties' (limited driving ranges and charging infrastructures) mainly due to current energy density limits of LIB pack technologies. It is commonly agreed that a driving range of around 320 km (200 miles) is sufficient to overcome the fears amongst society and meet average daily driving needs (Nava, 2017). But today, customers must still pay high vehicle prices if they desire a longer driving range (and vice versa).

A further barrier is the EV limited charging infrastructure coupled with long charging times. The frequency, on which EVs need to be charged today, makes the reliability and accessibility of a charging infrastructure critical for wider EV market uptake. Currently, the number of EVs on the road outnumber public available charging points by a six to one ratio, indicating that most EV drivers must currently rely on private charging points (International Energy Agency, 2016). It is therefore important to place public charging points where there is a high concentration of parked vehicles for longer periods of time such as in the workplace, city parking area, shopping malls, airports, and hotels. Although this is not a new finding, the impact of its implementation will be of catalytic influence to develop the market exponentially.

Coupled with the charging infrastructure is the charging time for EVs, which is typically done through alternating current to the EV battery from an external charger ('slow charging') and can take from 4 to 12 hours for a full charge (International Renewable Energy Agency, 2017). On the contrary there are fast charging stations ('DC quick charging') that provide a direct current of electricity to the EV battery from an external charger with charging times between 30 minutes to 2 hours for a full charge (Trigg et al., 2013). Fast charging stations are desirable, but they increase battery stress and degradation as well as that for most people, which have charged their vehicles overnight on a slow charger, a fully charged vehicle might be sufficient for their daily average trip needs as mentioned before. To tackle the above mentioned issues, novel business strategies have emerged such as the appearance of the start-up company Better Place that introduced the concept of battery swapping stations, which replaced degraded EV batteries with a fully charged battery of the same type in less than 5 minutes (Zheng et al., 2014). But the company had to file for bankruptcy in 2012, losing $812 million, mainly caused by the high initial investments needed to set up their business infrastructures coupled with mismanagement issues such as the overestimated market penetration in their pilot study countries. However, the case of Better Place demonstrates again that current prevailing business models and strategies in the EV industry might be considered under new approaches from product-based towards fully service driven (Budde Christensen et al., 2012).

From an environmental perspective, there exists criticism that EVs are seen as 'green washing' as most vehicles are charged with non-renewable unsustainable electricity such as from coal (Van den Hoed, 2005; Mariasiu, 2012). Further, there remains a lack of proper EOL EV battery management mechanisms, underlining that sustainable and circular economy approaches such as battery reuse followed by material recycling efforts will become increasingly important (International Energy Agency, 2017). Moreover, a growing EV market will stimulate demand for commodities required for EV battery manufacturing such as lithium or scare and value raw materials such as cobalt. Shankleman (2017) emphasizes on the importance of minimising the environmental impact of such material extraction and monitoring price and availability stating that demand for the EV LIB materials such as nickel and aluminium will both rise to about 327,000 tons a year compared to only

5,000 tons in 2015 and production of lithium, cobalt and manganese will each grow by more than a hundred times.

At this point it can be concluded that secondly using EV batteries in less demanding stationary storage applications may therefore solve current unsustainable issues in the industry, which in turn results in diffusion and competitiveness of EVs on a global scale. However, as discussed in Chapter 2, there are also major potential barriers that could impact the success or failure of a prospective B2U market. In synthesizing these findings, the following key potential batteries for B2U have been identified. These are unclear regulatory status, lithium-ion battery price reductions (competition of new and cheap batteries specifically design for energy storage purposes), insufficient availability of second life batteries (as a result of slow market growth), absence of standardised battery testing procedure ('design for B2U'), uncertain battery condition after 1st life in the electric vehicle, high repurposing costs of degraded EV batteries and fire hazards during battery transportation and storage. Nevertheless, an in-depth of potential barriers but also opportunities for a prospective B2U market and considering SBM perspectives is not in the scope of the review and shall be further explored in future research.

2.7 Discussion

2.7.1 Battery second use market potential

The emerging concept of B2U is a timing topic with substantial market potential (Reinhardt et al., 2017; Fischhaber et al., 2016). A study by Jaffe & Adamson (2014) predict that the global B2U business will accelerate, from $16 million in 2014 to $3 billion in 2035. However, it is difficult to estimate the exact B2U market size as it is strongly dependent on two factors. Firstly on the volumes and type of EV waste batteries to become available for B2U, which is directly linked to the market uptake rate of EVs, and secondly on the future need for storage solutions that is influenced by costs and usability of other storage technologies (Rehme et al., 2016). With regards to the volumes of EOL waste batteries to become available for B2U purposes, it must be underlined that there are no reliable findings on the exact volumes that will be returned. Most EV models have entered the market within the last years and therefore it won't be until 2020-2025 when large volumes of batteries will start to retire.

Available previous studies found that the global annual quantity and weight of EOL LIBs would surpass 25 billion units and 500,000 tons, respectively, in 2020 (Zeng et al., 2012). Standridge & Corneal (2014) estimate in various scenarios that the number of post-vehicle application battery packs eligible for B2U would rise from 1.4 million to 6.8 million by 2035. Regarding the future global battery storage market, a recent study by BNEF (2017) predicts the market to ‘double six times’ from less than 5 gigawatt-hours (GWh) in 2016 to more than 300 GWh (125 GW capacity) by 2030 while estimating investments in battery storage sectors of $103 billion. A recent study by Reid & Julve (2016) attempted to predict future B2U market size using EV sales forecasts as set out by Bloomberg (2016) and considering average battery sizes between 24 kWh – 64 kWh and secondary life rate of 80% after a 7 year EV in-use phase, forecasts that global EV cumulative sales will reach 6.7 million by 2020 and 88 million by 2030; at the same time cumulative worldwide installed capacity of secondary batteries are predicted to reach 230 GWh in 2025 and an increase by four times to 1000 GWh in 2030 (Reid and Julve, 2016).

2.7.2 Battery second use: a sustainable business model catalyst?

B2U holds the potential of being incorporated in prospective innovative (sustainable) business models that put sustainable development at its core. But until today, only very few authors have evaluated B2U from a pure market and business model perspective. A study by Klör et al. (2015) evaluated essential economic properties for a potential market for trading second life batteries by distinguishing between basic market designs of an open, closed or intermediary market and concluding that most likely an intermediary-based B2U market will occur whereby an ‘intermediary’ on behalf of an EV manufacturer will be responsible for battery collection, repurposing and finally selling second life batteries to final customers. A study by Rehme & Richter (2016) builds upon the open and closed market design as established by Klör et al. (2015) and proposes two concepts: the integrated business model in a closed battery market whereby the OEM implements the B2U process into existing organisational structures through diversification and vertical integration of activities (e.g. remaining ownership of batteries), and the multi-agent business model in an open market that allows trading and resale of second life batteries and therefore opens competition among several agents. Similarly, Jiao & Evans (2017) propose a typology of B2U business models that are categorised as standard, collaborative and integrative. Given the B2U project landscape presented in chapter 1 and previously discussed results, this study observed that innovative cross-sector multi-stakeholder relationships are forming to evaluate the full potential of second life batteries in a prospective B2U market. Based on these studies and extending their findings, this study presents a conceptual B2U innovative business model framework (Figure 8).

However, there exists no universal agreement on how LIBs should be regulated as waste. In the case of the United States (US), even though LIB wastes are part of the Environmental Protection

Agency (EPA) Universal Waste Rule, they are classified as non-hazardous to the environment due to the absence of toxic elements, such as lead, mercury, or cadmium (EPA, 2019).

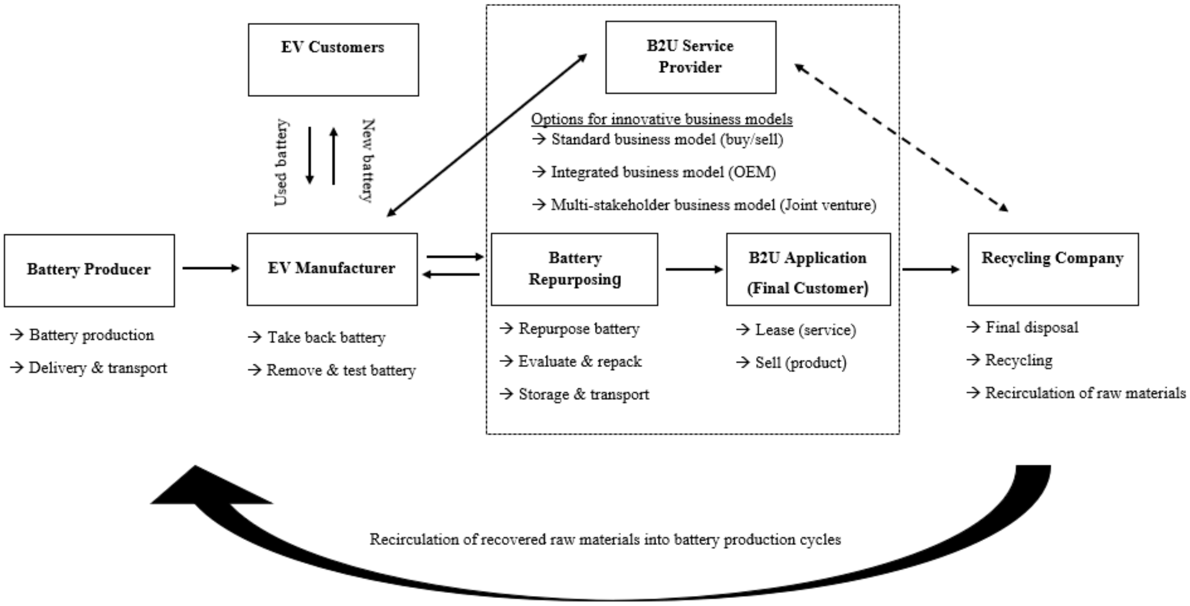

Figure 8 Conceptual battery second use innovative business model framework

In the EU on the other hand, EV producers are legally required to take back degraded batteries from their customers, which will be increasing in volumes as EV market share rises (EU directive 66/2006/EC; Winslow et al. 2018). This can be underlined as a driving force that will increasingly bring together cross-sector stakeholders that are interested in the full potential of second life batteries and hence new business opportunities. Such stakeholders are experts on ESS solutions in the energy markets and recycling companies that are interested in closed-loop business model designs that generate new value. This is reflected in the current B2U pilot project landscape as OEMs have entered collaborative joint venture agreements with primarily experts on the energy storage markets (B2U service providers) and the battery recycling industries. But what remains further clarification by existing legislations is the issue of the re-introduction of used EV batteries (as a new product) in the energy storage markets. This raises a major concern on whether there is a previous transfer of battery ownership and how legislation regulates who is responsible for the battery. This is a critical as there are major technical and safety concerns (e.g. fires during battery transportation to repurpose facility/storage) and legislation must be proactive in clarifying producer responsibilities along the entire battery life cycle.

B2U contributes to slowing and closing resource loops as the battery's value is enhanced through increased material and resource efficiency, total service lifetime is extended while distributing the high initial cost among a variety of stakeholders. Thus, the previously considered waste of spent EV batteries is re-used to create new value e.g. in the stationary storage markets and the recycling phase is significantly delayed, which has been shown to indicate additional costs and environmental pollution for OEMs. Ultimately, once not useful in specific B2U applications, environmentally sound recycling mechanisms will eventually recirculate recovered materials back into the battery production processes.

This is in conjunction with a study from Bocken et al. (2016a) on product and business model strategies for the circular economy; as B2U slows and closes resource loops it fits within the business model of 'extending product value' (i.e. exploiting residual value of products) as "…in this type of business model, remanufacturing typically becomes the activity of the original manufacturer" (p313). But it remains unclear how participating stakeholders in the emerging B2U industry can innovate such strategies into innovative business models. Scholars have recently argued that even though the concept of the circular economy prioritises environmental sustainability and the economic systems (circular models), the social dimensions and objectives are only implicitly addressed and usually absent, which have been previously identified to be a key characteristic of SBMs (key stakeholder to the firm) (Geissdoerfer et al., 2017a; Murray et al., 2017; Sauvé et al., 2016). This is supported by Antikainen et al. (2016) emphasizing that there is a lack of frameworks for business model innovation in the context of the circular economy as well as that business models should be comprehended through sustainable value creation for all stakeholders, including the environment and society (i.e. sustainable business models).

Therefore, the concept of business model innovation for sustainability can drive innovation across the entire B2U supply chain whereby value is no longer created by single firms but through collaborative arrangements as indicated by the previously mentioned B2U joint venture agreements. According to Porter and Kramer (2011) such efforts will results in shared value creation that aims to identify and expand the relationships between economic and societal progress through not only innovating products but also markets and activities within the value chain. Building on this and the aforementioned traditional business model concept (chapter 3.2), Bocken et al. (2015) introduce a conceptual framework for a sustainable business model that captures such value (Figure 9).

In applying this framework to the concept of B2U, the **value proposition** is focused around exploiting residual value of EV batteries through remanufacturing and reuse and offering customers affordable B2U ESS (through remanufacturing or repurposing). There is further value for customers that use products longer and employees as new jobs are created as part of reuse and recycling activities (i.e. the engagement in an environmentally sound business). The **value creation and delivery** are primarily centred on collaborations (sharing resources, knowledge and expertise) and take-back systems for degraded EV batteries in order to ensure consistent flow of product returns. Lastly, **value is captured** by reducing materials costs (environmental value) while generating new revenue as the economic battery value is increased through B2U in the stationary storage market.

Value Proposition	Value Creation & Delivery	Value Capture
• Product/Service offering • Target customer differentiation • Value for customer, society and environment	• Key activities • Key resources & capabilities • Partners and suppliers • Technology and product features	• Cost structure • Revenue model/streams • Value capture for key actors including environment & society • Growth strategy/ethos

Figure 9 Conceptual sustainable business model framework (adapted from Bocken et al., 2015)

It was further revealed that in considering the previously mentioned SBM archetypes (i.e. generic SBM strategies) the concept of B2U may fit within the environmental innovation type of ‘closing resource loops’ (remanufacture, reuse, recycle) or ‘deliver functionality rather than ownership’ (product/service/use oriented product-service systems). In fact, the different archetypical strategies can be combined to form a sustainable business model. However, despite their widely known benefits for the economy, society and environment, successful adaption by industries has not been achieved. This highlights the need for further discussions that address and conceptualise methods and tools that facilitate firms in integrating all aspects of sustainability into the business model innovation process (Despeisse et al., 2017). Thus, this review aims to open up a further dialogue between researchers and practitioners on the topic. It must therefore be underlined that to better comprehend the feasibility of the interconnectivity between B2U and SBMs in theory and practice, follow-up studies are in demand as an incremental shift is needed, triggered by the help of researchers in the field to identify areas for improvement, ultimately making B2U a business case for sustainability.

A further interesting point to raise is whether the presented conceptual SBM B2U system is fundamentally different from other cases where SBM research and concepts have been or might be applied in the future. This is from major importance considering that there is paucity in empirical SBM research that is emphasised by the limited number of case studies and empirical analyses in the field (Evans et al. 2017b). Therefore, one illustrative example is the global sustainability management problem of electronic waste (e-waste) that has arisen as a new sustainability challenge of the 21st century. Ongoing changes in technology and demand have made the global electronic industry the fastest economic growing sector (Puckett et al. 2002). As these products contain large volumes of critical metals, including rare earth elements, couple with the persistent supply risk as a result of limited sourcing in countries, the importance of sustainable material recovery is underlined (Marra et al. 2018). Relatedly, Peñaherrera et al. (2018) propose a conceptual design for a database management system for e-waste within the EU (that tracks e-waste flows and critical metal content) but concluded that participation from producers is unlikely without sufficient economic incentives in place as otherwise such systems are merely seen by producers as an extra administrative burden. Therefore, as major beliefs and concepts of SBMs go beyond sub-categories (e.g. circular economy) the SBM system presented in this study could facilitate participating stakeholders in establishing innovative multi-stakeholder relationships to evaluate possible reuse/second use strategies before undergoing current unsustainable disposal mechanisms, ultimately establishing the business case for sustainability within the global electronics industry.

2.8 Final remarks

This review argued that the concept of B2U holds the potential to increase the residual value of EV batteries leading towards a faster EV market uptake and improvements of overall sustainability performance through SBM perspectives. However, the available literature remains ambiguous on what SBMs entail as there is a dearth of empirical research and hence more holistic views on the topic are needed. At the same time, the rise of the sustainable technology of EVs with its underlying potential disruptive technology of B2U will challenge prevailing business models in the automotive industry, which has historically been heavily dependent on the use of fossil fuels. This review aimed to address this paucity by offering a new interdisciplinary perspective through an investigation of SBM perspectives for the emerging sustainable technology of EVs with a focus on the concept of B2U

B2U was identified to be a major value creation mechanism for the EV industry. Results indicated that current practices in the EV industry are unsustainable with regards to the presently high EV

LIB costs, ‘customer anxieties’ because of limited driving ranges and charging infrastructures and environmental pollution due to unsustainable charging sources and EOL disposal. It was found that B2U holds the potential to facilitate or even solve these current unsustainable practices in the EV industry. However, the evaluation of the B2U lifecycle stages underlined that key opportunities and challenges remain.

The discussion further revealed that the B2U market potential is strongly dependent on the market uptake of EVs and on the future need for storage solutions. Therefore, there is the potential of an evolving B2U market as increasing volumes of cheap batteries will be taken back to the OEMs in upcoming years that could provide valuable services in ESS. The discussion further found that because of this market potential, OEMs have started pilot projects to comprehend the feasibility and capabilities of B2U. But market developments were found to be still speculative as companies entering this new industry are still evaluating if B2U is a profitable business or not.

Therefore, although B2U business models seem to emerge as a major new way forward for the industry of EVs, the market landscape remains mysterious. It will be several years before first-mass market generation of EV batteries will start to retire, which is directly dependent on the EV market uptake and can be identified as one of the key limitations of this review. However, ongoing B2U projects informed that innovative multi-stakeholder cross-sector relationships between the previously isolated automotive and energy markets are forming that aim to investigate the full potential of second life batteries and hence new business opportunities.

Therefore, a B2U business model framework was conceptualised that addresses these innovative forming stakeholder relationships as well as opens new roads for future discussion among researchers and practitioners. It appears that multi-stakeholder business models are preferred over integrated business models, but further practical rich case studies that take a multi-stakeholder perspective must be carried out to evaluate how OEMs are forming such collaborative agreements to capture to full value of second life batteries. Therefore, it was discovered that prospective B2U business models that take a multi-stakeholder network centric business model design rather than firm-centric one, may prove to be a viable business case for sustainability.

Interestingly, as a result of B2U industrial projects being mainly still in the piloting phases, there is the issue of a dearth of data on identifying all stakeholders that will participate in a prospective B2U market. We are convinced that this is both an important gap but also an exciting opportunity for the market and academia. Therefore, we invite and push for further research on the topic through comprehending attitudes and characteristics of multiple stakeholders that are interested in participating in the emerging B2U market. Moreover, future research should address the different business model relationships that will be established between stakeholders participating in this market, mainly OEMs and B2U service providers, whereby for instance the degree of battery ownership and exchange flow of expertise and knowledge between those stakeholders varies. As a first important step, this review demonstrated that the EV EOL strategy of B2U is a promising way to increase the residual value of the battery that in turn could reduce upfront costs of EVs and lead to a faster global EV market adoption while making the technology itself more sustainable.

Chapter 3

The Business Environment

3.1 Motivation

This chapter analyses the emerging B2U market from a macro environmental perspective to comprehend key opportunities and threats in the future as this emerging secondary market remains unclear from a business model perspective.

3.2 Introduction

EVs have recently attracted increased attention from the electricity markets as they can provide valuable services to the existing energy markets by offering grid services such as peak load shifting and integrating renewable energies (Peterson et al., 2010; Yong et al., 2015). But, a prospective market uptake of EVs also poses threats and challenges to the grid as there will be additional electricity sales for utilities and increased demands for charging infrastructures and related services. The appearance of energy storage technologies represents a viable solution to these problems by providing services such as load levelling and backup power. However, the integration and storage of intermittent renewables is still challenging due to the lack of cost-effective large-scale energy storage systems (Heymans et al., 2014; Elkind, 2014).

Apart from these technological challenges that must be overcome, there are issues around end-of-life (EOL) disposal mechanisms for automotive manufacturers. It will be several years before the first mass-market generation of degraded EV batteries will start to retire. However, current recycling frameworks for automotive lithium-ion batteries do not contribute to waste and resource exploitation issues and are motivated by economic revenues while disregarding that re-capturing value from these batteries in alternative secondary applications could potentially be an engine for the transition towards a more sustainable transport sector (Gaines et al., 2011; Ramoni and Zhang, 2013).

In this respect, re-purposing retired EV batteries for secondary applications may provide a cost-effective solution to address these challenges. EV batteries are considered not useful for traction purposes and have degraded after a service life of about 6-8 years (Ahmadi, Fowler, et al., 2014). However, as these batteries still have around 70%-80% capacity, one feasible solution to re-use these batteries more efficiently while decreasing overall battery lifecycle costs, is to repurpose them for less demanding battery second use (B2U) applications such as renewable energy storage, back-up and transmission support (Cready et al., 2003; Wolfs, 2010; Neubauer and Pesaran, 2011; Beverungen et al., 2016).

Many studies (Cready et al., 2003; Wolfs, 2010; Neubauer and Pesaran, 2011; Viswanathan and Kintner-Meyer, 2011; Ahmadi, Fowler, et al., 2014; Neubauer et al., 2012; Gaines and Cuenca, 2000; Williams and Lipman, 2010a; Beer et al., 2012; Lih et al., 2012) have evaluated the technical and economic feasibilities of B2U whereby no major technical barriers for wider adoption on larger scales were found. With regards to the economic features, it is suggested that using degraded EV batteries for stationary storage applications such as grid support or power backup, represents an economic feasible option as it extends total battery life time value and offers a cost effective solution to presently cost expensive storage systems (Gaines and Cuenca, 2000; Williams and Lipman, 2010a; Beer et al., 2012; Lih et al., 2012; Gaines et al., 2011). Secondary markets for discarded EV batteries are emerging whereby the current preferred method of recycling discarded batteries may be diminished and new innovative business models will arise that have yet to be quantified.

3.3 Research approach

This research aims to contribute to the scientific literature on business strategy in the case of EV B2U as very few authors (Rehme et al., 2016) to date have studied business model perspectives in the case of B2U and thus a research gap has been identified. Sustainable technologies such as B2U, which have the specific feature to decrease environmental degradation, challenge current dominant business practices that are heavily dependent on the use of fossil fuels such as the automotive industry (Kley et al., 2011). The emerging market for degraded EV batteries is therefore in need of business models that create economic value and address barriers for a further market penetration based on a process of learning, experimentation and adaption (Bohnsack et al., 2014). Finding the right business models at an early stage in emerging industries such as the B2U market is however still very rare (Teece, 2010).

Due to the complex nature of the research context, this study makes use of the qualitative methodological case study approach, which aims to study things in their natural settings by interpreting phenomena in terms of the meaning people bring to them mainly expressed through non-numerical beliefs, opinions, ideas and attitudes (Punch, 2014). The approach of the comparative case study approach is applied, where the focus is within and across cases and hence the evidence and overall study is therefore regarded as more robust (Yin, 1994). As the objective of this study is to evaluate similar or contrasting trends in the arising global B2U industry, the three representative case study regions of Europe, Asia, and United States of America (USA) have been chosen as this is where most progress has recently been made with regards to B2U pilot projects.

The data for the case studies were collected using secondary data sources including scientific and academic journals, governmental and non-governmental organizational publications, and press releases. To analyse gathered data from the selected case study regions, this study makes use of the macro environmental analysis technique of the Political, Economic, Social, Technological, Environmental, and Legal (PESTEL) framework as the selected cases contain some or all the framework's factors (Figure 10).

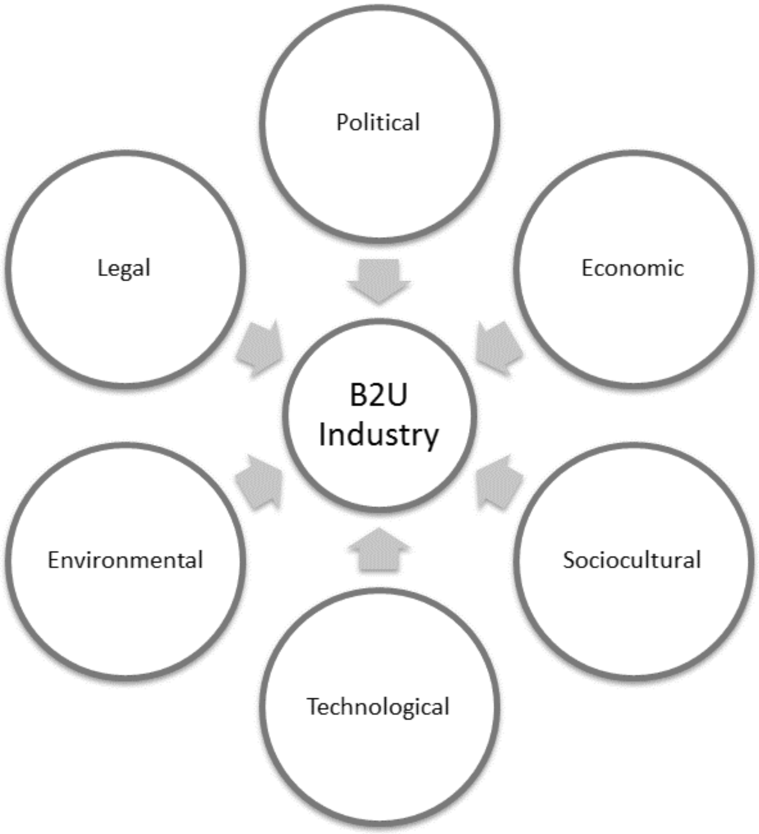

Figure 10 The PESTEL methodological framework

The application of this strategic management tool allows comprehending the 'big picture' trough an examination of a variety of external factors that may have an impact either now or in the future on the benefits, issues and problems around the global B2U market and it provides a comprehensive list of potential success or failure of particular strategies (Worthington and Britton, 2003). Due to the complexity of the research context and the possibility of being overwhelmed by a multitude of details, only those key drivers for change are identified that are most important with regards to the B2U market in the case study regions. These external drivers are continuously given the highest priority and their implications are classified into external opportunities and threats that affect the global B2U either now or in the future (Gerry Johnson et al., 2008). Lastly, commercial B2U projects are still very rare today, because of limited EV market share and economic uncertainties of B2U projects. Thus, there is the issue of limited data availability and generalization of proposed research findings. However, in comparing or replicating developments in the emerging B2U market with the help of the selected case study regions with each other in a systematic way, it can be explored and concluded which recommendations may or may not be feasible soon.

3.4 Results and discussion

With prospective increased global EV market share, a growing number of retired EV batteries will become available for the emerging B2U market. Therefore, the global automotive sector has attracted a growing interest from the energy markets in recent years and led to a variety of leading EV manufactures evaluating how much value their batteries have in a second life through the development of pilot projects Table 1. It is evident that there is a growing investment, experimentation, and interest in B2U, and indicating the creation of a secondary market for retired EV batteries and hence new market opportunities. Nevertheless, the economic value of degraded EV batteries in this second life has yet to be quantified and it can be concluded that most developments are speculative at this point.

3.5 The Macro environment

The findings of the PESTEL analysis in the global B2U market have been prioritized and classified into the external factors of opportunities and threats.

3.5.1 Opportunities

The appearance of B2U holds the potential to be a more viable EOL solution for degraded EV batteries than recycling. Thus, B2U can address key issues on side of EV manufacturers as the total lifetime value of a battery can be extended by increasing its economic revenue through second use alternative applications, the initial cost of the battery can be decreased as linked energy and material investments compensate initial battery cost and the recycling phase is postponed where by raw materials may be recirculated into new battery production cycles (Figure 11).

B2U has the potential to deliver the same purpose as newly fabricated batteries in energy storage applications but at substantially lower costs while at the same time accelerating the transition towards increased integration of intermittent renewable energy. Recent forecasts expect second life battery costs at $100/kilowatt hours (kWh) in 2016 with further price decrease estimations to $49/kWh in 2018; adding in the $400/kWh cost to convert these batteries for B2U purposes in stationary storage applications the true economic potential (B2U at <$500 kWh) is evident in comparison to purposely energy storage designed batteries that are currently estimated to cost around $1000/kWh (Liebreich and McCrone, 2016).

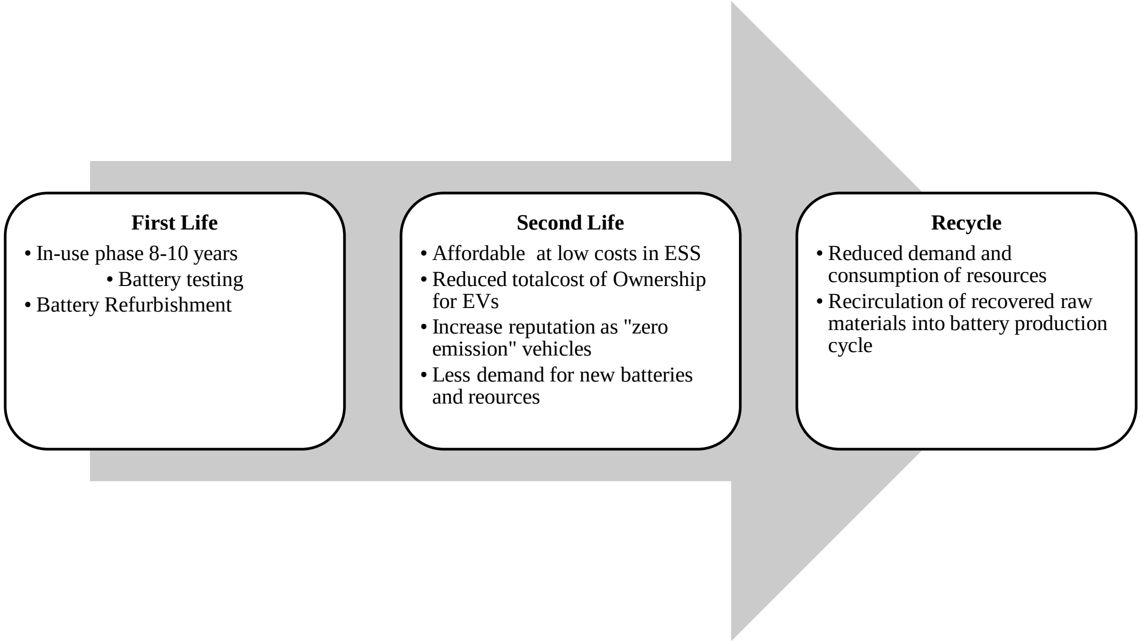

Figure 11 Battery second use conceptual process

This economic potential is reflected when looking at the B2U business landscape. Most recently, Japanese car manufacturer Nissan has started pre-orders in Germany, UK and Norway with its residential energy storage unit ‘Xstorage’, which is built of 12 retired EV batteries, and connected to the grid or renewable generators, offering its customers time-of-use pricing and back-up power (Nissan, 2017b). German automaker BMW also plans to enter the residential energy storage market soon, recently announcing to use retired i3 batteries as a plug-and-play storage application with capacity of 22 or 33 kWh (BMW, 2016).

3.5.2 Threats

In theory everyone can agree, that B2U in energy storage applications can increase total battery lifetime, address resource consumption and waste management issues and open up new market opportunities. However, the actual feasibility of this evolving market is purely profit driven and its success will depend on the following factors.

Primarily, there is a lack of global and fiscal legislations and government support. As the economics of the B2U market is directly linked to a prospective EV market uptake, increasing efforts of global policies and fiscal subsidies to stimulate the market penetration of EVs are urgently needed. Recently, Mock and Yang (2014) demonstrated that funded public policies in the EV key markets in USA, EU and Asia have led to faster adoption rates. However, with regards to B2U there exists no single targeted legislation. Both, automotive and energy binding legislations have to achieve a harmonized policy framework that allows for flexibility options such as storing energy from degraded EV batteries in B2U projects. Furthermore, policy makers shall clarify liability options for EOL batteries through the implementation of already established concepts such as extended producer responsibility. Financial incentives for B2U applications and additional incentives for pilot projects can further accelerate a transition towards a more sustainable transport system.

Besides this, there is the threat of price reductions of newly fabricated EV lithium-ion batteries. A study by (Nykvist and Nilsson, 2015b) analysed 80 different cost estimates between 2007-2014 in a systematic way and concluded that battery prices fell by 14% annually from more than $1000/kWh in 2007 to $410/kWh in 2014, while leading EV manufacturers battery packs are even predicted to be lower, at around $300/kWh. The authors suggest in a further study (Nilsson and Nykvist, 2016) that it is plausible that battery prices will continue to decline to around $200-250/kWh in 2020 and $150/kWh in 2025. Hence, there might be a threat of whether B2U can sustain itself as a profitable and competitive solution.

As EV batteries have their own individual state of health depending on their previous exposure and treatment in their first-life, costly manual disassembly processes are currently the norm as each battery must be cleaned, inspected and replaced to reach like new condition (Ramoni and Zhang, 2013). Therefore, a standard testing procedure is urgently needed so that degraded batteries can be safely used in B2U applications. Presently, the independent safety standard organization UL is developing a safety standard procedure (UL 1974) for retired EV batteries through e.g. tracking rates of electrical charge and discharge (UL, n.d.). It is likely that the cost of doing business will be decreased once the UL 1974 has been published, but currently it remains a difficult challenge to study all the differences of each retired battery including a consideration of their specific B2U application. According to a recent study (Lux Research, 2016) recycling degraded EV batteries represents a more cost-effective option to create most from existing materials of these batteries compared to B2U; the study concludes that an oversized B2U 11.2 kWh residential energy storage system will cost $4,600 compared with $6,000 for a new 7 kWh system but factored in round-trip efficiency and cycle life hence representing a more feasible option. With ongoing price reductions but also with new battery technologies entering the EV market soon, prices of new energy storage systems will further drop and represent a strong competition to the B2U market. With regards to the

B2U industry in the US, Tesla is in favour for recycling batteries at their Gigafactory in Nevada, claiming that recycling processes will use 100% clean renewable electricity, recover 100% of the battery's lithium and achieve drastic battery cost reductions as most of the expensive battery materials can be recovered and recirculated into new production cycles. Looking at the European B2U landscape, EV market leaders such as Daimler and BMW appear to fully believe in the B2U potential through their ongoing pilot projects and investments.

Comprehending all of these factors, the emerging B2U industry is facing many technological, market and policy threats. It must be underlined that a prospective B2U market is not only dependent on the battery sector but also to automotive industry itself as an EV market uptake and their competitiveness to gasoline cars is key for degraded EV batteries to increasingly become available for B2U.

3.6 Final remarks

In conclusion, the B2U market landscape remains mysterious from a business model perspective, because it will still be several years before the first mass-market generation of EV batteries starts to retire. Further, B2U projects are mostly still in demonstration stages and therefore no companies have yet specialized in the field on a large scale. This also leads to uncertainty with regards to a future market potential as the optimal business model needs to be quantified as no B2U market exists just yet.

Further, it is emphasized that new relationships between the automotive and energy sectors are forming. Hence, future research shall focus on multi-stakeholder perspectives and how companies would interact to efficiently use degraded EV batteries in B2U applications. Due to the issue of limited data availability, future research shall also evaluate those micro factors that will affect companies participating in the B2U market and how business model innovation can serve as a trigger for achieving competitive advantage as a strong research gap from a business model perspective remains for both industry and academics.

European Union Legislation

4.1 Motivation

This chapter critically evaluates the (existing) EU regulatory framework on the emerging concept of B2U in relation to energy storage technologies. This chapter aims to identify barriers that EU regulators are facing in developing harmonized legislation that facilitates energy storage from retired EV batteries (through the concept of B2U).

4.2 Introduction

The automotive sector plays an increasing role in the European Union (EU) energy use and in the interrelated emitted greenhouse gases (GHG) (Morgadinho et al., 2015). The emitted GHG of the EU road transport sector have increased from 13% in 1990 to about 20% in 2013, while global numbers of motorized vehicles are reaching over 2 billion by 2050 (European Environment Agency, 2016; Sperling and Gordon, 2009). In order to stop GHG emissions to further grow, climate change mitigation, energy and power related legislation and policies as well as sustainable growth practices must be implemented. Due to recent developments in battery technology, electric vehicles (EVs) have gained a renewed global interest as they are seen as a promising solution towards low carbon mobility with increased energy efficiency (Massiani, 2015; Abdul-manan, 2015). A prospective uptake of EVs will represent an important area for the power sector, as there will be additional electricity sales for utilities and increased demands for charging infrastructures and related services. EVs further serve as an energy storage channel in supplying power to utilities through smart grids (‘Vehicle-to-Grid’).

Further, EVs can provide valuable services to the existing energy markets such as meet peak demands through selling the electricity from the battery while charging during off peak times (Yong et al., 2015). Once an EV battery is degraded and no longer appropriate for traction purposes, it may be used for second use applications such as energy storage systems (ESS). However, the majority of EU electricity networks and systems were not designed to allow for energy storage systems and, as a result, they have to be restructured towards additional rollouts of innovative solutions such as the smart grid. This is due to the increasing volumes of the renewable energy generation that is feeding electricity into the grid and such energy production is currently of an intermittent nature (Swinkels et al., 2016).

4.3 Methodology

This study makes use of a two-level approach. At the first level, existing European Directives and Regulations in relation to the Automotive Industry and Energy industry were evaluated in order to comprehend the status-quo of current legislations. Data were collected from corresponding Automotive and Energy EU secondary binding legislations as well as from those legislations that partially make references to EVs, traction batteries and ESS. Further, collected data were clustered in a graph in order to demonstrate the contrast and disharmony in existing number of legislations. At the second level industry examples of ESS joint ventures between leading EV manufacturers and energy companies were identified, followed by a discussion highlighting that current evolvements in the industry are in fact ahead of existing legislative developments at EU level.

4.4 Results

4.4.1 Definition approaches: re-use or second use?

Within existing EU legislations, there is no common definition of the terms ‘re-use’ and ‘second-use’, but rather there is a variety of terminologies equally used within the different life-cycle stages of batteries such as ‘re-pair’, ‘re- manufacturing’, ‘re-building’, ‘re-conditioning’ and ‘re-designing’. With regards to the term ‘re-use’, European regulators define the term within the Waste Framework Directive (WFD) (Council Directive 2008/98/EC), the End-of-life vehicles Directive (ELV) (Council Directive 2000/53/EC), the Waste Electrical and Electronic Equipment Directive (WEEE) (Council Directive 2012/19/EU) whereas there is no definition delivered within the Waste Batteries Directive (WBD) (Council Directive 2006/66/EC). There are no definitions delivered of the term ‘second use’ in any of the European Directives. In this chapter, ‘second use’ refers to transforming a battery after its vehicle application for use in off-road applications such as ESS (Standridge and Corneal, 2014)

4.5 Second use applications

Once an EV traction battery has degraded to about 70 – 80% of its capacity, it can no longer meet vehicle requirements (Neubauer et al., 2015; Manzetti and Mariasiu, 2015). The second use of a retired battery extends the total lifetime value of a battery by increasing economic revenue through second use alternative applications and decreasing the initial cost of the battery as linked energy and material investments compensate initial battery cost (Neubauer and Pesaran, 2011). According to a number of studies (Standridge and Corneal, 2014; Neubauer and Pesaran, 2011; Gaines and Sullivan, 2010) the environmentally and economically beneficial second-use application markets of

EV traction batteries lay within industrial and partly residential uses including current and emerging grid-related applications. This is why the automotive industry is currently highly interested in such alternative revenue schemes, which may offset the high cost of a new EV as the fabrication of batteries employed in EVs currently represents approximately 30% - 40% of the final sale price (Casals et al., 2015).

4.6 Discussion

4.6.1 Regulatory framework

EU regulators face the problem that the rapid changes in electric mobility technologies are not in alignment with the pace of legislative development at European and national levels. Mazur et al. (2015) emphasizes on this regulatory transition in the automotive industry stating, that "alike other sustainability transitions this will induce significant changes to the current structure of the (automotive) industry, making it for some national governments a question of industrial policy as well as of energy and environmental policy". It seems that these substantial changes of the current framework have yet not been implemented when evaluating existing Automotive and Energy related legislation (Figure 12).

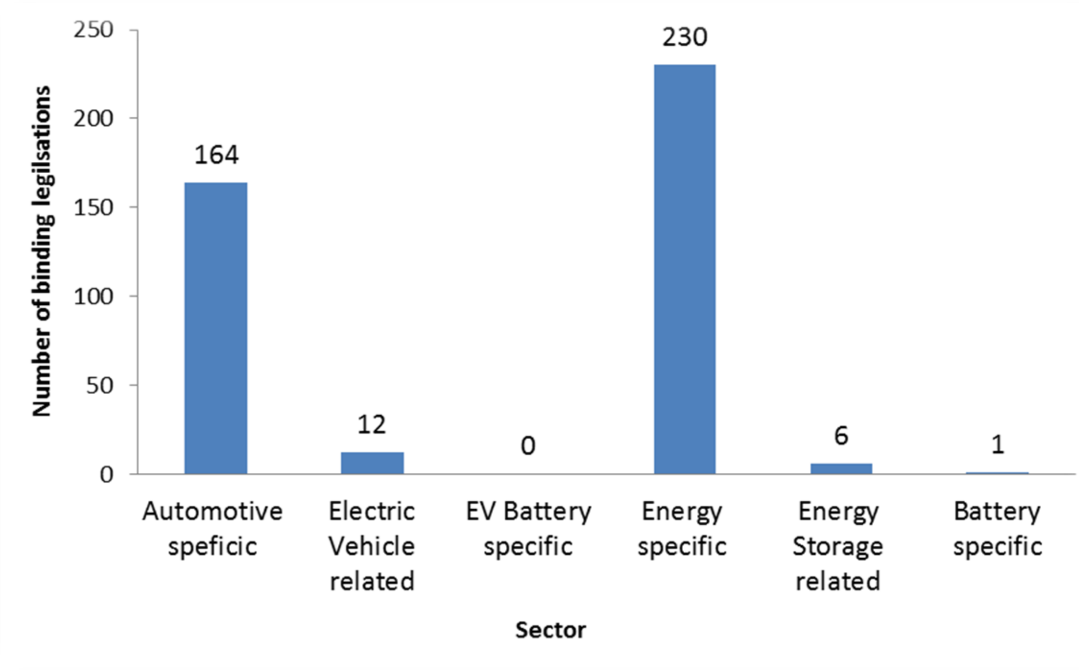

Figure 12 EU legislation in the Automotive and Energy Sector

4.6.2 Legal barriers: electric vehicles & waste batteries

Since EVs entered the mass market in 2009, there has been a rapid uptake resulting in one million EVs sold globally in September 2015 (Cobb, 2015). Despite this, there exists no specific EV legislation but rather EVs are partially referenced in 12 EU Directives (European Commission, 2015). There are 164 EU Directives that are directly linked to internal combustion engine vehicles (ICEVs) but also affect EVs, particularly with regards to clean and energy-efficient road transport vehicles that directly or indirectly promote the electrification of road transport. Nevertheless, there is still uncertainty on a variety of issues; ELV (Council Directive 2000/53/EC) sets stringent targets of reusing and/or recycling to a minimum of 85% by weight per vehicle as well as reusing and/or recovering to a minimum of 95% by weight per vehicle. Further ELV advises car manufacturers to consider recyclability of vehicles during design and production phases (Council Directive 2000/53/EC). However, this Directive mainly addresses ICEVs and does not apply to EV batteries such as emerging new lithium-ion batteries (LIBs) that are difficult and costly to recycle (Council Regulation No 443/2009).

Moreover, it can be observed that a large proportion of EV components (battery pack weighs about 500 kg) can be applied to second use markets and will indeed meet the targets set out by the ELV Directive Council Directive 2000/53/EC. Council Regulation (No 443/2009) sets limits of emitted grams of CO_2 per kilometre (g CO_2/km) for all cars registered within the EU and offers a 'super-credit' for cars emitting less than 50 g CO_2/km. These targets require a substantial market rollout of EVs and subsequently incentivize car manufacturers to focus their business strategies on EVs. Yet, EVs require additional consideration as they incorporate different material compositions (e.g. battery), which means that legal issues that are relevant for EVs may not be associated with ICEVs. This is further underlined by a study from the International Energy Agency (2013) underlining the lack of policies and clear regulations that limits wider global EV market adoption.

The recent introduction of the Europe 2020 Strategy (COM (2010) 2020 final) is as a first proactive step in dealing with the legal issues around EVs. Europe 2020 objectives aim at boosting the European economy in the areas of employment, innovation, education, social inclusion and climate/energy (COM (2010) 186 final; Council Directive 2005/64/EC). Under this framework, the 'European strategy on clean and energy efficient vehicles' (COM (2010) 186 final) has been introduced, which promotes the market uptake of EVs by encouraging the transitions towards a low-carbon and resource efficient economy. Regardless of these incentives, since the strategy launched in 2010, no additional EV legislation or draft proposal has been published at EU level. Article 3.7 of the WBD (Council Directive 2006/66/EC) defines a waste battery as "…any battery or accumulator, which is waste within the meaning of…" the WFD (Council Directive 2008/98/EC).

Further, batteries are not defined within the WFD (Council Directive 2008/98/EC), the ELV Directive (Council Directive 2000/53/EC) and the WEEE Directive (Council Directive 2012/19/EU). According to the WBD, EV traction batteries are classified as 'industrial' as the battery provides most of the motive power. Even more, WBD (Council Directive 2006/66/EC) does not impose any more requirements on EV batteries than those waste prevention and limit measures (by vehicle mass/weight) that are stated in the ELV Directive (Council Directive 2000/53/EC) and the Recyclability Directive (Council Directive 2005/64/EC). This results in legal problems such as that the WBD sets minimum rates of recycling (75% for nickel-cadmium, 65% for lead-acid and 50% for other batteries) whereby the manufacturers shall bear the recycling costs (Council Directive 2006/66/EC). As these recycling rates include batteries from EVs, this can be underlined as a barrier as it would add the total costs of EVs and harm a quick market penetration. Furthermore, recent studies (Manzetti and Mariasiu, 2015; Gaines et al., 2011; Gaines and Sullivan, 2010) highlight that the recycling of batteries from EVs is currently not economically profitable due to the absence of full recycling frameworks as well as that energy storage applications suspend the return of materials for recycling.

4.6.3 Legal barriers: energy storage

In the EU Energy sector, there are 230 specific binding legislations aiming to contribute to the long-term goal of decarbonizing the European economy. The most noticeable Directives are the Energy Efficiency Directive) (EED) (Council Directive 2012/27/EU), Renewable Energy Directive (RED) (Council Directive 2010/31/EU), Energy Performance of Buildings Directive (Council Directive 2010/31/EU) and the EU Emission Trading System Directive (Council Directive 2003/87/EC). In 2009, the climate and energy package 2020 entered into force, and collectively with the EED and Energy Efficiency Plan (EEP), form the legal basis for achieving the so-called 20-20-20 targets that demand a 20% cut in emitted GHG compared to 1990 levels, a 20% improvement in energy efficiency and to source a 20% share of renewable energy by 2020 (European Commission, 2016a). This was followed by the introduction of the European Commission Energy Roadmap 2050 (COM (2011) 885 final) in 2011, with the key long-term goal of reducing GHG emissions by 80-95% by 2050 (compared to 1990 levels). In 2014, the EU energy package was supplemented with the introduction of the 2030 policy framework for climate and energy (European Commission, 2016a) that includes policy objectives between 2020 – 2030 as well as sets additional targets, mainly to cut 40% in GHG emission by 2030 (compared to 1990 levels).

The European Commission (2016b) states the aim of "…a more competitive, secure and sustainable energy systems to meet its long-term 2050 greenhouse gas reductions target…".

Hence, one might assume that issues around energy storage from EVs have been comprehended and communicated within the EU. But there are presently 6 energy storage related legislations, of which none are related to EV traction batteries. This is a further barrier as the share of electricity generated from renewable energy sources needs to grow to 36% by 2030 and 50% in 2050 to achieve previously discussed targets (European Commission, 2013). Therefore, current substantial shares of discontinuous renewable energies in the electricity mix will result in a growing demand to implement flexibility options, including ESS. This is reflected in RED (Council Directive 2009/28/EC), which prioritizes renewable electricity production through ESS in order to achieve a security of the electricity system.

However, even though RED priorities access to the grid for electricity from renewable energy sources, no responsibility is put on operators to contribute to the system's flexibility (Ugarte et al., 2015). Aside from this, with regards to key EU internal market regulations for energy, which are the Gas and Electricity Directive (Council Directive 2009/72/EC), 'energy storage' is specifically referenced within the Gas Directive as being crucial for the gas distribution systems whereby the Electricity Directive makes no references. As a result, the absence of specific targeted regulations and the lack of clear definitions of energy storage within the Electricity Directive can impede substantial investments from stakeholders. Despite these challenges, within Article 2.7 of the Trans-European Energy Infrastructure Regulation (TEN-E) (Council Regulation No 347/2013), the EU comprehends the significance of smart grids through the delivery of clear definitions that identify the economic and technological benefits of smart grids while realizing all relevant stakeholders involved along the value chain. But in the appearance of key barriers for the uptake of EVs, which are purchase price and limited driving range, European regulators shall aim at implementing legislations that combine the economic benefits around ESS of EVs (including second life) in order to further deliver incentives (Sarker et al., 2015). This becomes even more important with regards to recent advancements in LIBs, mainly cost and energy density (Figure 13).

According to Nykvist and Nilsson (2015a), these advancements resulted in cost decreases by 14% annually between 2007 and 2014 from more than $1000 per kilowatt-hour (kWh) to around $400/kWh; at the same time an increase in the battery's volumetric energy density (Wh/l) was achieved, from 200 Wh/l in 2011 to estimated 600 Wh/l by 2022 (Figure 13). Thus, interest of second life batteries lays in their price, which is expected to be below $100/kWh, thus meeting the 2022 selling price target. This is further demonstrated with (on-grid) ESS status-quo polices in

Spain and Japan. In Spain, it is prohibited to install a battery as an ESS between the generation facility such as photovoltaics (PV) and measuring equipment (España Real decreto 1699/2011).

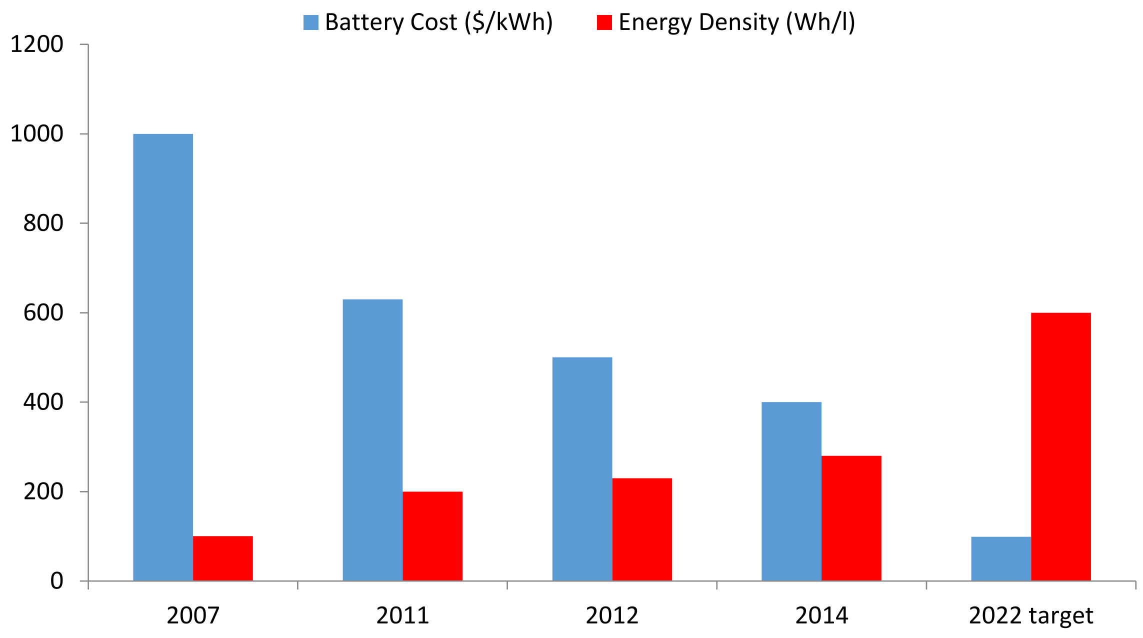

Figure 13 Projected electric vehicle battery progress in the future

Further, a recently passed law (España Real decreto 900/2015) introduces a tax for PV self-consumption and prohibits selling electricity from on-grid ESS back into the grid. Japan, on the other hand, has taken proactive steps as in 2015, a $100 million budget subsidy program was presented that supports the installation of ESS (>1 kW) covering up to two-thirds of total system costs by offering individuals up to $10,000 and businesses up to $1 million in subsidies. Further, national government aims to produce half of the global battery storage market share by 2020 and hence it is realized that battery prices can be driven down through economies of scale while further expanding available renewable energies ESS that can balance grid supply and demand and stabilize power supply.

4.6.4 Industry examples

Global EV manufacturers in partnership with energy companies are currently developing business models around ESS for degraded EV battery packs (Table 1). This is supported with a recent study from Jaffe and Adamson (2014) predicting the global second-life battery business to rise from $16 million in 2014 to $3 billion in 2035. In 2016, Daimler AG, in partnership with energy/environmental companies, launched a second life battery energy storage facility in Germany with total capacity of 13-megawatt-hours (MWh) (Daimler, 2016a); this project maps entire battery chain including manufacturing, stationary applications in energy markets and final recycling processes of second used batteries whereby valuable raw materials are fed back into the production cycle. 96 degraded battery modules with total capacity of around 500 kWh are already connected to the grid, with the result that Daimler offers its customers a 10-year guarantee on EVs while realizing that retired batteries can be deployed for another 10 years within their in-house energy storage facility. However, Daimler appears to fully comprehend economic benefits of energy storage solutions as the company launches further projects by investing about $110 million in their battery subsidy company ACCUmotive in the next years (Daimler, 2016a).

In previous years, European energy markets have not attracted participations of EV companies due to their diversified nature. But apart from the example above, other leading EV companies are also entering into the second life battery business. Hence the second use of degraded EV batteries is in commercial use and has arrived at EU markets with no stringent regulations in place. In fact companies are working ahead of existing EU legislation, which can be further discussed with the example of WBD (Council Directive 2006/66/EC); recycling is preferred over disposal in order to recover materials but no references are made around second-life applications, life-cycles or resource efficiency concepts. However, the WFD (Council Directive 2008/98/EC) and its waste hierarchy promote re-use and second use of waste materials over recycling mechanisms, which therefore stands in contrast to the WBD. Both, WFD (Council Directive 2008/98/EC) and WBD (Council Directive 2006/66/EC), define the policy approach of Extended Producer Responsibility (EPR) that makes producers responsible for the total life-cycle of their products especially for the take-back, recycling and final disposal (Council Directive 2008/98/EC). WBD (Council Directive 2006/66/EC) clearly defines EPR for those producers placing their products on the market for the first time (e.g. EVs) or/and re-using those products where there is no transfer of ownership, as it is the case with Daimler. On the other hand, if second use of a degraded battery requests a transfer of ownership and hence a second placing on the market, the WBD (Council Directive 2006/66/EC) does not identify responsibilities of such ‘new’ producers. This is critical, as there are technical, safety and regulatory concerns, (e.g safe transportation of degraded batteries to repurpose facility) that nobody is currently held responsible for and hence must be addressed in the WBD

4.7 Final remarks

This chapter highlights that the regulatory framework in place is not of a proactive nature as emerging technologies of EV batteries and energy storage technologies as they arrive at the market are not in alignment with evolved legislations at EU level. Automotive and Energy binding legislations have to work towards a harmonized policy framework that allow for flexibility options, including the changing role of storing energy from retired EV traction batteries. This is further underlined by the number of EV companies entering the second-life battery business on a global scale. Hence, there is still a variety of unanswered questions within a consistent regulatory framework contemplating different players and imperatives in this emerging industry. All of these improvements will further increase the need for developed efficient legislation in order to provide a level playing field for an electric mobility transition within the European economy.

Chapter 5

Cathode Materials In Lithium-Ion Batteries: An Economic and Environmental Assessment

5.1 Motivation

Lithium-ion battery (LIB) based technology is most likely to dominate the rapidly growing electric vehicle (EV) in the near future, indicating that there will be a substantial acceleration of raw material demand in the future. Relatedly, this leads to a growing sustainability concern of material criticality and resource security of raw materials such as Cobalt that is a critical component within the battery cathode. Therefore, this chapter focuses on cathode materials within EV LIBs, as they currently need to overcome critical challenges. In fact, cathode materials affect overall battery energy density, rate capability and working voltage that led to the cathode currently costing twice as much as the anode. For this reason, this chapter reviews cathode materials for electric vehicle lithium-ion batteries under economic and environmental perspectives to optimize the batteries' structures and properties as well as highlight the importance of alternative innovative battery material recovery, reuse/second use strategies, such as the emerging concept of B2U.

5.2 Introduction

For more than 20 years, lithium-ion batteries (LIBs) have been the predominant power source of choice for portable consumer electronics such as mobile phones and laptops as they offer higher energy densities and a longer lifespan compared to other rechargeable battery systems (Tarascon & Armand 2001; Deng 2015). In recent years, LIBs have been increasingly applied to electric vehicles[1] (EVs) and stationary storage for electricity produced by renewable sources such as wind and solar. Although LIBs have been successful on a commercial scale, in the context of EVs, there are still major challenges that must be addressed with regards to material costs, environmental impacts, cycle life, safety, energy and power that are all directly relate to the selected combination of battery materials (Dinger et al., 2010). In particular, there are issues around EV limited driving ranges and high costs of present commercially installed lithium-ion battery packs (Bonges and Lusk, 2016). Hence, the EV industry presently desires an augmentation of capacity and power, increase in the battery's lifetime and dramatically reduced battery pack costs. Besides this, as EVs have null tailpipe emissions that can substantially help fight issues around pollution, one might

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[1] Including plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs)

conclude that they are no issues around environmental impacts (Nealer et al., 2015). In fact, during EV manufacturing processes the environmental impact is higher than that of internal combustion engine vehicles (ICEVs), with the battery production phase contributing significantly to emitted greenhouse gases (GHG) (Notter et al. 2010).

This is why there has been continuous research focus on all material aspects of LIBs such as electrodes, electrolyte and separator (Armand & Tarascon 2008; Whittingham 2008; Amine et al., 2014). In particular, the limited theoretical capacity and thermodynamics of the available cathode material in a typical LIB is a critical component with regards to the working voltage, energy density, rate capability and battery cost (Xu et al. 2013). In previous years, the primary research focus has been on cathode material cost reductions as it costs nearly twice as much as the anode material and has the highest weight of all materials within a typical LIB (Gaines & Cuenca 2000; Whittingham, 2008). Besides this, the gravimetric capacity of common cathode materials (e.g. $LiCoO_2$) is one-half that of anode materials (e.g. graphite) (Whittingham, 2004). Furthermore, cathode materials are a critical factor of energy density within a LIB, as it has a lower specific capacity than the most common anode material, graphite (372 mAh/g), to which it must be matched (Doeff 2012).

All these considerations led to the development of several types of cathode materials as there is not yet one ideal material that can meet requirements for all applications while being economical and environmentally friendly at the same time (Whittingham 2008; Doeff 2012). Consequently, the objective of this study is to evaluate present commercially available cathode materials for LIBs in EVs from an economic and environmental perspective.

5.3 Methodology

This study makes use of a three-level approach whereby first of all, the characteristics of common cathode materials for LIBs are categorized and subsequently this knowledge is used to assess economic and environmental implications. Finally, proposed economical and environmentally friendly cathode materials are compared with lithium-ion battery packs that are commercially available in EV models today.

At the first level, present common cathode materials for LIBs are identified and their characteristics are summarized with respect to their specific energy and power, cycle life, voltage and commercial applications. Data were collected from selected available literature on LIBs (Table 6). It is necessary to differentiate and comprehend that LIB technologies incorporate a variety of alternative chemistries (e.g. $LiFePO_4$, $LiMn_2O_4$), electrode designs, different shapes (pouch, cylindrical, prismatic) and capacities of the individual cells that make up the pack; depending on the potential combination, there is a direct impact on performance, weight, costs and degradation rates (Sakti et al., 2015).

Table 6 Existing literature on cathode materials in lithium-ion batteries

Reference	**Research Focus**
(Deng, 2015)	Basics, progresses and challenges of lithium-ion batteries
(Liu et al., 2015)	Understanding electrochemical potentials of cathode materials in rechargeable batteries
(Amirault et al., 2009)	Electric vehicle battery landscape: opportunities and challenges
(Dinger et al., 2010)	Batteries for electric vehicles: outlook 2020
(Nitta et al., 2015)	Lithium-ion battery materials: present and future
(Lu et al., 2013)	A review on the key issues for lithium-ion battery management in electric vehicles
(Huat et al., 2015)	Integration issues of lithium-ion battery into electric vehicles battery pack
(Nelson et al., 2011)	Modelling the Performance and Cost of Lithium-Ion Batteries for Electric-Drive Vehicles
(Hakimian et al., 2015)	Economic analysis of lithium-ion battery manufacturing
(Casals et al., 2015)	Second life of electric vehicle batteries: relation between materials degradation and environmental impact
(Scrosati and Garche, 2010)	Lithium batteries: Status, prospects and future
(Xu et al., 2012)	Recent progress in cathode materials research for advanced lithium ion batteries
(Etacheri et al., 2011)	Challenges in the Development of Advanced Li- Ion Batteries: A Review
(Amine et al., 2014)	Progress, challenges, and future directions of Rechargeable lithium batteries
(Thackeray et al., 2012)	Electrical energy storage for transportation - approaching the limits of, and going beyond, lithium-ion batteries
(Goodenough and Park, 2013)	The Li-ion rechargeable battery: A perspective
(Armand and Tarascon, 2008)	Building better batteries
(Manthiram, 2011)	Materials challenges and opportunities for lithium ion batteries
(Whittingham, 2008)	Materials Challenges Facing Electrical Energy Storage
(Whittingham, 2004)	Lithium batteries and cathode materials

At the second level, the previously identified cathode materials are analysed and compared under economic and environmental perspectives. At the economic perspective, this study evaluates cathode material cost data from two well-established cost evaluations models, Battery Performance and Cost model (BatPac) and the PHEV cost assessment study (TIAX) (Table 7) (Barnett et al. 2010; Nelson et al. 2011). The BatPac model studies cell and component masses, pack-level performance with previously modelled cell chemistries and delivers a determination of cost vs. performance characteristics (Nelson et al. 2011).

Table 7 Details of stated costs for cathode materials

Cathode Material	Abbreviation	Unit	BatPac 2010	TIAX 2010[1]	TIAX 2013[1] (update)
Phospholivine cathode	LFP	$/kg	20	15 – 20 – 25	15 – 18 – 20
Manganese spinel cathode	LMO	$/kg	10	12 – 16 – 20	12 – 16 – 20
Layered oxide cathode[2]	NCA	$/kg	33	34 – 40 – 54	36 – 40 – 48
Layered oxide cathode	NMC	$/kg	31	40 – 45 – 53	33 – 36 – 45

[1] Cost represents range of values possible

The TIAX study on the other hand examines the manufacturing costs of battery packs for PHEVs whereby the major focus lies on the material selection trade-offs and power/energy optimization and capacity fade effects (Barnett et al. 2010). Both studies are evaluating costs of common cathode materials lithium iron phosphate (LFP), lithium manganese oxide (LMO), lithium nickel manganese cobalt oxide (NMC), and lithium nickel cobalt aluminum oxide (NCA). Furthermore, the fluctuations of historical raw material prices (Figure 14) are perceived in both studies. The BatPac model uses a co-precipitation of Nickel, Manganese and/or Cobalt based off a correlation with Cobalt 44 $/kg and the TIAX study applies average traded metal prices of the last 25 years with 95% confidence intervals of Cobalt 44.4±18.3 $/kg and Nickel 14.9±7.6 $/kg (Barnett et al. 2010; Nelson et al. 2011).

Both studies use different input data for their cost models such as pack energy requirements, power input/output, production volumes, battery chemistries, material performance and fluctuations in raw material prices. Hence, this study determines the average cost for each cathode material based on cost data from both studies. In 2013, TIAX published a revised study with updated cost data for the raw materials Cobalt and Nickel according to their trading prices between 2011-2012, respectively 31±5 $/kg and 20.5±4.5 &/kg (Barnett et al. 2013). Thus, the average cathode material costs are calculated using identical cost data from the BatPac model but substituting the TIAX cost values from 2010 with their updated data from 2013 (Nelson et al. 2011; Barnett et al. 2013). The results of the calculated average costs for each cathode material under both scenarios are put in a graph and their implications are evaluated.

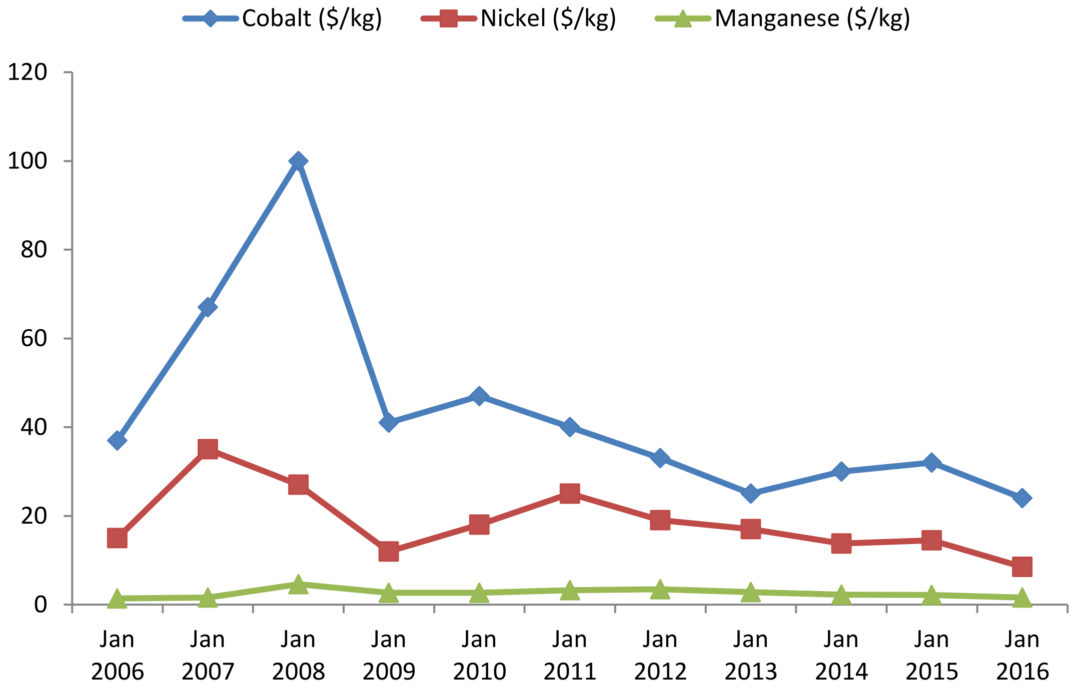

Figure 14 Historical 10-year prices (2006-2016) of Cobalt, Nickel and Manganese[2]

At the environmental perspective, the key parameter of discussion is on GHG emissions during battery manufacturing processes as the emitted CO_2 levels during EV production currently outweigh ICEV production emissions (Nealer et al., 2015). The majority of the emitted GHG result from battery manufacturing processes, of which the selected cathode material composition used for a desired LIBs contributes significantly; consequently, data on CO_2 emissions of the cathode

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[2] Historical 10-year price data taken from the mining knowledge website www.infomine.com

materials LFP, LMO and NMC were collected from available life-cycle-assessment (LCA) studies (Majeau-Bettez et al., 2011; Notter et al. 2010; Frischknecht 2011) and are discussed in Chapter 3.2. Data on emitted CO_2 levels and energy flows of all four commercially available cathode materials following the same equations are scarce and thus subject to uncertainties. This is why the presented results should therefore be interpreted as an estimation of emissions.

At the third level, the evaluated economic and environmentally sound cathode materials for LIBs are compared to cathode materials in LIBs for commercial EVs. As the battery technology and hence the price and overall performance of a vehicle is the key selling point of any EV manufacturer, data on specific cathode material compositions in commercial EVs are generally not published by EV companies and were therefore collected from scientific journals and put in a table. Consequently, the discussion aims to critically analyse, which cathode materials are preferred amongst key industry players and how this affects overall vehicle performance and competitive advantage over other industry players.

5.4 Results and discussion

In LIBs, the most common cathode materials are lithium cobalt oxide (LCO), LFP, LMO, NCA and NMC (Table 8).

Table 8 Characteristics of commercially available cathode materials in lithium ion batteries

Cathode	$LiCoO_2$ Lithium Cobalt Oxide	$LiFePO_4$ Lithium Iron Phosphate	$LiMn_2O_4$ Lithium Manganese Oxide	$LiNiMnCoO_2$ Lithium Nickel Manganese Cobalt Oxide	$LiNiCoAIO_2$ Lithium Nickel Cobalt Aluminum Oxide
Abbreviation	LCO	LFP	LMO	NMC	NCA
Anode	Graphite	Graphite	Graphite	Graphite	Graphite
Type			Metal Oxides		
Specific energy Wh/kg	150-200	80-120	100-130	160-220	180-250
Cycle life	300-500	1000-2000	300-700	1000-1500	500
Voltage (V)	3.6	3.2/3.3	3.7	3.6/3.7	3.6
Applications	Portable consumer	Power tools, Electric	Power tools, Electric	Electric powertrains,	Electric powertrains,

	electronics, Used in early Tesla Roadster	powertrains	powertrains, Medical devices	E-bikes, medical devices, industrial	medical devices, industrial

The key requirements for cathode materials for LIBs are a high free energy of reaction with lithium as well as an integration of large volumes of lithium (Deng, 2015). The first commercially available cathode material, LCO, was introduced in 1991 and it has since been highly successful in commercial portable consumer electronics due to the material's high specific energy (150-200 Wh/kg) (Armand and Tarascon, 2008). EV manufacturer Tesla used LCO batteries within their early Tesla Roadster model but soon switched to more stable chemistries due to low capacity, toxicity, poor safety and high cost of LCO (Amirault et al. 2009). As a result of these risks, LCO became undesirable for applications in EVs and global battery manufacturers have since opted for enhanced cheaper and safer cathode materials for EVs.

5.4.1 Economic perspectives of cathode materials for EVs

Cost reductions in LIBs for EVs can be achieved first and foremost by substituting battery materials, economies of scale in the production process and/or through the establishment of new material supplies; in particular, the cost of cathode materials can be decreased either by material substitution or by finding ways to attain the same materials at a lower cost (Gaines and Cuenca, 2000). As cathode materials incorporate raw material transition metals such as Cobalt, Nickel and Manganese, of which some have shown substantial trading price inconsistencies over recent years, the price of specific battery materials are of some debate. In determining the average costs for the studied cathode materials, the results show that the impact of volatile raw material prices is evident.

First and foremost, the vast average price variances of the different cathode materials are visible. The NCA/NMC cathodes cost on average about twice as much as LFP/LMO based LIBs, respectively 40.25/42.25 \$/kg and 20/14.5 \$/kg. This is due to the high contents of the expensive raw materials Cobalt and Nickel in the NCA/NMC based LIBs. The market price for Cobalt and Nickel has varied dramatically in the last 25 years and thus reducing the volumes in the cathode materials will lead to a decrease of overall cathode prices and less price volatilities. In fact, the market price for Cobalt and Nickel has substantially dropped since the BatPac and TIAX study were published in 2010, reaching a historical 10-year low in April 2016, with Cobalt trading for 22.50 \$/kg and Nickel for 8.28 \$/kg (Figure 14). Hence, in evaluating the updated TIAX cathode material costs, which are based on raw materials prices between 2011-2012, it becomes evident that decreased raw material prices have a direct impact on final cathode costs (Figure 15).

This resulted in moderate to high cost reductions for the NCA/NMC cathodes, declining by 1 $/kg / 6 $/kg respectively. Furthermore, it is assumed that these reductions were also a result of economies of scale as NCA and NMC based LIBs have been increasingly applied to EVs due to their high operating voltage (3.6V) and excellent specific energies, in that order 160-220 Wh/kg and 180-250 Wh/kg (Liu, Neale & Cao 2015; Nitta et al. 2015).

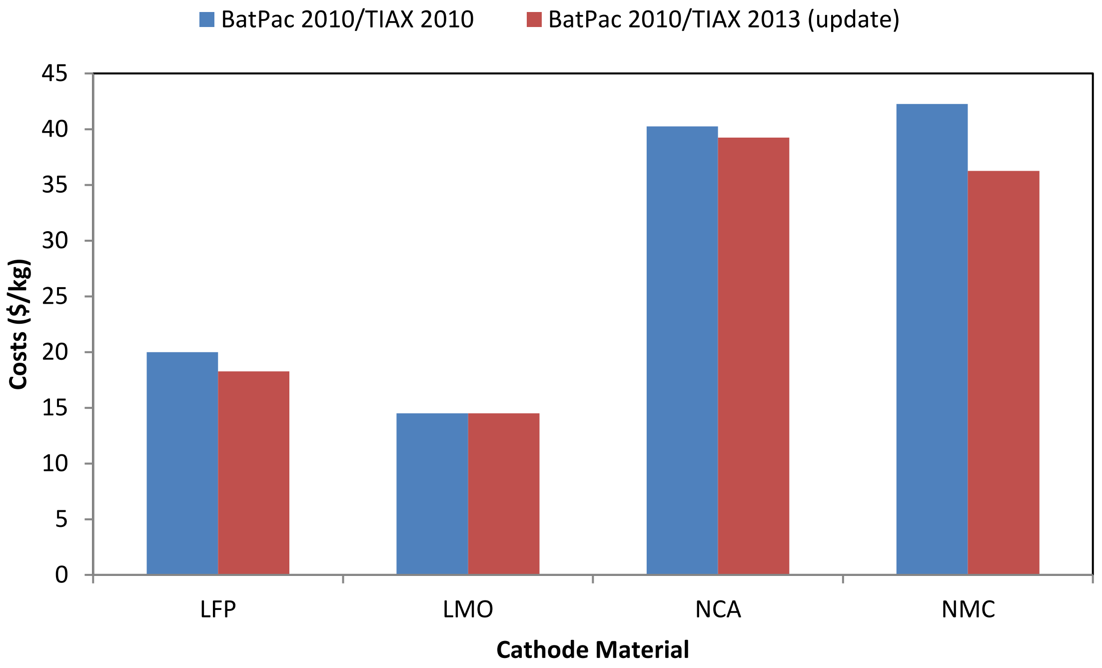

Figure 15 Average costs of common cathode materials in lithium-ion batteries

The comparison of the LFP/LMO cathodes reveals that LFP is more cost extensive as a result of the increased complexity in the manufacturing process (e.g. carbon coating) to LMO, which is relatively easy to manufacture (Nelson et al. 2011). Nevertheless, both cathodes include inexpensive earth abundant elements such as Iron and Manganese in comparison to the rare earth and expensive Cobalt and Nickel elements in NCA/NMC based LIBs. Therefore, cathode materials based on abundant elements such as Manganese should be the prevailing transition metal if a low cathode material, and thus a cost-effective LIB, is desired. But it must also be underlined that if EV manufacturers seek low-cost cathode materials, they have to reach a compromise between overall LIB pack cost and performance of the battery. This is underlined with the low-cost lithium manganese oxide cathode ($LiMn_2O_4$) offering specific energy of 100-130 Wh/kg, in comparison to the high-cost lithium nickel cobalt aluminum oxide cathode ($LiNiCoAIO_2$) with specific energy of 180-250 Wh/kg (Lu et al. 2013).

5.4.2 Environmental perspectives of cathode materials for EVs

With regards to GHG during battery production processes, Aguirre et al. (2012) found that total BEV lifetime CO_2 equivalent emissions accumulate to 31,821 kg CO_2 equivalent, of which 24% are caused by battery manufacturing processes. Depending on the choice of materials, including the choice of cathode material, this directly affects emitted GHG (Table 9).

Table 9 CO2-equivalent emissions of cathode material-based Li-ion battery production

Reference	CO_2- equivalents kg/kWh battery	Cathode chemistry studied
(Notter et al. 2010)	52	LMO
(Frischknecht 2011)	134	Not specified
(Majeau-Bettez et al., 2011)	200	NMC
(Majeau-Bettez et al., 2011)	166	LFP

It is evident that the cathode chemistries LMO/LFP are the most environmentally sound material choice with CO_2 equivalent emissions of 52 kg/kW and 166 kg/kWh compared to NMC based batteries with 200 kg/kWh. LFP achieved superior emissions to NMC due to the use of less environmental intensive materials (Majeau-Bettez et al., 2011). kg CO_2-equivalent emissions for each cathode material chemistry is directly related to whether they include scare and valuable raw materials such as Cobalt and to a lesser extent Nickel or earth abundant materials such as Manganese. This is critical, as Nickel and/or Cobalt based cathode materials such as NMC/NCA, are becoming increasingly popular in EVs with no alternative more sustainable (not dependent on materials such as Cobalt) EV battery technology arriving at market soon, as further discussed in the next section.

Gaines & Nelson (2009) estimated cumulative demands of cathode materials needed by 2050 for light-duty EV LIBs in the United States (U.S.), on the world reserve bases (million tons) of Cobalt (13 million tons), Nickel (150 million tons) and Manganese (5,200 million tons). It was concluded that in order to meet 2050 demands, 9% of Cobalt, 4% of Nickel and 0.12% of Manganese world reserve bases are required. This is a critical issue because prospective EV adoption rates and the demand for critical raw materials such as Cobalt will accelerate simultaneously. Even though trading prices of Cobalt and Nickel are currently low, if the demand increases these metals will become gradually rarer and hence prices will increase radically. Further, EV LIB manufacturers are importing materials (e.g. Cobalt) from leading raw material suppliers such as Russia. All of these factors indicate that there must be more aggressive recycling efforts on critical materials such as Cobalt and Nickel, which are today often motivated merely by their high economic values with some degree of disregard of how to handle other non-valuable and toxic materials. However, a comprehensive discussion of recycling issues around cathode materials from LIBs is not in the scope of this study.

What stands in a direct relationship to GHG emissions of cathode material production, is the use of more renewable energies for the entire LIB production process as well for the EV use-phase (e.g. charging). Both are strongly impacted by the electricity mix in a given country. This is further emphasized by Saevarsdottir et al. (2015) claiming that the electricity consumed during a typical LIB production process is decreased by 95% - 98% if production is moving away from less sustainable regions such as China to more sustainable energy countries such as Iceland[3].

Besides this, the in-use phase of EVs alongside a prospective uptake in sales on a global scale represents an important area for the power sector, as there will be additional electricity sales for utilities and an increased demand on the grid for charging infrastructures and related services. EVs can further serve as an energy storage channel in supplying power to utilities through smart grids (‘Vehicle-to-Grid’) by providing valuable services to the existing energy markets such as meet peak demands through selling the electricity from the battery while charging during off peak times. However, according to a study by the World Energy Council (2013), global total primary energy supply (by resource) will reach 17,208 million tons of oil equivalent by 2020, of which 76% originates from fossil fuels, 16% from renewables (other than large hydro), 2% from hydro (>10 megawatt) and 6% from nuclear sources. Without a doubt, this underlines that the full potential of overall energy efficiency still remains untapped, especially with the vast opportunities associated with EVs.

5.4.3 The commercial electric vehicle battery landscape

In the global automotive industry, leading EV manufactures are currently using different cathode materials for their LIB systems whereby LMO, NMC and NCA are the predominant materials (Table 10). In 2015, Navigant Research predicted that the global market for LIBs in light duty and medium/heavy duty vehicles will accelerate from \$7.8 billion in 2015 to \$30.6 billion in 2024, which underlines that this industry is currently undergoing an important economic transition.

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[3] Electricity production in Iceland causes a footprint of 18 to 23.5 g CO_2/kWh (Saevarsdottir *et al.*, 2015)

In evaluating Table 10, the most popular cathode materials in commercial EVs are LMO and NMC, followed by NCA and LFP. It is evident that the choice of cathode material chemistry has a direct impact on total vehicle cost and driving range. The previously identified economical and environmentally sound cathode materials, LMO and to some extent LFP, are available in commercial EVs such as in the Nissan Leaf or Ford Focus Electric. The reason for the choice of these cathode materials is purely economic and less due to environmental concerns as a low-cost vehicle towards consumers is desired.

Table 10 Cathode materials in selected commercial electric vehicles

Company	**Model**	**EV Type**	**Cathode Material**	**Vehicle Cost[1,2] ($)**	**Driving Range[2] (km)**	**References**
Nissan	Leaf S	BEV	LMO	29,000	135	Shen et al. 2016 Cluzel & Douglas 2012
Tesla	Model S	BEV	NCA	70,000-109,000	335-435	Lu et al. 2013 Nitta et al. 2015
General Motors	Chevrolet Volt	PHEV	LMO	33,000	61	Lu et al. 2013
Ford	Focus Electric	BEV	LMO	29,000	122	Shen et al. 2016
Fiat	Fiat 500	BEV	NMC	32,500	140	Shen et al. 2016
VW	E-Golf	BEV	NMC	29,000	134	Shen et al. 2016
BYD	E6	BEV	LFP	52,000	200	Lu et al. 2013
Renault	Zoe	BEV	NMC	25,000	210	Shen et al. 2016

[1] Vehicle costs based on commercial available electric vehicles on the U.S. market 2016 [2] Vehicle costs and driving range information from http://evobsession.com/electric-cars-2014-list/2 (updated 2016)

Nevertheless, the different cathode materials used in LIBs for EVs underline that there are trade-offs between total vehicle costs (price impact of cathode material) and desired driving ranges (overall performance of cathode material), as discussed previously. Hence, most EV companies are currently selling their models at around $30,000 but with limited driving ranges of about 120-140 km in order to attract potential new customers. On the other hand, there are also market players that have aimed at substantially increased EV driving ranges with higher costs such as BYD (E6) offering 200 km and Tesla (Model S) offering up to 435 km driving ranges. This may result in competitive advantages with respect to driving ranges within the industry, but the high costs of such models can represent a barrier for potential customers, as switching costs from ICEVs towards EVs are already high.

5.5 Final remarks

This study highlights that the economic and environmental performance of commercially available cathode materials for LIBs directly impacts overall EV cost and performance. Both, at the economic and environmental perspective, LMO/LFP based LIBs perform superior compared to NCA/NMC cathodes due to the absence of the expensive and rare transition metals Cobalt and Nickel, that directly impact total cathode costs and CO_2 emissions during battery manufacturing processes. However, this means that if low-cost cathodes are desired, overall EV performance will be reduced resulting in limited driving ranges. For this reason, EV companies currently have to reach a compromise between driving ranges, that are directly dependent on the overall performance of the cathode material, and affordable total vehicle cost, which relates to the choice and cost impact of cathode material and hence the total battery pack cost, towards their consumers.

So far, there is no battery that can satisfy both, economic and environmental concerns while offering an overall excellent performance. Nevertheless, the ongoing improvements on cathode materials in LIBs in the last two decades have provided one promising solution towards a low carbon future with a society that is less dependent on motorized vehicles.

Chapter 6

Conceptual Database Management System For Sustainable Material & Resource Recovery: The Case Of E-Waste

6.1 Motivation

Until very recently, the global market of LIBs has been dominated by the use in consumer electrical and electronic equipment (EEE) industry, which in fact is one of the fastest growing economies globally. The growing demand of LIBs for use in EVs as well as related accelerating application in energy storage technologies, indicate newly evolving battery supply chains and incremented demand for (critical) raw materials and metals. This highlights that strategic responses are in urgent demand in order to recover such (critical) raw materials and metals through sustainable reduce, second use/reuse and recycling mechanisms and frameworks. In fact, only those additional (critical) raw materials needed should be sourced through, ultimately, 'environmentally sound' mining and production processes. Therefore, this Chapter draws from experiences made in the global consumer electronics industry and the resulting 21st century sustainability management problem of electronic waste (e-waste) and linked serious harm to the environment and human health. Sustainable recovery of critical metals (CM) from Waste Electrical and Electronic Equipment (WEEE) in the European Union (EU) requires information for detailed analysis, monitoring and decision-making. Available and related knowledge is currently insufficient or disseminated through the network of stakeholders. This chapter conceptualises an adequate Database Management System (DBMS) with participation of different stakeholders involved for the sustainable recovery of CMs. Last, the difficulties opportunities found for its implementation are analysed, which has implications of the emerging EV B2U industry.

6.2 Introduction

Due to the finite nature of raw materials stocks, the flow of substances through the various stages of processing, consumption and use should be managed to facilitate optimum second use/reuse and recycling (OJEU, 1993). The production of modern electronics requires the use of scarce and expensive resources (Eurostat, 2017). Waste management is indicated as a key component for functional sustainable development (OJEU, 1993). The change in technology and the consumer demand for electrical and electronic equipment (EEE), has accelerated in recent years, making the electronics industry the fastest growing and largest economic sector around the world (Puckett et al., 2002). The uncontrolled rapid uptake of information technology (IT) in combination with continuous re-designs and new technologies has created a culture of use-and-throw. The result of this technology driven paradigm is that EEE becomes obsolete at an early stage in their product life cycle, sometimes within only a few months of their release. The average lifespan of central processing units in computers has decreased from 4-6 years in 1997 to 2 years in 2005, which has been reduced even further (Babu et al., 2007).

Reliable data on waste production, treatment facilities and management are partial requirements for the implementation of community legislation and for the evaluation of the waste management (OJEU, 1993). Measures must be taken by actors across the lifecycle of a product to facilitate the preparation for re-use and correct treatment. The whole product lifecycle should be considered to optimize reuse and recovery (Council Directive 2012/19/EU). For products in the category of Electrical and Electronic Equipment (EEE) and the generated Waste Electrical and Electronic Equipment (WEEE), statistics on their lifecycle are necessary to monitor the achievement of the objectives of the European Union (EU) Directive (Council Directive 2012/19/EU).

There are existing data sources on WEEE in Europe, such as Eurostat, which provides statistics collected under the Waste Statistics Regulation and a database on imported and exported goods (Eurostat, 2017). However, limited information on WEEE treatment capacity in the EU28 Member States (MS) is available in the existing databases. Additionally, precise information about the CM content in WEEE is difficult to obtain, a problem increased when looking for the content of critical metals (CM) in the individual components. The large volumes of CM in EEE, including rare earth elements, as well their supply risk due to limited sourcing in countries have driven the interest of sourcing these elements from WEEE (Marra et al., 2018). Given the increasing demand for these materials alongside geopolitical pressures, the recycling and recovery of CM from E-waste has been underlined as an opportunity to conserve primary resources, prevent waste production and promote circular economy approaches.

Often the producers have insufficient information on content of specific CM (Bakas et al., 2014). This indicates lack of data and data accessibility across the distinct stages of the lifecycle (Huisman et al., 2007). Lack of available data and information does not allow for an assessment of the impacts of the EU WEEE Directive. This problem, combined with poor collection rates and the threat of (illegal) exports from Europe to developing countries, such as Ghana, Nigeria or India, creates a risky investment environment for recycling infrastructures (Bakas et al., 2014).

To increase recycling rates of CM in WEEE in the EU, improved access to data on CM quantities in different products is necessary (Bakas et al., 2014). This includes understanding where the metals are in various components, the composition of collected WEEE, and accurate sales figures in the

EU. Building such a database (DB) of information is additionally complicated by different national interpretations of the WEEE Directive. Instead of making a product information DB at national level, it seems more relevant to do it at an EU scale. The creation of a centralized Database Management System (DBMS) is presented as a solution to address the mentioned gaps and difficulties. This DBMS will allow input of data from different actors, provide transparency on the calculation and estimation methods, give open access to the results to different actors, and allow the presentation of information to the public. This study discusses the general requirements of such a DBMS, and the limitations for its implementation.

6.3 Information requirements from the EU WEEE directive

The EU WEEE Directive establishes requirements for information sharing and processing for reporting, to ensure the recycling quotas by MS. Information about the weight of EEE placed on the EU market and the rates of collection, preparation, recovery or recycling and export of WEEE collected is necessary to monitor the achievement of the objectives (Council Directive 2012/19/EU). MS shall ensure that information concerning WEEE that is separately collected is transmitted free of charge, including information by collection and treatment facilities, by distributors, or by other means. Information is to be collected annually on the quantities and categories of EEE placed on the markets, collected through all routes, prepared for reuse, recycled and recovered within the MS, and on separately collected WEEE exported, by weigh (Council Directive 2012/19/EU). For calculation of collection rates, a common methodology for the calculation of weight of EEE should be developed. MS shall ensure cooperation to establish an adequate flow of information, granting access to the relevant documents and information, subject to the provisions of the local data protection law. Producers and suppliers of EEE in MS shall register and provide all relevant information regarding their activities, and shall provide information about preparation for re-use and treatment of each type of new EEE placed for the first time on market within one year after their placement, to identify the different EEE components and materials, as well as the location of hazardous substances (Council Directive 2012/19/EU).

6.4 Conceptual design of a database management system for WEEE

A Database (DB) is an integrated collection of logically related records or files consolidated into a common pool which provides data for one or more multiple uses (Halvorsen, 2016). The DBMS is a collection of interrelated data and a set of programs to access those data efficiently (Taneja, 2017). A primary goal of a DBMS is to retrieve information from and to store additional information in the DBMS (Taneja, 2017). Additional functions of a DBMS include: data management and structuring, data manipulation, provision of data security, and concurrent control (Wei-Pang, 2017). A DBMS standard proposed by ANSI SPARK in 1975 is used worldwide and is the agreed upon standard for DBMS. It proposes an architecture layer which decouples external views on data and the implementation view of data (Darbar and Suthar, 2014). Three levels of data description within the DBMS are in the ANSI SPARK model: conceptual, external, and internal level (Figure 16) corresponding to different views of the data (Darbar and Suthar, 2014). The core of the DB architecture is the internal level of schema, which implements all the inner details and defines the intentions of the DBMS. The conceptual level contains the definition of all data to be stored as well as rules and information about that structure and type of that data.

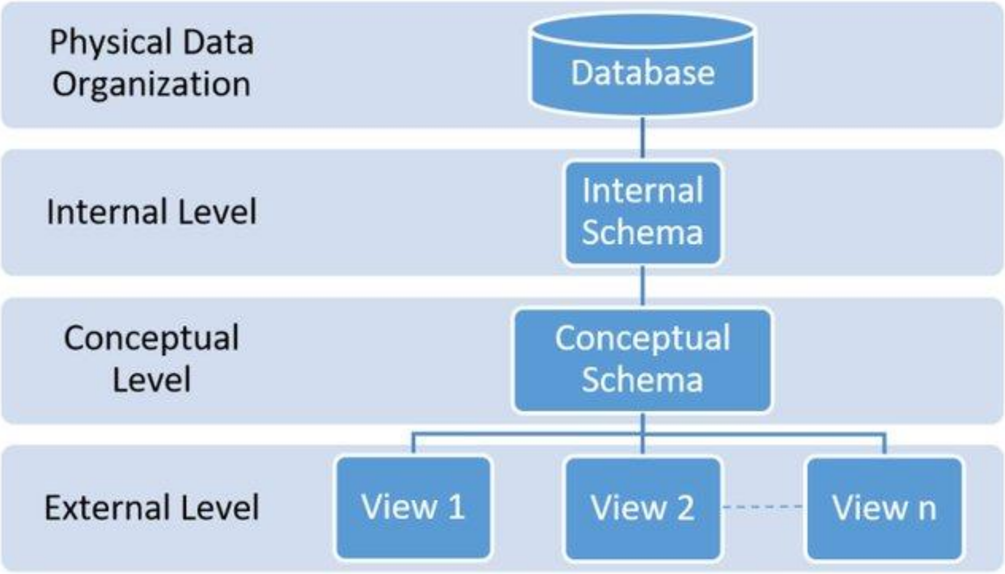

Figure 16 Three level architecture of a DBMS

6.4.1 Requirements of WEEE data

The required DB shall capture the dynamics of WEEE flows. A proposal for a relational measurement framework was developed by Balde et al. (2015), which is based on flows and stocks of EEE and WEEE (Figure 17). Parameters that can be used to gather data for WEEE statistics include: sales of EEE, possession of EEE (in stock), collection of WEEE, non- collected WEEE, exports and imports of WEEE and lifetime of products (Balde et al., 2015). Data should reflect country totals for the EU-28 nations and might need the application of estimation techniques to obtain the national totals. The classification system for WEEE statistics should categorise products by similar function, comparable material composition (in terms of hazardous substances and CM) and related end-of-life attributes. To categorize diverse EEE, UNU-KEYS can be used to collect statistical data on sales. The 54 categories described can be grouped into 10 primary categories, according to the EU WEEE Directive (Balde et al., 2015). DB need to comply with certain formats to ensure that data processing is efficient. Harmonized aggregates can be constructed from the DB, and key indicators according to the distinct categories can be calculated. Once collected, the total can be processed into indicators. The indicators developed shall provide an overview of the size of the local electronic market, collection and recovery volumes: Total EEE put on market (kg inh-1), Total WEEE generated (kg inh-1), WEEE Collected (kg inh-1), WEEE Collection Rate (%) (Balde et al., 2015). No data that can identify individual companies are to be published.

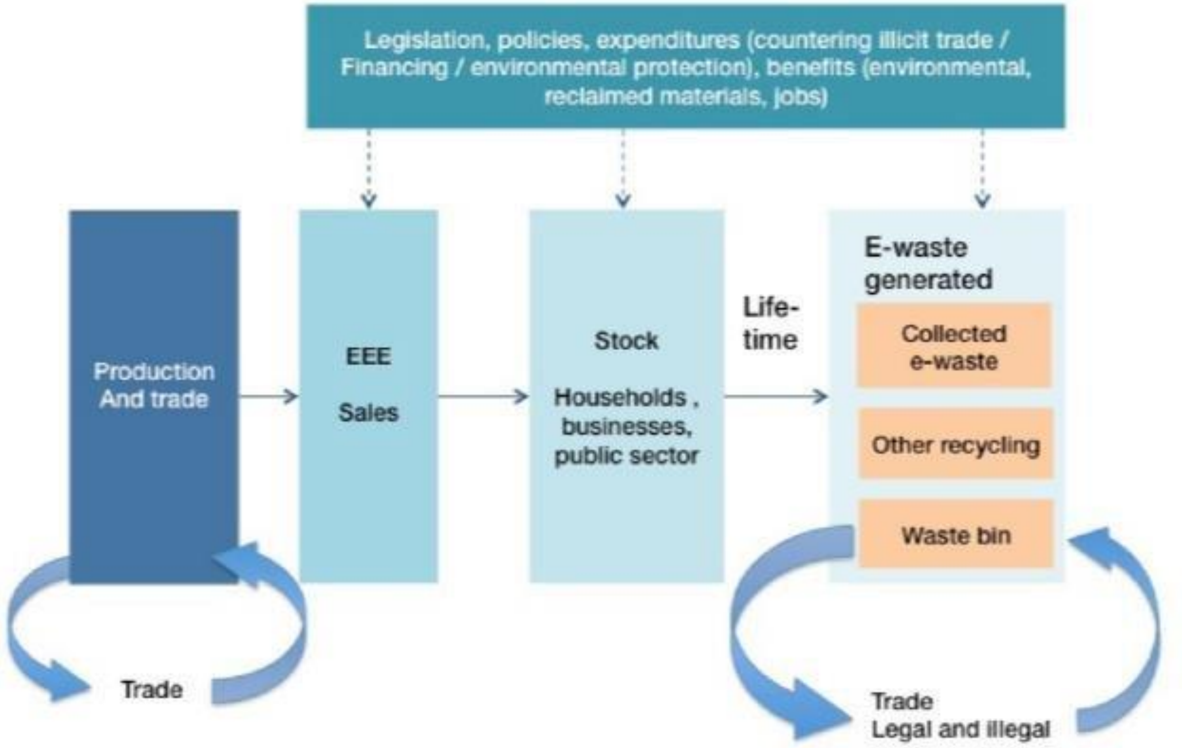

Figure 17 Measurement framework for WEEE Flow (adapated from Balde, 2015)

6.4.2 Conceptual model of a DBMS for WEEE

A data model is a conceptual representation of the data structures. There are two major methodologies used to create a data model: The Entity-Relationship (ER) approach and the Object Model. The focus of this study is the ER approach, often used in statistical DBMS. This model consists of a collection of basic objects, called entities, and of relationships among these objects (Taneja, 2017). A relational DB matches data using common characteristics, so that such data can be easily accessed (Halvorsen, 2016). A basic component of the model is the ER diagram, which is used to visually represent data objects. The information of the requirements of the DBMS is transformed into a conceptual design stage connected with the analysis phase for the different requirements of information of WEEE. Based on the requirements of the WEEE Directive (Council Directive 2012/19/EU), the authors are presenting a first conceptual DBMS for WEEE based on the ER approach (Taneja, 2017). An initial ER diagram with entities and relationships containing the different information flows is developed in this study (Figure 18). The goal is to provide a general structure of the DBMS, reaching a logical design level, indicating what attributes should be recorded in the database.

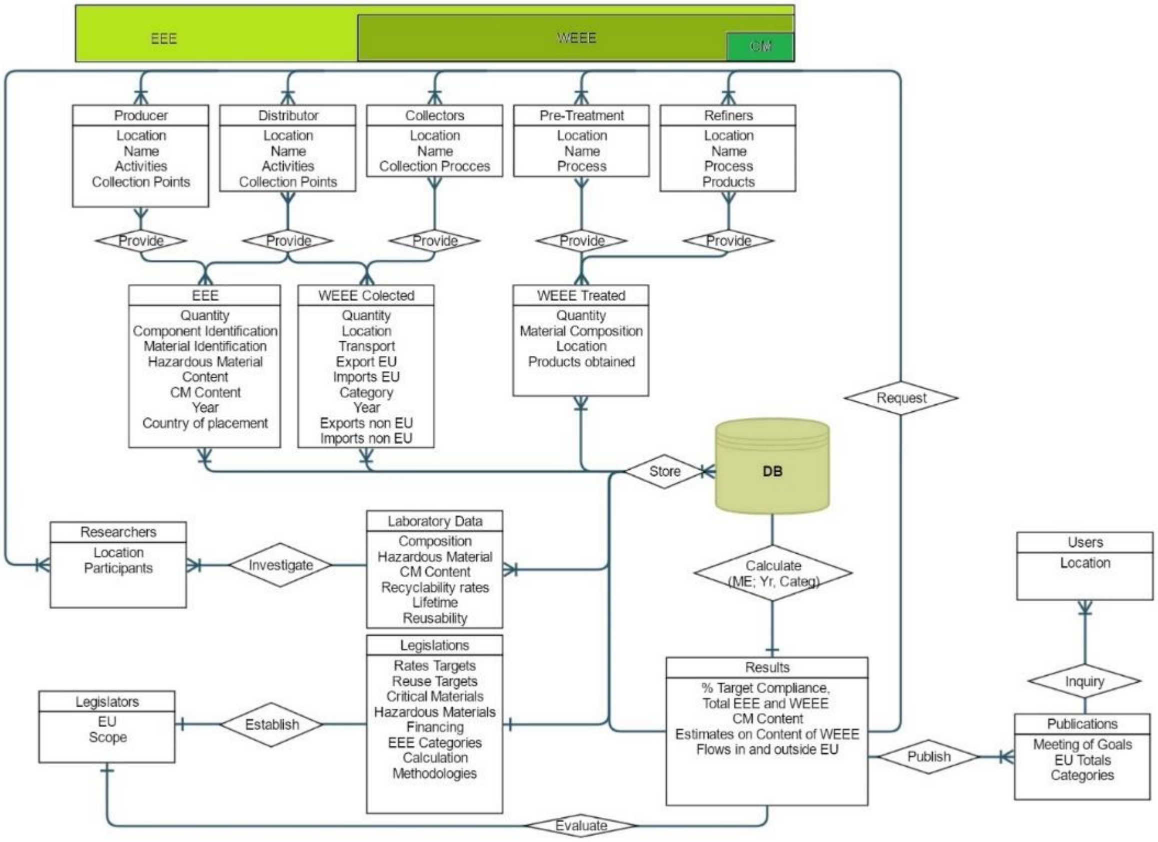

Figure 18 Conceptual design for data flow within database management system

6.4.3 Objectives of the WEEE DBMS

Users of the DBMS are to provide data according to the WEEE Directive. These actors are categorized in the Directive as: producers, distributors, consumers, collectors, treatment plants, and refiners. Information of the running programs and projects, as well as from the legislators, shall be contained. Advanced users include administrators and designers, who shall develop the proposed conceptual model. The goal is to provide access to all users regarding the following items: contents of EEE placed on the market, existence of hazardous materials, quantities of WEEE collected, location, composition, and WEEE material flows. Additional to this data, information regarding results on specific projects shall be shared among users to avoid duplication of knowledge and allowing a common poll. This information gathered from different actors will account for estimations of the target rates set by the EU Directive in every member state. Public reports shall be available to all users to verify the achievement of the different recycling quotas. The model of the DBMS is developed to fulfil these requisites (Figure 18).

6.5 Survey on existing database for WEEE

EEE producers that have chosen to deal with the WEEE Directive report to the national authorities, who report the data every two years to Eurostat, which provides access for its complete database (Eurostat, 2017). It contains data on waste generation and treatment, total waste, waste treated, total waste flows, imports and exports, and capacity of disposal facilities by country. Within the waste DB, an overview of WEEE is presented for the EU and some European non-member countries according to the WEEE Directive. Data of EEE placed on the market and of WEEE collected and treated for the EU is presented. Missing data are estimated to show developments for the EU. Data of WEEE collected are presented by country in kg per inhabitant, and subdivided in ten categories of EEE covered by the EU Directive (Eurostat, 2017). Methodologies for estimations are not explained on the internet site. ProdCom provides statistics annually on the domestic production and import/export volumes of manufactured goods for all European countries (Johnson and Fitzpatrick, 2016).Country specific EEE and WEEE data for France, Italy, the Netherlands and Belgium (Table 11) are already available from previous research conducted by the United Nations University (Huisman, 2014).

Table 11 Survey on WEEE statistics in different member states

Country	Prod. Registry	Collector Registry	EEE Placed	Stock	WEEE	WEEE Treated	WEEE Flows	WEEE Recycled	Format
Denmark	Y	N	Y	Y	Generated	Y	N	N	PDF
UK	N	N	Y	N	Collected	Y	N	N	XLSX
Ireland	N	N	N	N	Collected	Y	N	Y	XLSX
Netherlands	Y	Y	Y	Y	Generated	Y	Y	N	PDF
Belgium	N	N	Y	Y	Generated	N	Y	N	PDF
Italy	N	N	Y	Y	Generated	N	N	N	PDF

(adapted and developed from Huisman, 2012; DPA, 2015; UK EA, 2017; EPA, 2013; Huisman and Baldé, 2013; Magalani, 2014)

This data show that there is already a development towards publishing statistics on these fields, but the data published contain only parts of the required field, and are presented heterogeneously, providing difficulties for its aggregation. There is no distinction between generated and collected waste, so the collection rates are not clearly presented.

6.6 Issues with WEEE data and practical solutions

Given the various sources of data, the problem of heterogeneous disaggregated data appears as a challenge (Table 11). A solution to this is the implementation of a common standard for data transfer, so it can be easily processed. Data content of hazardous materials and CM contents is missing in every DB analysed in this study, presenting difficulties to estimate these values since a harmonized methodology is lacking (Huisman, 2014). Estimations on the contents of CM can be done based on sample testing of WEEE, information is to be gathered by research institutions. Within the EU, the key challenge of how to establish reliable information flows of WEEE and CM content remains. However, current data are quite unreliable and insufficient as the quality of the sources is not ensured since procedures are not in place to check the accuracy of these data sets.

As EEE producers and distributors place products on the markets, questions on the feasibility of the participation of such actors in the proposed DBMS arise. Due to the following reasons this study assumes that such participation is rather unlikely. First, the quantities of EEE products they put on the market is their key business and mainly profit driven. Second, the participation in the proposed DBMS may present additional administrative work. Third, there is a lack of product eco-design policy principles, such as extended/individual producer responsibility, and their current effective integration would rather raise questions on side of the producers as no economic incentives for a transition towards a more circular economic approach are given.

Hence, the following practical solutions are presented:

- Use End of Life (EOL) estimations to forecast WEEE stocks
- Use market models to estimate the quantity of EEE put on the market each year
- Estimate, based on laboratory results, contents of CM for different EEE and WEEE categories

To achieve these solutions, the following is recommended:

6.6.1 Strengthen research relationships between leading WEEE research institutions

Within the EU, research institutions can support to extend this DB. Several existing EU projects focus on the recovery of CM such as REECOVER (Scandinavia), HydroWEEE (with partners from Italy) and BIOLOX (partners from Belgium). Such research shall be aligned and oriented on estimations of EOL, composition of WEEE, CM contained in WEEE, recycling mechanisms, recyclability of WEEE mixtures, economic feasibility of WEEE recycling and CM recovery. This would avoid duplication of results, coordinate actions of these projects, and integrate state of the art research results at faster pace (such as tags in EEE products that estimate CM compositions). Furthermore, it would provide reliable results and conclusions of these projects, creating conditions so EEE producers investigate CM compositions in their products through eco-design and legislators include state policy making for the increased recovery of CM.

6.6.2 Recyclers (pre-treatment and refinery companies)

Recyclers may find some incentives since the information on existing WEEE is critical for their business. Reliable information of treated WEEE volumes and recovered CM rates can be crucial for incentivising its recovery; therefore, feedback on this information is of high importance for a successful evaluation

6.6.3 Reinforce EU member states local data gathering and collection schemes

A cross country flow of information, such as in the case of Nordic countries, as examples of high collection rates and successful policies, can be useful to develop MS policies where recycling rates are not being achieved. The models of gathering and processing data shall be shared across the EU. Such information exchanges can facilitate the establishment of a DBMS. A minimum requirement of WEEE statistics is also proposed, which can be obtained via household surveys (Balde et al., 2015)

6.6.4 Implementation of the conceptual design on existing DBMS

A standardized DBMS is convenient for future growth, facilitating expansion, development and integration with existing ones. The conceptual design presented in this study could be used as framework for expansion and improvement of existing DBMS, such as Eurostat, which already present information on recovery and recycling rates EEE put on the market, collection and, Treatment of WEEE, by country, year and EEE-Category, in tonnes and kg per inhabitant, but lacks information on fields lie CM content or hazardous substances (Eurostat, 2017).

6.7 Final remarks

Knowledge on critical metals (CM) compositions in waste electrical and electronic equipment (WEEE) in the EU currently lacks reliable information for detailed analysis as the information is insufficient and disseminated through different stakeholders included in the electrical and electronic equipment (EEE) value chain. Hence, the authors proposed a conceptual design for a common database management system (DBMS), which incorporates different relevant actors that can help in gathering the principal information on the recovery of CM and follows the requirements of the EU

Directive. The architecture of the proposed DBMS ensures an appropriate flow of information, availability for different actors, and clarity on the mechanism of processing this information, so that the target values set by the EU Directive can be properly monitored and are used as guidelines for further development.

After the proposed schema is compared to existing DBMS on WEEE, potential of implementation of this concept to expand the information flows was identified, so that the requirements of the EU Directive can be satisfied. However, it is difficult to modify existing DBMS configurations, especially if these are not standardized.

Therefore, this study concludes that practical difficulties appear when considering the role of EEE producers and distributors, which can have access to relevant information on the CM compositions in their products and are unlikely to participate in the proposed DBMS without sufficient economic incentives in place. Furthermore, current data sets are insufficient, as they lack information on CM content, recoverability, and the methodologies for calculations are not clear, making their results uncertain. Heterogeneous unstructured data from different countries hinder aggregation and comparison between MS. These problems are also observed when considering existing DBMS, such as Eurostat.

Adequate information exchange and completion of results were identified as key problems for the implementation of the proposed DBMS. It was therefore recommended that research institutions within the EU tighten their relationships to collectively produce relevant results for CM recovery methods that may lead to enhanced pressure on EEE producers and EU policy makers to help make the proposed DBMS feasible, and establish reliable information flows. Future research should address the practicability of implementing the proposed conceptual schema of the DBMS, expanding existing DBMS, and on improving the quality of the data supplied by the different actors involved.

Chapter 7

A conceptual sustainable business model for the electric vehicle battery second use industry: opportunities and threats

7.1 Motivation

This chapter explores sustainable business model (SBM) evolution in the prospective electric vehicle (EV) battery second use (B2U) industry through reporting evidences from EV B2U stakeholder sustainability related business activities, leading to the identification of key opportunities and threats for a potential future market uptake. The appearance of a sustainable value proposition that benefits multiple stakeholders in the value network is highlighted. Thus, a refreshing conceptual SBM framework for the B2U industry is suggested that includes and stresses the importance of such sound sustainable value propositions in the business modelling process.

7.2 Introduction

The global stock of passenger EVs increased by 57% from 2016 to 3.1 million cars in 2017, with Norway having the highest total EV stock share globally (Bunsen et al., 2018). However, this promising market uptake still performs poor compared to total number of passenger internal combustion engine vehicles on the road (around 1 billion), which is expected to reach 2 billion by 2050 (International Energy Agency, 2016). EVs as sustainable innovations can address current challenges in the unsustainable automotive sector that has traditionally been heavily dependent on the use of finite fossil fuels. Therefore, EVs can accelerate the inevitable shift away from internal combustion engine vehicles towards a prospective sustainable transport sector (Casals and Amante García, 2017).

However, a global mass market is still impeded by presently expensive commercially installed lithium-ion batteries (Bunsen et al., 2018). The battery is the most expensive element in an EV and the industry urgently demands high performance cost effective batteries (Reinhardt et al., 2019). In fact, Jiao and Evans (2016a) found current practices in the EV industry to be unsustainable from the economical (high battery costs), societal (range ‘anxiety’ and limited charging infrastructure) and environmental perspective (unsustainable charging sources and lack of environmentally-sound and economic viable end-of-life disposal mechanisms).

In this regard, reusing, repurposing and recapturing value from retired EV batteries in so-called battery second use (B2U) applications hold the potential to address these issues while reducing first-cost impediments of EV and making the overall technology more sustainable. Even though EV batteries have usually degraded after an in-use vehicle lifetime of around 5-8 years, they still have sufficient capacity (around 70%-80%) to be cost-effectively re-used in less demanding B2U applications (Eddahech et al., 2014). The most prominent B2U applications have been found to be further (second) use in non-automobile energy storage systems (ESS) such as for renewable energy integration (Derousseau et al., 2017; Podias et al., 2018). The concept of B2U allows EV companies to generate additional revenues that in turn will reduce total cost of ownership (i.e. faster global market uptake) of their vehicles by increasing the battery product lifetime (capture residual value), reducing initial costs (linked energy and material investment compensate initial battery costs) and substantially delaying the usual cost extensive recycling phase (Jiao and Evans, 2016b; Reinhardt et al., 2016).

Simultaneously, there is a growing trend towards renewable energy production and decentralized generation, which underline that more attention must be given to grid integration issues such as the establishment of suitable electrical storage capacities in upcoming years. This has most recently been addressed and underlined in the Paris Agreement for Climate Change and United Nations Sustainable Development Goal 7: “ensure access to affordable, reliable, sustainable and modern energy for all” (United Nations Secretariat, 2018). The concept of B2U seems to be able to address a persistent fundamental problems in the energy markets, which presently lack to cost competitively integrate and store intermittent renewables in large-scale energy storage systems as a result of ongoing high battery costs (Heymans et al., 2014). This is why B2U may lead to unlock hidden value of the energy storage markets while generating additional revenues for the electric vehicle industry. For example, the energy storage market will be boosted as used batteries can be procured at low cost and in a sustainable perspective, indicating new businesses opportunities (Reinhardt et al., 2017).

With future increases in global EV market share, millions of retired EV batteries will become available to provide valuable service in the stationary energy storage markets. However, this also suggests that there will be a heavy burden on the environment if those batteries are not treated properly. It remains to be unearthed how participating stakeholders in the emerging B2U industry can innovate their novel and sustainable battery product life extension strategies into business models that contribute towards sustainability. In this regard, the evolving major research field of sustainable business models (SBMs) seem to be able to bridge these concerns as they have been identified to be a useful framework to create and push a ‘systems change’ towards ‘true’ sustainability in organizations (Bocken et al., 2015).

Sustainability-related thinking has evolved over time that aims to explore the complex interrelationships between sustainability, firms and stakeholders by proposing theories such as corporate social responsibility (CSR), eco-efficiency and eco-design, clean technological processes and product innovations, stakeholder theory and the resource-based view of the firm to increase competitive advantage, amongst many others (Chang et al., 2017). However, these approaches have often been incorporated as a result of compliance with regulations as well as received criticism to be insufficient to generate the necessary radical transformation of organizations and societies towards functional sustainable development (Amit & Zott, 2012; Schaltegger, Hansen, & Lüdeke-Freund, 2016).

As a result, a variety of researchers and international organizations are emphasizing that the current business as usual practices are not a long-term option to generate the necessary radical transformation of organizations and societies towards functional sustainable development, whereby socio-economic and environmental parameters are recognized (Engert, Rauter, & Baumgartner, 2016; Broman & Robèrt, 2017). Such a transition towards a sustainable society requires a shift in how business is done through a long-term vision and holistic solutions that redesign business models towards sustainability (Evans et al., 2014). Relatedly, the emerging research field of sustainable business models (SBMs) seem to be able to bridge this transition as they have the potential to solve economic, ecological and social issues simultaneously (Boons & Lüdeke-Freund, 2013; Lüdeke-Freund & Dembek, 2017). SBMs use a firm-level and wider systems perspectives, with the triple bottom line at its core to measure performances and purposes of firms through including environment and society as key stakeholders (Elkington, 1997; Stubbs and Cocklin, 2008).

Consequently, there exists an urgent need of empirical case study research in order to provide firms with frameworks and methods that include a more holistic view of how to include the three metrics of sustainability into the business model innovation processes, eventually contributing and advancing knowledge on a prospective sustainable transportation sector. Therefore, this Chapter has identified the following research questions:

RQ1: to examine the necessity and development of a sustainable business model (SBM) for the rapidly developing battery second use (B2U) market within the emerging electric vehicle (EV) industry

RQ2: to identify key opportunities and threats for a prospective EV B2U market uptake considering SBM perspectives

Therefore, this study has identified the following research questions:

Therefore, the aim of this study is to examine the necessity and development of a sustainable business model (SBM) for the rapidly developing battery second use (B2U) market within the emerging electric vehicle (EV) industry. This study begins with an introduction to the relevant theoretical background, followed by used the methodology for this study and an overview of the interviewed stakeholder role case studies. In combining field interview data with the literature background, first major opportunities and barriers for a prospective B2U market uptake are identified. Continuously, the different conceptual SBM elements are discussed in the context of the collected evidence from the B2U stakeholder cases, leading to a refreshing re-conceptualization of a SBM for the B2U industry. Lastly, conclusions coupled with research limitations and indications for future research are presented.

7.3 Background

The concept of 'business models' gained popularity in the 1990s with the introduction of the dotcom age boom. It is a complex research field whereby key strategy-oriented literature perceive a business model as a holistic description on 'how a firm does business' by creating and capturing value within a value network (Chesbrough & Rosenbloom, 2002; Johnson et al., 2008; Richardson 2008; Zott & Amit, 2010). The central element of any business model is the value propositions as customers do not only need to comprehend a company's offering but also its value proposition and how it differentiates to competing offerings (Chesbrough, 2010; Zott & Amit, 2010). Richardson (2008) introduced a widely accepted business model framework, including the value proposition (product/service offering and target customer segments and differentiation strategies), value creation and delivery (key activities, resources & capabilities, position in the value network etc.) and value capture (revenue model and cost structure). Business model innovation (BMI) is about businesses identifying new value propositions (and how to create, delivery and capture it), which will lead to increased competitive advantage in the particular markets (Amit & Zott, 2012; Bocken et al., 2014).

However, businesses have usually not put sustainability at the core of their business models with an integrated solution but rather the key focus remains on financial business growth, making their impact on corporate sustainable development limited (Baldassarre et al., 2017). Sustainability in businesses is about finding a balanced integration between people, planet and profit by reducing negative impacts on earth and its ecosystems including both the environment and society. Thus, sustainability in organizations has become a crucial research area as companies are the productive resources of the global economy and without the backing of such firms, sustainable development cannot be achieved. As companies have the ability to change their normative settings, they may prove as a catalyst or a barrier with respect to sustainability but either way their contributions to sustainable development are considered highly important (Rauter, Jonker, & Baumgartner, 2017).

Therefore, BMI has been acknowledged to facilitate in recognizing greater social and environmental sustainability in the industrial system, ultimately resulting in more sustainable business models (SBMs) (Lüdeke-Freund, 2010). According to Schaltegger et al. (2016), SBMs assist in: "…describing, analyzing, managing, and communicating (i) a company's sustainable value proposition to its customers, and all other stakeholders, (ii) how it creates and delivers this value, (iii) and how it captures economic value while maintaining or regenerating natural, social, and economic capital beyond its organizational boundaries" (p3).

Relatedly, the emerging research field of sustainable business model innovation (SBMI) is a company's ability to include sustainability objectives (TBL – People, Planet, Profit) into the business model (Stubbs & Cocklin, 2008; Geissdoerfer et al., 2018; Naor et al., 2018). Eventually, this may lead to firms realizing that apart from focusing on economic value (profit), they must also comprehend the benefits to society and the environment, commonly titled 'sustainable value' (Evans et al., 2017; Morioka et al., 2017). The key characteristic of SBMs is to go a step further than creating economic value but rather to reach a harmony of the interests of all stakeholders to create sustainable value, a shift towards multiple forms of shared valued by including the environment and society as key stakeholders to the firm (Porter & Kramer, 2011; Bocken et al., 2013; Baldassarre et al., 2017).

At the core of a SBM is the 'sustainable value proposition' (SVP), which has been found to offer a more holistic view of the traditional 'value proposition' concept as it comprehends several needs across a network of stakeholders such as shareholders and suppliers but also the environment and society, leading to the creation of shared sustainable value that is in turn relative to each stakeholder (Morioka et al., 2017). According to Baldassarre et al. (2017) a sound SVP is built and combined from '…three interrelated building blocks: generating shared value for a network of stakeholders, addressing a sustainability problem, and developing a product/service that tackles this problem by taking the stakeholders into account' (p. 177).

However, research efforts on SBMs are only recently emerging as a field that underline the complexity of the concept as practical tool and framework development efforts are still scare (Evans et al., 2014; Geissdoerfer et al., 2016). The research field is not yet mature as there is a lack of agreed concepts and clarifications as well as that SBM theory is only beginning to emerge (Yang et al., 2017; Dentchev et al., 2018). According to Evans et al. (2017), there is a paucity of empirical research on SBMs as the lack of theoretical research is reflected in the scarce number of case studies and empirical analysis in the field.

7.4 Methodology

In order to comprehend numerous aspects of SBMs for the unfolding EV B2U market, background material were collected. Given the complex and emerging nature of the two research fields of electric vehicle (EV) battery second use (B2U) and sustainable business models (SBMs), a qualitative multiple-case study research approach was considered as most suitable (Lee & Saunders, 2017). This is related to findings by Morioka et al. (2017) highlighting the lack of studies that deal with SBM adoption in practice and concluding that case studies are a useful method to build theory in this upcoming research field. Adopting a multiple-case study approach is superior to single case study as it allows to generate more robust, replicable, and generalizable results (Yin, 2003).

First and as a result of the interdisciplinary research nature, this study is building upon the methodological approach and related key findings and recommendations from Chapter 2 "…we invite and push for further research on the topic through comprehending attitudes and characteristics of multiple stakeholders that are interested in participating in the emerging B2U market. (p35). The literature review confirmed the research gap as most available studies on B2U have focused on quantitative techno-economic and environmental parameters. These studies confirmed that no major technical barriers for B2U market adoption remain and call for increased research efforts on (sustainable) business models (Heymans et al., 2014; Jiao & Evans, 2016a; European Commission, 2018). These quantitative findings were synthesized in tabular forms using different headings such as aim/objective of the study, research methodology, and key findings. It was identified that there is a knowledge gap in existing literature on comprehending SBM necessity, evolution and occurrence in the rapidly evolving EV industry and its underlying B2U market.

Consequently and as a second step, data collected from the first and preceding research phase were used as the basis to select, plan and execute multiple stakeholder interviews that are the main sources of data for this study. Semi-structured interviews were carried out with stakeholders participating in the B2U market, combined with document analysis published by those companies (grey literature). Using qualitative semi-structured interviews, which principally rely on the participants' view of the phenomenon in question, allow researchers to explore these subjective viewpoints in order to comprehend in-depth meanings and beliefs (Flick 2009; Creswell 2014). As a result of the diversity of the emerging innovative B2U market along the difficulty of classifying all participating stakeholders, this study applies the purposeful sampling technique of critical cases that '…involves identifying criteria in advance that distinguish cases from others that make up the majority of a population and using those criteria to select cases'(Lee & Saunders 2017, p. 85). This type of sampling is especially suitable if a small number of cases can be sampled whereby the focus is on comprehending what and why is happening in each critical case (Struwig & Stead 2001). This permits to develop logical generalizations from collected rich evidence of the selected in-depth case study data that can also apply to other cases because if it is true in this case, it is likely to be true for all other cases (Patton, 2002). Therefore, in identifying the dimensions that make the cases 'critical', the selected samples include those stakeholder cases that have employed innovative business model approaches in the developing B2U industry and thus have crucial knowledge and insights about the phenomenon of interest. In order to provide a multi-stakeholder perspective on the topic, four different exemplary stakeholder role cases were selected, mainly managers and Chief Executive Officers (CEOs) (Table 12).

Table 12 Electric vehicle battery second use case studies

Case	Company	Stakeholder Role	Region	Interviewee's Position
1	Company A	EV Manufacturer	South Korea	Manager
2	Company B	Battery Lifecycle Management (Start-Up)	Australia	CEO & Co-Founder
3	Company C	Energy Storage Provider (B2U service & system)	United Kingdom	CEO
4	Company D	Battery Recycling	Belgium	Manager

The interviews lasted between 45 min – 2 hours and were carried out on the phone or in-person at the company's site. Interviewing multiple stakeholders in the emerging B2U industry delivers rich source of in-depth and insight information on the developing market as well as its impact on current business models. The following topics and themes were covered with the interviewees:

- The topic of battery second use (B2U) and its correlation to the electric vehicle sector
- The company's B2U involvement, ongoing activities and projects and relatedly stakeholder's beliefs and experiences on the topic

- Status quo and forecast of the B2U industry based on industry key insights and experiences
- Innovative sustainable business model perspectives for B2U

All interviews were recorded and transcribed and relied on the strong operational method of qualitative thematic analysis, a process of identifying themes or patterns within collected data (Braun & Clarke, 2006; Lee & Saunders, 2017). This enabled us to compare and contrast data from all sources to categorize and develop robust results and implications for fellow researchers and business practitioners. As a first step, recurring themes and categories were classified with respect to a prospective EV B2U market uptake and success. Secondly, these themes were further explored in the relation to the view of the particular interviewed stakeholder. Last, these results and findings were analysed against previously identified and relevant (sustainable) business model theories and perspectives.

To this end, we decided to use the conceptual SBM framework (Figure 19) as a lens for analysis to investigate the occurrence of business models towards sustainability in the industry stakeholder case samples (Bocken et al., 2014; Bocken et al., 2015).

Value Proposition	Value Creation & Delivery	Value Capture
• Product/Service offering • Target customer differentiation • Value for customer society, and environment	• Key activities • Key resources & capabilities • Partners and suppliers • Technology and product features	• Cost structure • Revenue model/streams • Value capture for key actors including environment & society • Growth strategy/ethos

Figure 19 Conceptual sustainable business model framework (Bocken et al., 2015; Bocken et al., 2014; Richardson, 2008)

7.5 Case Description

Company A is a South Korean multinational automobile manufacturer headquartered in Seoul. It operates the largest vehicle manufacturing plant in the world, making the company the third largest producer globally. Initially the company’s key focus has been on fuel cell electric vehicles, but because of investor pressures, the company changed its course to include EVs. So far, the company has an EV fleet of around 8 models, but they are ramping this up until 2025, by introducing 14 alternative vehicles to the US markets by 2020. In the context of B2U, in 2017 the firm has established an internal project team that focuses on integrating second life EV batteries to energy storage systems as large volumes of retired batteries are expected to be returned and reused in the near future.

Company B is an Australian based battery control technology specialist Start-Up that was founded in 2015. The company is a developer of advanced battery control solutions, a lifetime-extending battery management system technology for EV batteries. This system reduces the upfront costs of batteries by 30% through recycling the ‘best’ cells within degraded EV batteries and connecting them with smart technology that extends overall lifetime and sustainability. Recently, the business has been recognized as one of the top 15 global start-ups, as the company’s battery control technology has been demonstrated to achieve capable, long-lived storage in a cost-effective manner in residential and commercial & industrial B2U applications.

Company C is a United Kingdom based site-integrated energy storage solutions provider. The firm has developed a battery-agnostic energy storage system technology that can use second life EV batteries in commercial systems in a variety of behind the meter applications in Europe. The system is unique in a way as it is currently the only commercially available system that can re-use EV battery packs as a whole (rather than just the modules) while offering the same performance as new batteries yet at substantially lower cost and in a sustainable manner. Currently, the company is securing additional investments with big players in the automotive and energy markets in order to make its technology fully integrated and to handle multiple battery variations of all sorts and types of EV batteries.

Company D is a multinational materials technology company headquartered in Belgium. One key focus of the company lies on the recycling of degraded batteries both from EVs and other electrical and electronic equipment and on high-end battery materials production. Company’s D EV battery end of life commitment is merely on recycling batteries (after their 1st, 2nd or even 3rd life) and to develop and produce battery materials. However, the business is directly related to the B2U market as recycling is the last step in every battery’s life cycle and thus collaborations with other B2U stakeholders are essential to close resource loops but also to maintain a competitive position in the market.

7.6 Results and discussion

Results from the B2U stakeholder case studies firstly informed that innovative multi-stakeholder cross-sector business relationships are slowly forming, namely between the previously isolated automotive and energy markets. A variety of EV companies have started initiating B2U pilot projects in collaborations or joint ventures with previously excluded stakeholders in this innovative evolving value chain such as energy companies, recyclers, service providers and other stakeholders to comprehend the economic feasibilities and development of viable innovative business models for sustainability (Gur et al., 2018). As a result of growing industry interests and experimentations there is thus clear evidence of a forming secondary market for degraded EV batteries. However, even though innovative B2U business model advances seem to emerge, case studies from the B2U industry underline that it is still in its infancy and the market landscape remains mysterious. This comes as no surprise as finding the right model at an early stage in a developing industry, as it is the case with B2U, is very rare (Teece, 2010).

Furthermore, the B2U stakeholder cases highlighted the emergence of several issues and concerns with regards to a prospective B2U market potential. This again stresses the uncertainty and exploratory complex nature of this nascent industry. In combining the theoretical literature background with field data, only those key drivers were categorized that are most relevant in the given case study regions. Consequently, these drivers were given highest priority and their implications are classified into opportunities and barriers that the EV industry and the underlying B2U market are facing either now or soon (Table 13).

Table 13 Opportunities and barriers for a prospective B2U market uptake

Opportunities	**Threats**
• Growing electric vehicle market • Increasing demand for energy storage • Development of innovative (sustainable) business models • Additional revenues and/or cost savings for OEMs (and partners) • Increase in cost-effectiveness through incentives/funding • Reduction of GHG emissions • Replacement of environmentally harmful batteries • Increasing environmental and resource awareness (UN SDGs, Paris Climate Agreement etc.)	• Low availability of second life batteries • Future competition from new and cheap batteries • Uncertainty on battery condition after 1st life • Unclear legal/regulatory situation (e.g. liability, obligation to recycle) • Uncertainty of lifetime in 2nd life • Repurposing costs • Lack of standardization (design for B2U) & safety concerns • Adaptation of user behaviour in 1st life: longer battery use phase in the vehicle

(adapted from Reinhardt et al., 2017; Reinhardt et al., 2016; Fischhaber et al., 2016)

One major opportunity has been found to be the expected volumes of degraded EV batteries to become available in the future, which is directly linked to the EV market uptake. As most EV models have been introduced in very recent years coupled with the still slow market growth, it will be until the 2025-230 when large volumes of batteries will become available for B2U. A second key factor for market success lies in the future need for energy storage solutions that is influenced by the costs of other competing technologies. Recent forecasts estimate that the global energy storage market will attract more than $620 billion in investment by 2040 (Bloomberg New Energy Finance, 2018). On the other hand, the persistent low availability of second life batteries today represent a critical problem for the EV industry, urgently desires an augmentation of battery capacity and power, increased lifetime and substantially reduced costs (Reinhardt et al., 2019). There is also the problem of cheap and new competing battery technologies entering the market soon. This has been confirmed by findings from Jiao and Evans (2018) that further underscore the issues around uncertain B2U performance in a specific application, unclear regulatory situation as well as the need for 'design' for B2U to facilitate their integration into storage systems.

7.6.1 Towards a conceptual sustainable business model for the B2U industry

The set of the multiple interviews have provided insights confirming that the B2U industry, in particular the EV companies, are creating and capturing new forms of value. Through entering into several cross-sector multi-stakeholder relationships with new market entrants such as energy storage system and service providers, grid operators, recycling and final consumers, findings suggest that the concept of B2U can accelerate SBM adoption in practice (e.g. there is an innovative evolving value chain). This directly contributes to a prospective sustainable transportation system due to increased sustainable use of environmental resources through a substitution of primary resources and raw materials by delaying the final recycling phase as well as implying technological, societal, environmental, and economic changes as part of prospective innovative SBMs. In relating interview case study data to the conceptual SBM framework (and its three key value elements) as a lens for analysis, the following was unearthed.

The **value proposition** is the central foundation of SBM adoption because it represents a company's economic, environmental and social added value (i.e. sustainable value). The case study data inform that the value proposition in the B2U industry is primarily focused around exploiting residual value of EV batteries in less demanding storage applications (product/service offering). Further, it was found that value for customers is achieved through offering affordable second life home energy storage systems through buying, leasing or renting). The concept of B2U can generate additional revenues to EV companies, which could lower total cost of ownership of EVs and accelerate the transition towards a sustainable transport system that is of enormous value towards society. Simultaneously, through remanufacturing and reuse, B2U achieves environmental benefits by slowing and closing resource loops. This directly leads to an increased sustainable use of environmental resources through a substitution of primary resources and raw materials by delaying the final recycling phase by up to 20 years as well as implicates technological, societal, environmental, and economic changes as part of prospective innovative SBMs. Hence, the concept contributes to sustainable development, in particular the principles of the circular economy with its key characteristic of ‘resource life extending strategies’ (Antikainen, Valkokari, & Mcclelland, 2016).

In synthesizing these findings, it can be detected that in the B2U industry there seems to appear a value proposition that benefits a variety of stakeholders, including the economic, society and the environment (i.e. sustainable value). In fact, relating to recent theoretical findings by Baldassarre et al. (2017), the B2U industry appears to fulfil the characteristics of a sustainable value proposition (SVP), which is based on the key interrelated elements of shared value creation for a network of shareholders, addressing a sustainability problem and consequently developing a product/service that is able to offer a solution. Given the evidence from B2U stakeholder industry activities, shared sustainable value is created as companies are entering into joint venture business partnerships to explore new business opportunities for reusing retired EV batteries in less demanding secondary market applications. This is the direct result of addressing a sustainability problem, to work towards a sustainable transport and renewable energy production system away from the ongoing dependency on finite fossil fuels that in turn will benefit a sustainable society in the future. However, this does not implicate that innovative markets, as it seems to be the case with B2U, are sustainable. In fact, as previously stated, according to Jiao and Evans (2016b) current routines in the EV industry are unsustainable. Through reusing retired EV batteries, the concept of B2U presents a developed product/service offering that addresses these critical issues. B2U substantially slows down resource cycles by increasing total battery service life in less demanding applications in the stationary energy storage market (e.g. renewable energy integration).

At this point it can be concluded and indicated that formulating a sound sustainable value proposition (SVP) which seems to be the case in the nascent B2U industry, will have a direct positive impact on the second element of the conceptual SBM: the **value creation & delivery**. We argue that SVPs will in fact result in a sustainable value & creation delivery system. This has been confirmed in the interviews and literature review, which highlight that the value creation and delivery is primarily centred on cross-sector collaborations, partnerships and joint ventures in the stakeholder value network by sharing resources, expertise and knowledge on the complex topic of

B2U. Eventually, this may lead to shared sustainable value capture for the multiple-stakeholder value network including society and the earth's ecosystems.

Lastly, data from the B2U stakeholder case studies underline that the **value capture** includes more than just monetary value (profit) but also environmental and social value (i.e. sustainable value). The residual value of the battery is extended through B2U in the stationary storage market, which leads to economic value capture. Furthermore, there are other economic value capture opportunities that will emerge such as new job creations or customer acquisitions, which result from the stakeholders' sustainability activities in reusing, remanufacturing and recapturing sustainable value from old EV batteries. Environmental value is captured through reducing waste and virgin material costs and substantially delaying recycling costs, leading towards reduced environmental footprints. At the same time, there is positive contribution to the environment as a result of storing intermittent renewables in second life EV batteries in the stationary storage sector. From the social value perspective, data inform that B2U related activities will lead to customers as well as employees gradually engaging in the overall purpose of the business (the value of engaging in an environmentally sound business).

The rapidly developing EV market and the underlying but emerging B2U industry insights emphasize the importance but also the occurrence of sustainable value for each element of the conceptual SBM framework within the overarching EV industry. As a result, we present an updated SBM framework (Figure 20) by building on Richardson (2008) and the conceptual SBM framework from Bocken et al. (2015) and including findings from Baldassarre et al. (2017). The framework shows the importance of the impact of a sound SVP that is driving sustainable value along all the SBM elements. Consequently, and in the context of the B2U industry we define a sustainable business model as a process of identifying a sustainable value proposition and how the company captures this in the form of long-term shared sustainable value for multiple stakeholders including society and environment.

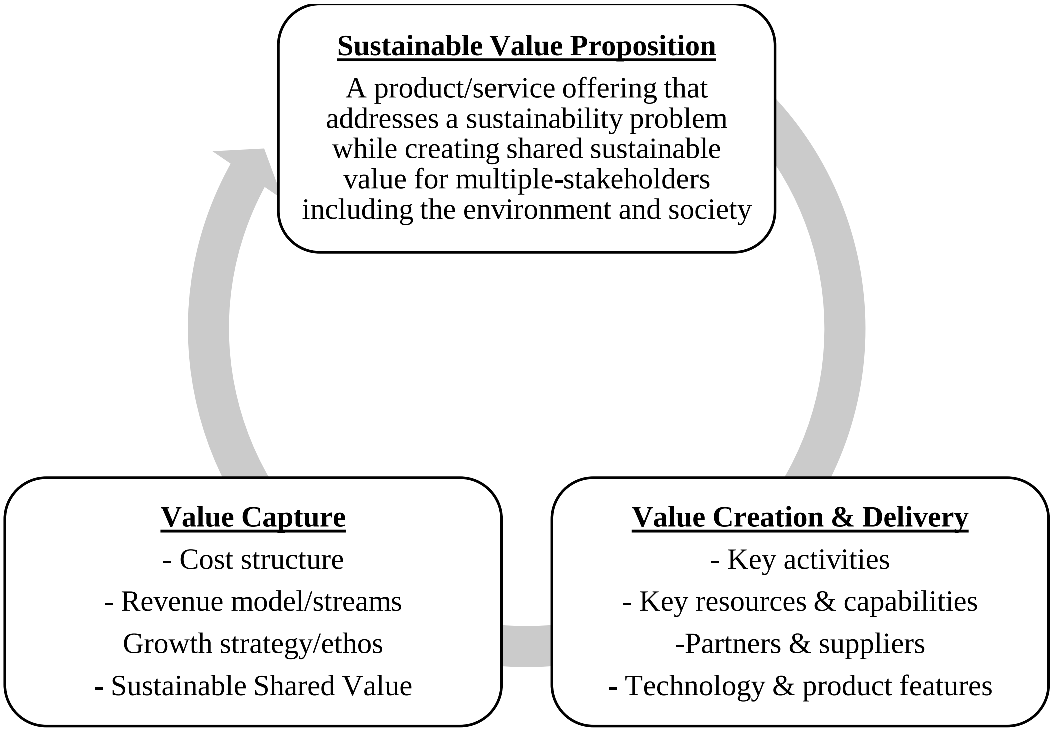

Figure 20 Updated conceptual sustainable business model framework (adapted from Baldassare et al., 2017; Bocken et al., 2015; Richardson, 2008)

7.7 Final remarks, limitations and future research directions

First of all, it must be pointed out that the presented, updated and proposed refreshing conceptual SBM framework is focused on the entire electric vehicle (EV) industry as a whole. Thus, future research needs to identify potential EV battery second use (B2U) business strategies towards sustainability such as the battery reuse and repair strategies that have been found to be in alignment with the principles of the circular economy. However, there has been significant criticism on the concept because environmental sustainability and economic systems are usually prioritized whereas the social sustainability dimension is only implicitly addressed that is an essential building block of SBMs (i.e. sustainable value creation) (Geissdoerfer, Savaget, Bocken, & Hultink, 2017; Murray, Skene, & Haynes, 2017). This is further demonstrated with recent findings from Ajmal, Khan, Hussain and Helo (2017) on social sustainability in the business context, concluding that managers must comprehend all the ‘multi-faceted indicators of sustainability’, or more broadly speaking sustainable development. Consequently, there is an urgent need for effective and practically feasible innovative sustainable business models (SBMs) that contribute towards corporate sustainable development. Such new business models must comprehend the complexity and difficulty that the different B2U sustainability business strategies are dependent on the objectives and interests of the specific stakeholder role in the value network (i.e. sustainable value is relative to each stakeholder). In this regard, the widely acknowledged sustainable business model (SBM) archetypes seem to be able to deliver a solution by harmonizing nine archetypes (i.e. business strategies towards sustainability) into environmental, social and economic major sustainable business model innovation types (Bocken et al. 2014; Bocken et al. 2016; Lüdeke-Freund, Massa, Bocken, Brent, & Musango, 2016). But, despite the widely acknowledged potential of these generic strategies to develop SBMs in theory and practice coupled with pressing global societal issues such as pollution and the need to address global scarcity of resources, they have not been accepted by industries (Despeisse, Yang, Evans, Ford, & Minshall, 2017). As an extra contribution of this study, this highlights the urgent need of further empirical case study work in the field in order to provide businesses with useful frameworks and practical methods that include a more holistic view of how to include the three metrics of sustainability into business innovation processes, eventually making a future sustainable transport system become reality.

This research contributes to identify sustainable business model (SBM) perspectives for the emerging electric vehicle (EV) battery second use (B2U) industry with the help of rich case study data (i.e. industry insights). First, critical opportunities and barriers for the EV B2U market to go forward have been identified. Further, in discovering valuable insights from the B2U stakeholder role sustainability related business activities, the necessity and occurrence of a SBM (and the three value elements) in the EV industry has been identified. In fact, the discussion highlighted and unearthed the appearance of a sustainable value proposition (SVP) that builds on the interrelated elements of shared value creation for a network of shareholders (including society and environment), addressing a sustainability problem and subsequently developing a product/service that is able to offer a solution. Therefore, a refreshing conceptual SBM framework is presented that includes and underlines the crucial importance of a sound SVP. This comprehensive framework can have substantial impact and significance on the business world as it may be adopted by companies to facilitate business model innovations towards functional corporate sustainable development. In turn, this will have direct implications for business managers, practitioners, policy makers that will have to reshape view on strategies and tactics in this market, whereas researchers will need to refresh and update their findings as this is an interdisciplinary effort that will revolutionize a whole business and its practices towards a sustainable future.

Therefore, this study aims to offer new and innovative ways of thinking about current unsustainable business practices in the EV industry and its underlying nascent B2U market and how new conceptual sustainable business model (SBM) perspectives can offer sustainable long-term business solutions. Such efforts towards new sustainable business model adoption are extremely important since companies are the engine of the global economy, and without their support, we cannot achieve sustainable development. This is why it was disinterred that innovative business models for B2U, which take a multi-stakeholder network centric business model design rather than firm-centric one as part of SBM approaches, may prove to be a viable business case for sustainability, significantly contributing to a sustainable transport system in the future.

Chapter 8

Sustainable business model archetypes for the electric vehicle battery second use industry: towards a conceptual framework

8.1 Motivation

This chapter examines the necessity and contribution of developing sustainable business models (SBMs) for the rapidly developing battery second use (B2U) market within the emerging electric vehicle (EV) industry. Previous work in this thesis identified that SBMs and EV B2U are emerging as major research streams but there is paucity among literature to deliver an overarching framework or a holistic view between these fields and highlight fresh areas for future research. The SBM archetypes were adopted as the major lens for our data analysis to study multiple cases of B2U stakeholder roles and comprehend further the scope and ultimate purpose of their operations. Last, this chapter proposes a conceptual sustainable innovation business model (SIBM) framework for the EV B2U industry that includes the in Chapter 7 identified EV B2U shared sustainable value creations which in turn drives forward business performance and sustainability at the same time, eventually creating the business case for sustainability within the EV industry.

8.2 Introduction

The sustainable innovation of electric vehicles (EVs) represents a promising alternative to address ongoing dependency on finite fossil fuels and associated serious societal concerns on climate change. Despite policy support from various governments, a mass-market uptake of EVs is still impeded, principally due to high costs of installed lithium-ion battery packs (LIBs), which represent the single largest cost item in the vehicle (IEA, 2019; Reinhardt et al., 2016). This is why the automotive industry urgently desires substantially reduced battery pack costs for EVs to become cost competitive to conventional gasoline cars (Reinhardt et al., 2019a). Among other promising mobility innovations, reusing retired EV batteries through the concept of Battery Second Use (B2U) has emerged. B2U significantly reduces resource cycles by increasing total LIB service life in less demanding applications in the stationary energy storage market (e.g. renewable energy integration), which in turn helps to build smart grid technologies and contribute towards a renewable energy infrastructure (Cready et al., 2003; Neubauer and Pesaran, 2011; Podias et al., 2018). With prospective EV market share, there will be millions of battery packs returned from their 1st in-vehicle life. Simultaneously, there is a trend towards renewable energy production, highlighting the growing necessity to establish suitable electrical storage capacities. Still, there seems to be a frustrating paradox. Integrating vast amounts of renewables is still interfered by the shortage of effective large-scale energy storage systems even though the concept of B2U could promote to unlock hidden value and utilities (Heymans et al., 2014).

A variety of EV companies have started initiating B2U pilot projects in collaboration with e.g. experts on the energy markets, recyclers and energy storage service & system providers to comprehend economic feasibilities and development of viable innovative business models. These reported B2U projects offer evidence that innovative multi-stakeholder cross-sectoral relationships between previously isolated industries are forming (Reinhardt et al., 2019b). These projects primarily serve to comprehend possible viable innovative business models, in fact some projects have already move to the commercial scale (Jiao and Evans, 2018). However, to date very few authors have examined the EV B2U market from a sustainable business model perspective. Recently, a comprehensive review article found that B2U can solve ongoing unsustainable practices in the EV industry, which in turn will lead to a faster EV market penetration and improvements of overall sustainability performance through increased and more sustainable business model (SBMs) perspectives (Reinhardt et al., 2019b). Yet, it remains to be unearthed how B2U stakeholders can innovate their novel product life extending strategies, which are in line with the principles of the circular economy, into innovative business models that contribute towards sustainability.

Relatedly, the concept of the circular economy has been identified as a "…popular approach to create sustainable business" (Tunn et al., 2018, p324). But there exists criticism that the circular economy is a rather wide and undefined research field because there are merely 'collection of vague and separate ideas' but no singular definition of the term has been reached (Korhonen et al., 2018). In fact, it was found that even though the concept of the circular economy prioritises environmental sustainability and the economic systems, the social dimensions are usually absent (Geissdoerfer et al., 2017; Murray et al., 2017; Sauvé et al., 2016). The emerging research field of sustainable business models (SBMs) seem to be able to overcome these concerns and to be a useful framework to create 'systems change' towards sustainability in organisations (Bocken et al., 2015). In this regard, the research focus among academics and business practitioners has been on the emerging major research field of sustainable business models (SBMs), which aim to systematically integrate sustainability into business (Bocken et al., 2014). SBMs have been defined as "…business models that incorporate pro-active multi-stakeholder management, the creation of monetary and non-monetary value for a broad range of stakeholders, and hold a long-term perspective (Geissdoerfer et al., 2018, p403). But, there is still a lot of work required to develop and adapt the occurrence of SBMs in practice (Tukker, 2015). Further, Evans et al. (2017) states that there is a paucity of empirical research on business model innovation (BMI) towards more SBMs as the lack of theoretical research is reflected in the scarce number of case studies and empirical analysis in the field.

This chapter aims to fill this knowledge gap in examining the necessity and contribution of developing a sustainable business model (SBM) for the rapidly developing battery second use (B2U) market within the emerging electric vehicle (EV) industry. We intend to gain knowledge through understanding how the electric vehicle (EV) industry and its underlying B2U market (and evolving stakeholders) undertake their business-related activities that are not only focused on economic profitability but also address wider social and environmental stakeholder value as part of SBM perspectives. These two streams are rapidly evolving, and its interconnection is still not extensively disinterred.

8.3 Towards new and more sustainable business models

Key authors (Chesbrough, 2010; Osterwalder et al., 2005; Osterwalder and Pigneur, 2002; Teece, 2010; Zott et al., 2011; Zott and Amit, 2008) have substantially contributed to the academic literature on business models. For the purpose this thesis and as previously outlined, business models are defined as "… the design or architecture of the value creation, delivery and capture mechanisms employed" (p.179). This study perceives business models by its three interrelated value elements (Figure 21). These are the value proposition (product/service offering and target customer segments and differentiation strategies), value creation and delivery (key activities, resources & capabilities, position in the value network) and value capture (revenue model and cost structure).

Business model innovation (BMI) is about organisations identifying new value propositions (and how to create, delivery and capture it) and has been widely acknowledged as the key to unlock the creation of sustainable business (Boons and Lüdeke-Freund, 2013). Accomplishing sustainability in business has become a central research area because companies are the productive resources of the global economy and without their backing, functional sustainable development cannot be realised. Subsequently and in order to respond to these persistent challenges, the United Nations (UN) have introduced the 2030 Agenda for Sustainable Development including its 17 Sustainable Development Goals (SDGs) and 169 targets to eliminate poverty and achieve global sustainable development by 2030 (United Nations Secretariat 2018). According to the World Economic Forum (2019) there has never been "…a more pressing need for a collaborative and multi-stakeholder approach to shared global problems" (Word Economic Forum 2019, p5).

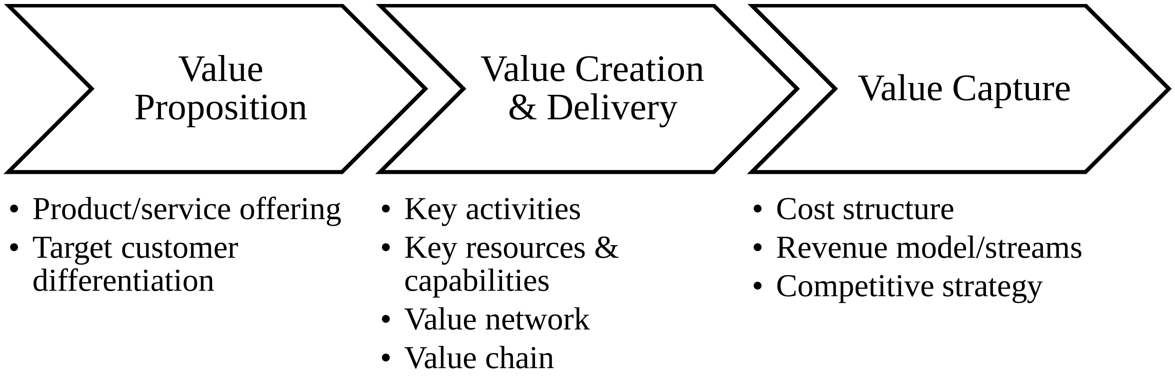

Figure 21 Business model framework (adapted from Bocken et al. 2014; Richardson 2008; Osterwalder & Pigneur 2005)

Considering the triple bottom line, the most known approach to advance sustainability integration into business practices, the emerging major research field of SBMs appear to offer a comprehensive solution as they incorporate the concept by acknowledging the environment and society as part of a wider stakeholder network (Bocken et al., 2014; Elkington, 1997). A SBM is defined as a business model for sustainability that "…helps describing, analysing, managing, and communicating (i) a company's sustainable value proposition to its customers, and all other stakeholders, (ii) how it creates and delivers this value, (iii) and how it captures economic value while maintaining or regenerating natural, social, and economic capital beyond its organizational boundaries" (Schaltegger et al., 2016, p3). Relatedly, at the core of any SBM is the sustainable value proposition (SVP) that has been defined as the "…promise on the economic, environmental and social benefits that a firm's offering delivers to customers and society at large, considering both short-term profits and long-term sustainability" (Patala et al., 2016, p144). Baldassare et al. (2017) introduced the SVP framework that is the result of a given sustainability problem, the resulting stakeholder network and developed product/service in the network that addresses this problem (Baldassarre et al., 2017).

However, existing available academic literature remains conceptual on SBM practical tool and framework development such as the value mapping tool (Bocken et al., 2013), sustainable value analysis tool (Yang et al., 2017, 2014, 2013), the flourishing canvas (Upward and Jones, 2016) and the triple layered business model canvas (Joyce and Paquin, 2016). These approaches and practical tools are rare among presently available research, yet they have been found to only focus on distinct phases of the innovation process (Geissdoerfer et al., 2016).

Against this background, Yip and Bocken (2018) identify SBMs as a type of 'sustainable innovation' as both concepts achieve a balance of "…competing and complementary interests of key stakeholders' segments, and contextually business sustainability should manifest as economic viability and contribute to both societal and environmental sustainability" (p151). We consider this notion of thinking as extremely important since there exists no clear consensus on defining the term 'sustainable innovation', further complicated due to the complexities around the terms 'sustainability' and 'sustainable development'. According to Arthur D. Little (2005) 'sustainability-driven innovation' is "…the creation of new market space, products and services or processes driven by social, environmental or sustainability issues" (p3). Building on the concept of business models and definition of eco-innovation set out in the review by Carrillo-hermosilla and Könnölä (2010), Boons et al. (2013) deliver a concise definition of sustainable innovation stating, "'innovation that improves sustainability performance', where such performance includes ecological, economic, and social criteria'" (p3). Thus, this chapter follows the argument from Yip and Bocken (2018) with the belief that the major emerging research field around SBMs highlights that any present or future innovation must include all sustainability dimensions. In any other case, it could be claimed that this is unethical and unmoral innovation, particularly considering the pressing needs for firms to achieve functional corporate sustainable development to tackle the ongoing global climate crisis.

8.3.1 A focus on the sustainable business model archetypes

The literature on SBMs further describes sub-categories, sub-types and generic strategies such as product service systems or base of the pyramid, which were examined in an extensive review by Bocken et al. (2014) and synthesized as the so-called 'sustainable business model archetypes' to develop a unifying research agenda. The emergence of the sustainable business model (SBM) archetypes or sometimes referred to as the SBM generic strategies, deliver a concise and unifying research agenda on types of major sustainable innovations that in turn leads to more SBMs (Bocken et al., 2014). The SBM archetypes present major orientations of diffusion of new and clean technologies, social innovations and organisational solutions that could contribute to building up the business model for sustainability while providing managers and practitioners with useful examples; hence Bocken et al. (2014) argues that "to tackle the pressing challenges of a sustainable future, innovations need to introduce change at the core of the business model to tackle unsustainability at its source rather than as an add- on to counter-act negative outcomes of business" (p44).

Recently, the archetypes have been further developed by Bocken et al. (2016) and Lüdeke-Freund et al. (2016) to include nine archetypes distributed to environmental, social and economic categories as the major innovation types derived from the concepts of sustainable development and the TBL approach (Table 14) (Ritala et al., 2018; Elkington, 1997). The archetypes are of immense value since they represent typical examples of solutions that contribute to establish SBMs in theory and practice. Ritala et al. (2018) emphasizes on the importance of the SBM archetypes stating, "…we expect this taxonomy to cover the most common instances of sustainable business activities, and therefore, it is an applicable tool to understand how sustainable business models are actually adopted" (p219). However, despite their momentous potential with emerging innovative solutions as it might be the case with EV B2U, and a noticeable call for action to tackle pressing issues such as pollution and resource scarcity, these generic SBM strategies have not been accepted by industries (Despeisse et al., 2017). Finally, it must be highlighted that this Chapter does not refer to cultural or decision-making archetypes but rather fundamental business models for companies. These categorizations are primordial and essential business models. They are the starting position that allows for later more complex business behaviour to emerge following the original formulation and thus this will be another contribution of this study.

Table 14 Overview of the sustainable business model archetypes (based on Bocken et al., 2014; Lüdeke-Freund et al., 2016; Ritala et al., 2018)

	Environmental			**Social**			**Economic**		
Archetypes	Maximise material & energy efficiency (1)	Closing resource loops (2)	Substitute with renewables and natural processes (3)	Deliver functionality, not ownership (4)	Adopt a steward-ship role (5)	Encourage sufficiency (6)	Repurpose for society/ environment (7)	Inclusive value creation (8)	Develop sustainable scale up solutions (9)
Definition	Do more with fewer resources Generate less waste, emissions, and pollution	Reuse materials and products. Turn waste into feedstocks for other products/ processes	Use of non-finite materials and energy sources.	Provide services that satisfy users' needs without their having to own physical products	Proactively engage with all stakeholders to ensure their long-term health and well-being	Solutions that actively seek to reduce end-user consumption	Seek to create positive value for all stakeholders, in particular society and environment	Sharing resources, knowledge, ownership, and wealth creation, inclusive value generation	Delivering sustainable solutions at a large scale to maximize benefits for society and the environment
Examples	Low-carbon manufacturing Lean manufacturing Additive manufacturing Low-carbon solutions Dematerialisation Increased functionality	Circular economy and closed loop Cradle-2-Cradle Industrial symbiosis Reuse, recycle, remanufacture Take-back management	Move from non-renewable to renewable energy sources Solar and wind power-based innovation Zero-emissions initiative Slow manufacturing	Product-oriented PSS-maintenance, extended warranty Use-oriented PSS-rental, lease, shared Result-oriented PSS-pay per use	Biodiversity protection Consumer care – promote consumer health and well-being Ethical trade (fair trade) Choice editing by retailers Radical transparency about environmental/societal impacts	Consumer education, communications and awareness Demand management Slow fashion Product longevity Premium branding/limited availability Frugal business	Not for profit Hybrid business, social enterprise (for profit) Alternative ownership; cooperative, mutual, collectives Social and biodiversity regeneration initiatives	Collaborative approaches (sourcing, production, lobbying Peer-to-peer sharing Inclusive innovation Base of pyramid (BoP) solutions	Incubators and entrepreneur- support models Open innovation (platforms) Patient/slow capital Impact investing/capital Crowdsourcing/funding Peer-to-peer lending

8.4 Methods

Due to the lack of empirical research on sustainable business model (SBM) occurrence in the electric vehicle (EV) battery second use (B2U) industry, a qualitative and exploratory research approach was adopted (Eisenhardt, 1989). As this research focuses on an area of knowledge where little is understood, an analytic inductive theory development approach with the help of semi-structured case study interviews was adopted (Figure 22) (Saunders, 2017).

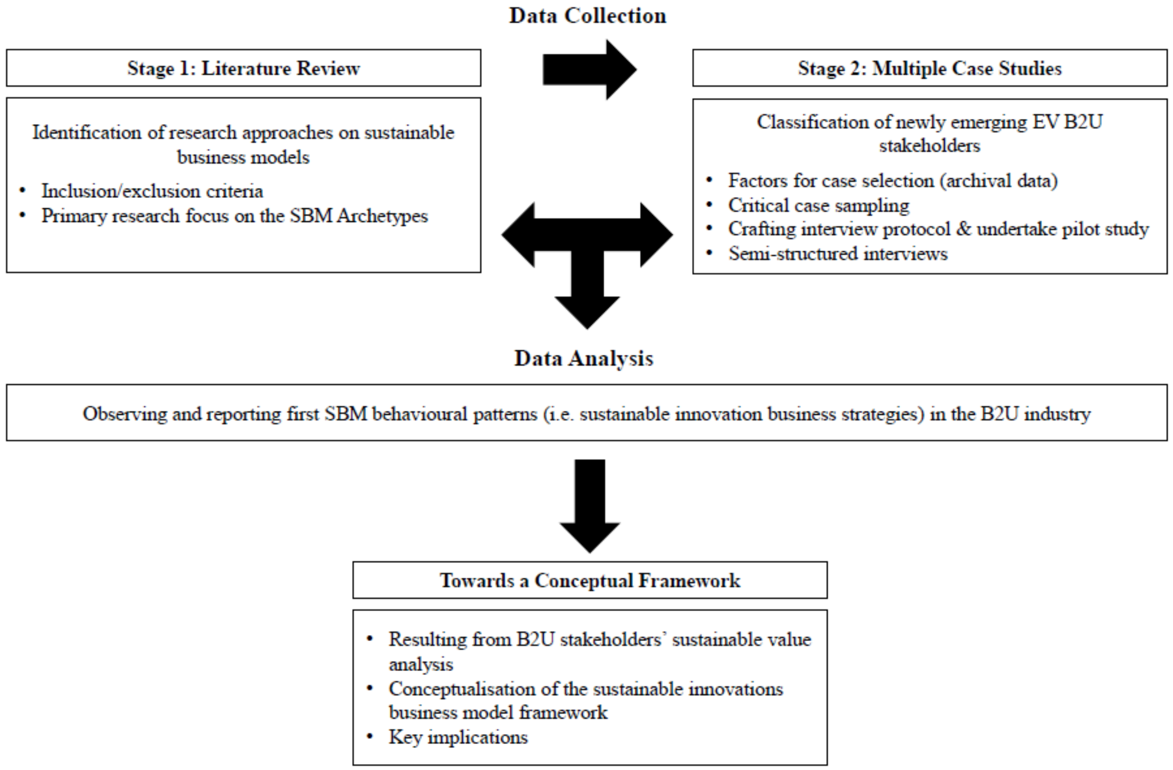

Figure 22 Research approach

8.4.1 Data Collection

This study first briefly reviews relevant literature on the developing research field of SBMs with the SBM archetypes emerging as a useful and key lens for data analysis of our case samples. Data were collected from peer-reviewed literature on SBMs through searching the academic databases of Web of Science and Scopus with a combination of the keywords of “sustainable business model” and “business models for sustainability” only. Subsequently, we applied previously identified inclusion and exclusion criteria to the literature set (Table 15).

In the second stage, fourteen semi-structured interviews were carried out with stakeholders in the emerging EV B2U industry to identify their current practices, views and experiences. The application of the multiple-case study research strategy fits particularly well for this study to comprehend the activities taking place in the context of the different stakeholders involved and business models deployed. Further, multiple-case study research , where the focus is within and across cases, underlies the logic of replication and has been found to be superior to single case study approaches as the evidence from the multiple cases is considered more compelling and overall study is regarded as more robust (Yin, 1994).

Table 15 Inclusion and exclusion criteria of literature search

Included	Excluded
Studies with a primary research focus on sustainable business models, sustainable business model innovation and sustainable business model archetypes	Studies with a distinct focus on sub-categories, sub-fields etc of sustainable business models such as circular business models, circular business model innovation, circular economy, eco-innovation, resource efficiency, sustainable resource management, sustainable consumption and production (etc.)
Type of study: peer reviewed journal articles, conference papers and book chapters	Type of study: non-peer reviewed journal articles, theses/dissertations and reports

As the B2U market is still in its very early stages, it is difficult to estimate and identify the exact number of emerging stakeholders over short amount of time. Therefore, we searched available archival data (e.g. company releases, news bulletins and press releases), which were all screened under the inclusion criteria of relating to the emerging B2U market and correlated innovative stakeholder activities (Yin, 2011). Given the diversity and exact classification of all stakeholders involved in the emerging B2U industry, their roles, experiences, and world views vary. Therefore, this study applied the sampling technique of critical cases, which "…involves identifying criteria in advance that distinguish cases from others that make up the majority of a population and using those criteria to select cases" (Lee and Saunders, 2017, p85). The criteria selected for this study include those stakeholders (i.e. companies) that are participating in the evolving B2U industry through adapting (innovative) business models. As the majority of stakeholder engagement in the nascent B2U industry is classified through pilot projects with only a few projects having moved to early commercialisation stages, both have been considered for this study. Given the problem of dearth of data in determining all participating stakeholders in this innovative and disrupting industry, we have decided to further include EV B2U research experts in your sample to expand the perspective on the topic (Table 16). The rigorous scientific method of data triangulation was applied for this study through multiple data collection sources, tackling single sources bias and thus leading to an improved research credibility and dependability (Seale, 1999)

Furthermore, a comprehensive state-of-the art study on the concept of B2U from Martinez-Laserna et al. (2018) underlined that "…additionally, it needs to be pointed out that, to date, automotive OEMs or ESS integrators were barely involved in battery second use research publications" (p.713). Hence, we attempt to deliver such novel perspectives on the B2U industry through synthesizing results from the previously isolated automotive and energy markets, which are now entering into business agreements.

This study was conducted between September 2018 – March 2019. Most interviews were conducted with managers and chief executive officers (CEOs) and lasted between 60-120 minutes (min). The interview started with an introduction to the interviewer, brief contextual research background, previous research results on the topic and objectives of this research study. During the interview questions were asked and discussed that related to the rapidly developing EV market, the emerging topic of B2U and its correlation to the EV sector, the company's involvement in B2U projects and innovative sustainable business model perspectives for B2U.

8.4.2 Data analysis

Since the interviews were the primary technique of the data collection, it was important to be aware of the kind of the data analysis in the earlier stages, where the unit of analysis is the business model and sustainability-related business strategies of our case samples. Following the methodological procedure as set out by Leising et al. (2018), the stakeholder cases were analysed thematically through a document study as well as qualitative content analysis of all interview transcripts. The analysis was primarily based on the criteria and categories developed from our literature review on sustainable business models (SBMs), in particular the deriving importance of the SBM archetypes. Thus, mainly knowledge from the previously discussed SBM archetypes was integrated and used as a lens for qualitative data content analysis to classify B2U stakeholder sustainable business innovation related activities into a suitable and comprehensive set of SBM B2U archetypes and resulting sustainable value analysis. In doing so, the most recently updated SBM archetypes were used (Table 14) to investigate and structure current and prospective (sustainable business models) in our case samples. Consequently, first the importance and definitions of SBM Archetypes are highlighted, their occurrence in relation to the given case samples is identified and discussed and finally the key contribution of this Chapter is presented, the conceptual sustainable innovation business model (SIBM) framework for the emerging EV B2U industry and related stakeholders.

Table 16 Battery second use stakeholder cases

Case	Stakeholder Role	Position of interviewee	Location	Length and type of interview
1	EV manufacturer	Manager	France	About 60 min on the phone
1	EV manufacturer	Manager	Germany	About 45 min on the phone
1	EV manufacturer	Manager	South Korea	About 90 min on the phone
1	EV manufacturer	Manager	Spain	About 60 min on the phone
2	Energy storage/B2U service & system provider	CEO	United Kingdom	About 60 min on the phone
2	Energy storage/B2U service & system provider	Manager	USA	About 60 min on the phone
2	Energy storage/B2U service provider	Manager	Spain	About 45 min on the phone
2	Energy storage/B2U service provider	CEO & Founder	United Kingdom	About 90 min on the phone
3	Battery Lifecycle Management	CEO & Founder	Australia	About 90 min on the phone
4	Battery recycler	Manager	Germany	About 45 min on the phone
4	Battery recycler	Manager	Belgium	About 30 min on the phone
5	B2U Expert (Research)	Manager	Spain	About 120 min in-person interview
5	B2U Expert (Research)	Post Doc Researcher	Spain	About 90 min in-person interview
5	B2U Expert (Analyst)	Research Analyst	United Kingdom	About 60 min on the phone

8.5 Results

This section presents the identification of the SBM archetypes for the B2U stakeholder case samples and their associated B2U industry sustainability-related business activities and resulting value analysis (Table 2 – 5).

8.5.1 Case 1: EV manufacturers

Following interviews within Case 1, a combination of SBM archetypes occurrence has been identified (Table 17). It was further confirmed that B2U is a dominant cost-effective solution that could lead to additional revenue generation for EV manufacturers (Jiao & Evans, 2016a). Thus, EV companies would be able to lower their vehicle prices, making this innovative technology more competitive and attractive towards the global mass market.

The resulting and new value proposition is thus mainly centred on slowing and closing resource loops – archetype (2) – as previously considered EV waste batteries are reused in less demanding applications in the energy storage market. This directly leads to the identification of archetype (1) as the engagement in B2U activities has the positive impact of eliminating previously perceive waste that is no reused in new applications. In addition, archetype (4) has been identified as it is based on the literature of product service systems (PSS), which in essence is about shifting from offering products towards pure service driven business models (Tukker and Tischner, 2006). Considering that some of the interviewed EV companies are already offering battery leasing agreements to their customers, highlights the incremental shift to such business models.

As EV companies are the physical owners of the battery packs, the value creation & delivery is focused on activities and new partnerships and value network configurations. This has been confirmed in the set of multiple interviews since all of the interviewed EV companies are engaging in cross-industry multi-stakeholder partnerships to evaluate the full value of second life batteries. The value capture is centred on less resource use and thus aims at positive impacts on society and the environment. Therefore, the combination of identified SBM archetypes delivers a variety of positive impacts on this new and more sustainable business model, which are cost savings through enhanced efficiency and improved resource use, previously considered waste is turned into new value and thus new avenues of revenue streams and the potential to trigger an industry wide change for industrial sustainability.

Table 17 Identified SBM archetype(s) Case 1

SBM archetype	Value proposition	Value creation & delivery	Value capture
Maximise materials & energy efficiency (1)	Fewer use of resources, generate less waste and emissions than product/services that deliver same functionality	Activities and partnerships to reduce resource use with a focus on product and manufacturing process innovations, new partnerships and value network reconfigurations	Environmental value: Substantially reduced costs through optimised resource use Positive impact on environment and society through minimised environmental footprint

Closing resource loops (2)	Previously thought waste is eliminated and reused in a new application through life-cycle based approach	Activities and partnerships to eliminate life cycle waste Close material loops New partnerships, potentially across industries (e.g. with recycling companies)	Reduced costs through reuse/second use Positive impact on environment and society through minimised environmental footprint & extended producer responsibility
Deliver functionality, not ownership (4)	Services that satisfy customer's need without the need to physically own product as part of B2U ESS (pay per use/rental/lease/buy)	Delivery through product/service offerings that require significant changes to the firm New partnerships to deliver holistic solutions	Social value: support sustainability-related behaviour among customers and suppliers Decrease necessity to own physical good Market expansion: more consumers likely to pay for the service
Inclusive value creation (8)	Innovative collaborative cross-sectoral multi-stakeholder platform (B2U industry)	Sharing resources, knowledge, ownership, and distributed wealth creation. Inclusive value generation	Economic value: Major new business opportunities Leverage resources, time and talents

8.5.2 Case 2: Energy storage/B2U service & systems providers

With regards to Case 2, a combination of three archetypes was identified (Table 18). As the concept of B2U employs used EV batteries cost-effectively in ESS, the energy markets are highly interested in such alternative revenue streams. This results in a value proposition that is primarily focused on reducing negative impacts on environment and society – archetype (3) – through the use of increased renewable energy sources as a viable solution. From similar importance is the occurrence of archetype (4) as companies within Case 2 are the expert on the energy storage markets and are marketing B2U within ESS towards final customers (through pay per use/rental/lease/buy).

The resulting value creation & delivery is principally based around product/process innovations as it is the case with B2U. Most of the interviewed stakeholders in this sample have confirmed that such 'breakthrough innovations' avenues must be undertaken to effectively deploy second life batteries in the storage sector. New cross-industry partnerships are necessary to trigger such change and the creation of environmental and social benefits. In fact, companies within Case 2 have engaged in business model agreements with OEMs but at different scales such as standard business model (sell/buy batteries) or collaborative business models (share expertise, knowledge and resource).

Lastly, the value capture mainly refers to reducing finite resources, waste and pollution while capturing environmental value through increased renewable energy use. This in turn leads to major new business opportunities within the energy storage markets, which are predicted to grow substantially over the next few decades.

Table 18 Identified SBM archetype(s) Case 2

SBM archetype	Value proposition	Value creation & delivery	Value capture
Substitute with renewables and natural processes (3)	Use of non-finite materials and energy sources (B2U in storage systems)	Product/process innovation by introduction renewable energy sources (innovative B2U products/services) New partnerships to deliver holistic solutions	Environmental value: less resource use, reduce emissions related to non-renewables (fossil fuels)
Deliver functionality, not ownership (4)	Services that satisfy customer's need without the need to physically own product as part of B2U ESS (pay per use/rental/lease/buy)	Delivery through product/service offerings that require significant changes to the firm New partnerships to deliver holistic solutions	Social value: support sustainability-related behaviour among customers and suppliers Decrease necessity to own physical good Market expansion: more consumers likely to pay for the service
Inclusive value creation (8)	Innovative collaborative cross-sectoral multi-stakeholder platform (B2U industry)	Sharing resources, knowledge, ownership, and distributed wealth creation. Inclusive value generation	Economic value: Major new business opportunities Leverage resources, time and talents

8.5.3 Case 3: Battery Lifecycle Management

For Case 3, archetype (9) has been identified (Table 20). This came as no surprise since this stakeholder is a unique battery control technology specialist start-up developing advanced solutions around lifetime-extending battery management system (BMS) technologies for EV batteries. This system reduces the upfront costs of batteries by 30% through recycling the ‘best’ cells within degraded EV batteries and connecting them with smart technology that extends overall lifetime and sustainability.

The resulting value proposition is focused around scaling up the company from start-up to large scale to maximise sustainable value benefits, that in turn can create an industry wide change for sustainability by e.g. creating breakthrough innovations. In fact, the stakeholder of Case 3 has been named as one of the top 15 start-ups globally, because the company demonstrated to realise capable, long-lived, and cost-effective storage in residential and commercial & industrial B2U applications. As a result, the value creation & delivery systems are focused on securing partnerships and investments, including unusual relationships with e.g. governments, to scale up the business. Last, the vale capture is around receiving viable fees (profits) for scaling up a potential breakthrough innovation in the global energy market.

Table 19 Identified SBM archetype(s) Case 3

SBM archetype	Value proposition	Value creation & delivery	Value capture
Develop sustainable scale up solutions (9)	Unlock substantially extended lifetime and performance of EV batteries through BMS technology Sustainability solution to maximise benefits for society, environment but also economy	Partnerships with potential and unusual partners (e.g. government) and other organisations crucial to scale the business	Economic value: Achieve scale: from start-up to large scale project Ensuring a viable fee is paid for scaling up the solution/venture Potential breakthrough innovation

8.5.4 Case 4: Recyclers

In evaluating interview data from Case 4, it seems that none of the SBM archetypes can be related and identified. It appears that recyclers have no strong interest in the direct participation of an emerging B2U market but highlighted their interest in battery recycling (after 2nd or even 3rd EV battery life) to produce battery active materials. It appears that recyclers are merely ‘participating’ in the emerging B2U market and potential joint ventures agreements as a result of the ongoing unsustainable but economically viable battery recycling processes (value proposition). The interviews have confirmed that recyclers are not directly involved in B2U as they have no ambitions to assess batteries for functional refurbishment (i.e. second life applications). This raises the major sustainability concern to whether recyclers are actively engaging in sustainable innovation approaches at all in the B2U markets. In fact, we would argue that recycling LIBs remains immature and expensive, clearly underlining the importance of moving drastically towards integrating the concept of B2U. At this point, we argue that such business activities can be related to the entire business eco-system and conclude that there appears to be a lack of willingness towards functional corporate sustainable development in the EV sector. At this point we conclude that it is likely that other companies with newly emerging innovative SBMs will attempt to offer increased radical sustainable circular recycling solutions as part of collaborative joint ventures.

8.5.5 Case 5: B2U Research Experts

Data from Case 5 confirmed our previous notion on including B2U research experts in our sample. The concept of B2U and its relation to SBM perspectives remain relatively unexplored in the global scientific community. Thus, there are very limited number of global B2U experts and researchers available. We feel that such experts and researchers are crucial to be included in prospective SBM modelling process since their value proposition includes benefits to all stakeholders by engaging with the ‘full story’ (e.g. the concept of B2U contributes to business models for the circular economy or functional corporate sustainable development). This leads to a value creation & delivery system, which includes pioneering research activities in the field through international partnerships and collaborations both, in academia and industry. The direct results are valuable implications for policy makers, practitioners and business managers. Therefore, the value capture focuses on securing increased project and research funding based on scientific contributions and relevancy for industry. This will result in positive impacts such as to achieve long-term viability of the value network (Lüdeke-Freund et al., 2016). Further, there are associated important benefits to society as innovative studies on B2U and SBMs address contemporary major concerns: move towards a sustainable transport and energy system as soon as possible.

Table 20 Identified SBM archetype(s) Case 5

SBM archetype	Value proposition	Value creation & delivery	Value capture
Adapt a steward-ship role (5)	Benefits to all stakeholders (through academia) by engaging with the ‘full story’	Research activities through international partnerships & collaborations with leading experts in the field	Social value: Innovative studies and resulting solutions on urgent sustainability problems Increased Project Funding

in the field without breaching conflict of interests

8.6 Towards a conceptual framework

This is the major theoretical contribution of this article. The purpose of this paper was to examine the inevitability of developing sustainable business models (SBMs) for the rapidly developing battery second use (B2U) market within the emerging electric vehicle (EV) industry. To our great surprise we found that there is a lack of agreed concepts and frameworks that support sustainable business model innovation in the context of prospective functional corporate sustainable development. In synthesizing and building upon previously discussed literature and key results from our case analyses, this study proposes a conceptual sustainable innovations business model (SIBM) framework in order to facilitate participating B2U stakeholders to maximise shared sustainable value of degraded EV batteries through identifying major sustainable innovation strategies as part of innovative and more effective SBMs (Figure 3). This realisation and contribution alone, offers a range of important practical advice for managers and policy makers.

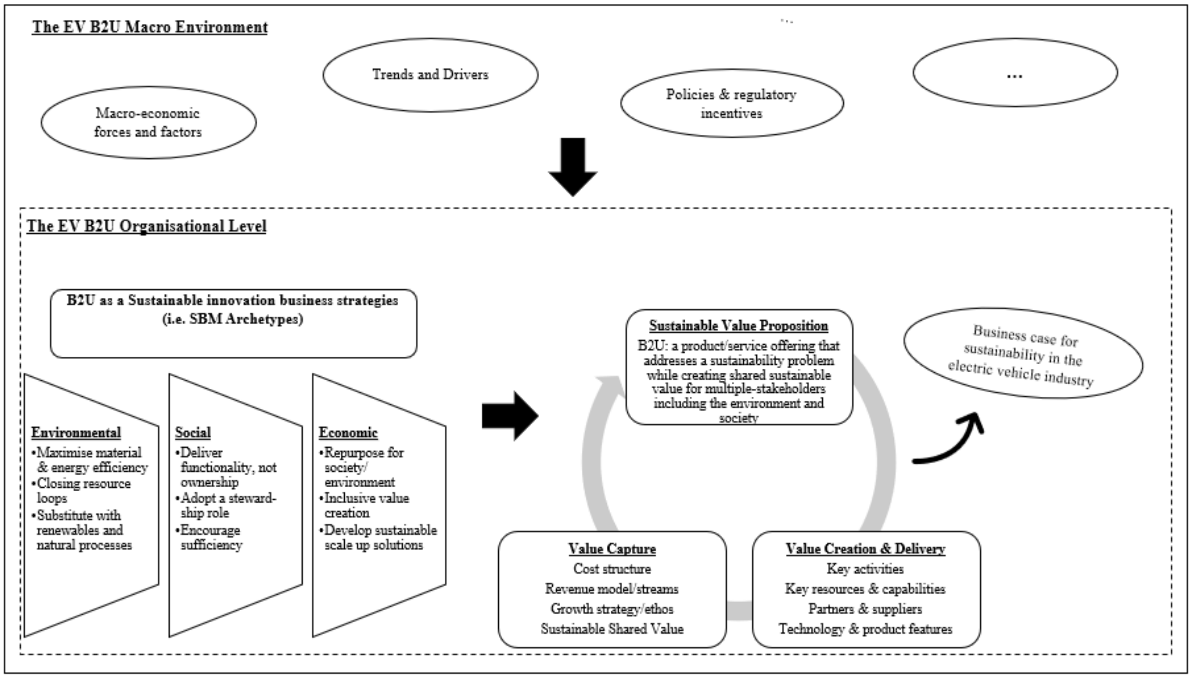

Figure 23 Conceptual sustainable innovation business model framework (based on and developed from Richardson, 2008; Bocken et al., 2014;2015; 2016; Lüdeke-Freund et al., 2016; Baldassare et al., 2017; Ratala et al., 2018)

Furthermore, the particular model includes major findings on the EV B2U macro environment (Reinhardt et al., 2017, 2016; Fischaber et al., 2016), as well as the impact of the SBM archetypes (as major sustainability innovations) on the organisational level towards establishing more and new SBMs. This is from great importance since adopting SBMs requires to integrate key macro and micro levels. In comprehending SBM archetype(s) occurrence and impacts in our case samples, we were able to draw an innovative sustainable business model that includes sustainable value propositions (Baldassare et al., 2017; Bocken et al., 2016). Thus, our framework informs that the SBM archetypes are a type of major sustainable innovations that drives sustainable value along the entire sustainable business model. Ultimately, this could then build the business case for sustainability within the emerging EV B2U industry. Our study attempts to deliver major implications to scholars and practitioners by opening up a major discussion on SBM adoption in practice with the help of rich in-depth interview data from EV B2U stakeholders. We invite further research, contributions and criticism on our work that we believe create a new research pathway with clear implications for the economy, environment and society. Through reporting first SBM behavioural patterns in the B2U industry, this study facilitates practitioners and managers in moving from theoretical to practical industrial sustainability as part of novel SBM approaches.

8.7 Discussion and contributions

There is strong evidence that participating stakeholders in the emerging B2U market have started to engage in various forms of sustainable value creation activities. This has become an integral part of their innovative sustainable business processes (i.e. SBM archetypes) within the emerging B2U industry that was not up until now clearly understood and emphasized. In other words, the application of degraded EV batteries at low cost in less demanding stationary storage systems in the energy markets seems to be now a key activity that is both sustainable from multi-stakeholder perspective and profitable. Understanding and practising a particular type of SBM archetype is a key strategic element in the business model of the major competitors within the B2U industry. This was, up until now, an underlying important link in the success and sustainability of these competitors but not unearthed, conceptualised and fully explored.

Further proof from our data demonstrates surprising differences in SBM archetype identification and occurrence among B2U stakeholder activities and resulting sustainable value(s) (Table 21). Our case samples provide key insights that there appears to be the existence of either none of the SBM archetype(s), a combination within one sustainable innovation archetype (e.g. environmental innovation) or the existence of all sustainable innovation archetypes.

Table 21 Overview of dominant SBM archetype(s) and resulting sustainable value

Case	Environmental Value	Social Value	Economic Value
1	✓	✓	✓
2	✓	✓	✓
3			✓
4		n/a	
5		✓	

Most notably, it was unearthed that EV companies and energy storage/B2U service & system providers appear to innovate at all three SBM archetype levels that are environmental, social and economic sustainable innovation business strategies.

Both stakeholders have an immense interest in the success of a potential B2U market as cheap batteries are becoming available for the energy markets while EV companies can generate additional revenues that in turn could lower total vehicle prices and overall sustainability performance. Therefore, it becomes comprehensible that the archetype of ‘inclusive value creation’ mainly occurs within Case 1 and 2. According to Reinhardt et al. (2019b), the emerging B2U industry has the potential to disrupt and revolutionize current landscapes of the automotive and energy sectors as reusing LIB batteries through B2U embodies the most cost-effective electricity storage solution available today. On the other hand, Case 3 and Cas 5 have engaged in economic and social sustainable innovations respectively. Yet, innovating at ‘merely’ one major archetype still has the ability to connect positively to more SBMs and positively create synergistic value. This value is respectively disseminated to different stakeholders and has a beneficial effect to society, environment and economy. The particular realisation is further supported by Lüdeke-Freund et al. (2016) stating, “…indeed, every single archetype can contribute to sustainable development, but their potential effects will be more powerful if they are combined” (p57).

In fact, the occurrence of one or a combination of more than one archetype, still has the same effect of creating (dominant) sustainable value, that in turn leads to a new and more SBMs where sustainable value is driven along the entire model. This is confirmed by relating the observed B2U industry activities to the recently proposed sustainable value proposition (SVP) framework. The SVP framework is not only a key contribution to theorists since it is based on the key interrelated elements of shared sustainable value creation for a network of shareholders. At the same time, it provides major implications for practitioners, addressing the sustainability problem and consequently developing a product/service as a solution to a much-needed sustainability equilibrium between natural resources and societal/economic prosperity (Baldassare et al., 2017).

8.8 Final remarks

The goal of this chapter was to contribute to the literature on sustainable business model (SBM) perspectives for the emerging battery second use (B2U) industry within the rapidly evolving electric vehicle (EV) industry.

Major results from our case samples indicate that there is evidence that participating stakeholders in the emerging B2U market have started to engage in some form of sustainable value creation activities as part of their innovative sustainable business processes (i.e. SBM archetypes). In fact, it was unearthed that either none, singular or a combination of the SBM archetypes are occurring within EV B2U sustainability business-related activities.

Finally, and as a direct result from our analysis, we propose a conceptual framework that captures such sustainable innovation business model strategies towards achieving more sustainable business models in practice. These could ultimately result in increased industrial sustainability in the EV industry. In addition, we argue that the concept of B2U might prove itself to be an exemplary case of how SBMs can be implemented in practice through adapting the widely acknowledged but not by industry accepted SBM archetypes for analysis.

However, as a result of the explorative research context, there can be some limitations to this study that must be acknowledged. First, this study and its resulting SIBM framework have only been applied to the EV B2U industry. Furthermore, at this point it is extremely difficult to estimate the exact size and number of emerging B2U stakeholders as the industry is still emerging and hence there is the issue of limited data availability and dearth of data. The SBM archetypes have been developed with a focus on the manufacturing industry and follow up studies have adapted the archetypes to e.g. banking industry. This raises another limitation since our study is focused on the B2U industry. However, this is an innovative forming market that brings together cross-sectoral stakeholders. Thus, this limitation is up to debate to some degree since it creates the space for further research and more creative efforts to fill gaps and links between the particular approach and current practices. Future studies shall evaluate further empirical case study research that contributes to identifying SBM occurrence and adaption by specific industries.

All things considered, we believe that this is an interdisciplinary effort that will revolutionise a whole business and its practises towards a sustainable future. Managerial implications reshape the way managers view strategies and tactics in this market, whereas we challenge current theoretical perspectives with fresh insights and new research streams on sustainable business model (SBM) adoption in the rapidly emerging EV B2U industry.

Chapter 9

Conclusions

9.1 Concluding remarks

This chapter presents the overall concluding remarks of this doctoral dissertation entitled ‘Sustainable business model perspectives for the electric vehicle industry: the case of battery second use’ addresses economic. This dissertation addressed societal, environmental, and business aspects of strategies as part of SBMs approaches to improve the sustainability, recovery, and productivity of resource use of EV waste batteries in B2U applications.

The first conclusion is that the overall resource efficiency and productivity of EV waste batteries is increased through suggesting the sustainable environmental management alternative of B2U. This directly leads to an increased sustainable use of environmental resources through a substitution of primary resources and raw materials by delaying the final recycling phase by up to 20 years as well as implicates technological, societal, environmental, and economic changes as part of prospective innovative SBMs. B2U increases the residual value of EV batteries leading towards a faster global market uptake of EVs and improvements of overall sustainability performance through SBM perspectives.

The macro environmental analysis revealed that with a prospective EV market uptake, increasing numbers of retired batteries will be available soon for battery second use (B2U). However, major results showed that this emerging secondary market remains unclear from a (sustainable) business model perspective through attempting to identify first key opportunities and threats. Without a doubt, EVs are one promising alternative towards a low carbon electric mobility future with less dependency on fossil fuels. The European Union automotive industry is a global leader but there currently exists no single EV targeted legislation that encourages the uptake of these sustainable technologies. In particular, the second use of degraded electric vehicle batteries in energy storage systems represents emerging economic and environmental opportunities as well as legal concerns that need to be addressed and managed in a timely manner. Hence, a more efficient regulatory framework in place will further increase the integration of renewable energy sources into the power system while at the same time creating a level playing field for an electric mobility transition in the European Union.

It was further unearthed that B2U can ease or even solve current unsustainable issues in the EV industry as part of innovative SBM approaches. Further, findings reveal that B2U can trigger the development of SBMs through the establishment of cross-sector, innovative, multi-stakeholder relationships. This is particularly relevant for the previously isolated automotive and energy markets that are now investigating the full potential of second life batteries and hence new business opportunities. Therefore, a conceptual B2U innovative business model framework is suggested that records and explains the stakeholder relationships as an innovative and forming phenomenon, as well as opens new roads for future discussion among researchers and practitioners. Therefore, it was discovered that prospective innovative business models for B2U, which take a multi-stakeholder network centric business model design rather than firm-centric one, may prove to be a viable business case for sustainability.

It was further exposed and confirmed that the emerging B2U industry is in fact far away from establishing market forms or mature business models as critical market uptake barriers and opportunities remain. Further, the importance of a sound sustainable value proposition (SVP) was identified and highlighted; that has been grounded on the three key interrelated building blocks of shared value creation for a network of shareholders, addressing a sustainability problem and collaboratively developing a product/service that offers a sustainable solution. Therefore, a refreshing conceptual sustainable business model (SBM) framework for battery second use (B2U) is suggested.

This dissertation further explored evidences from B2U stakeholder sustainability related business activities and adopted the SBM archetypes as the major lens for data analysis to study multiple cases of B2U stakeholder roles and comprehend further the scope and ultimate purpose of their operations. Major results indicate that the SBM archetypes as major sustainable innovation strategies have the potential to create a new conception of business models for sustainability in the EV B2U market. Additionally, although profitability is a key priority, it does not seem to be number one anymore. This is an element that confirms a new market perspective towards a sustainable circular economy in the EV industry. In turn, this creates, and drives shared sustainable value for multiple stakeholders through cross-sectoral collaborations as part of an entire new and more SBM.

Finally, this thesis proposes a conceptual sustainable innovation business model (SIBM) framework for the EV B2U industry that includes such shared sustainable value creations which in turn drives forward business performance and sustainability at the same time. Therefore, this thesis concludes that the concept of B2U has proved itself to be an exemplary case of how new and more sustainable business models (SBMs) can be implemented in practice.

9.2 Contributions

This PhD thesis provides several contributions in the form of knowledge and theory to the literature on sustainable business model innovation through an empirical investigation of the EV battery EOL strategy of B2U and the interaction with SBM perspectives. Every chapter, being a published paper, provides a detailed view of the contributions made to theorists and practitioners. In this concluding part, only a brief summary of the most important contributions that stem from the overall thesis are presented. It is thus advisable for the reader to seek further details in the particular contributions subchapters.

First, this doctoral dissertation contributes by offering new and innovative ways of thinking about current unsustainable business practices in the EV industry and its underlying nascent B2U market and how new conceptual sustainable business model (SBM) perspectives can offer sustainable long-term business solutions. The main theoretical contribution of this thesis lies in providing a novel understanding of how SBMs in the emerging B2U market can be achieved by the creation of cross-sectoral multi-stakeholder network centric business model designs instead of using traditional firm-centric models.

Furthermore, this dissertation aims to advance in this gap of knowledge by proposing a theory and practice-based framework to support companies towards more SBMs in the context of the nascent EV B2U market. This thesis is among the first works to identify and confirm a SBM for an emerging industry as it is the case with B2U. Therefore, one key conclusion is that the concept of B2U might prove itself to be an exemplary case of how SBMs can be implemented in practice. This will have implications for business managers, researchers and policy makers by creating a paradigm for future discussions as this interdisciplinary effort can revolutionize a whole business and its practices towards a sustainable transport sector in the future.

9.2.1 Implications for practitioners

The major results presented in this doctoral dissertation can facilitate organisations to identify possible sustainable innovation business model strategies that contribute to increased functional corporate sustainable development. In particular, and in the context of the EV B2U industry, this dissertation shows that through reusing degraded EV batteries, exemplary SBMs can be and are implemented in practice. Practitioners could benefit from the important gaps in knowledge and resulting key findings of this thesis since it will assist companies to challenge existing ‘business-as-usual’ practices and encourage to adapt and strive for more and new SBMs.

9.2.2 Implications for theorists

This doctoral dissertation enhances inter-disciplinary research with significance for theorists. Major findings of this doctoral dissertation can be used by other academics and fellow researchers. Most notably, this dissertation deals with very trending and contemporary inter-disciplinary research topics: SBMs and EV B2U. Results and frameworks presented in this thesis can be used by other academics to create a common ground for understanding how SBMs can be adapted by emerging industries as it is the case with EV B2U. Therefore, this dissertation and related scientific publications and presented innovative frameworks and ideas, will lead to an interesting debate within academia as the intercorrelation between both research areas are very novel and under researched.

9.3 Recommendations for future research

Overall findings of this doctoral dissertation contribute to comprehend SBM adoption by industries, namely the EV B2U market. This thesis opened up a new inter-disciplinary stream of research on innovative sustainable business models for EV B2U. In fact, the resulting published works of this thesis have been presented at conferences, workshops and publishers. Feedback has been immense as experts in the field confirmed that this is indeed an upcoming and crucial research streams to comprehend how SBMs can implemented in practice. The following are major research areas for future works as both research streams, SBMs and B2U, are still emerging as major new research avenues:

- Increased research efforts on sustainable business model (SBM) theory, frameworks, methods and tools
- Impact studies on SBM occurrence and adoption by other industries
- More research efforts on SBMs for EV B2U markets (including newly emerging stakeholders, types of identified SBMs etc)
- Future fit, system paradigm studies (e.g. Back-casting) that evaluate EV B2U future market viability and potential under the umbrella of a functional circular economy and corporate sustainable development

Overall, as the author of the particular thesis, I would like to thank the reader for taking the time to dive into my research. I did enjoy following my passion investigating the particular topic. Through this original effort, I hope that I managed to create a considerable impact on the field of SBMs for emerging industries as it is the case with EV B2U and that more research will follow igniting a new research stream.

Thank you very much.

References

ABB (2012) GM and ABB demonstrate Chevrolet Volt battery reuse – world's first use of electric vehicle batteries for homes. [online]. Available from: http://www.abb.com/cawp/seitp202/8cb38a9d23816174c1257ab500497848.aspx [Accessed October 15, 2017].

Abdelkafi, N., Täuscher, K. (2016) Business models for sustainability from a system dynamics perspective. Organization & Environment. **29**(1), 74–96.

Abdul-manan, A.F.N. (2015) Uncertainty and differences in GHG emissions between electric and conventional gasoline vehicles with implications for transport policy making. Energy Policy. **87**, 1–7.

Ahmadi, L., Fowler, M., Young, S.B., Fraser, R.A., Gaffney, B., Walker, S.B. (2014) Energy efficiency of Li-ion battery packs re-used in stationary power applications. Sustainable Energy Technologies and Assessments. **8**, 9–17.

Ahmadi, L., Yip, A., Fowler, M., Young, S.B., Fraser, R.A. (2014) Environmental feasibility of re-use of electric vehicle batteries. Sustainable Energy Technologies and Assessments. **6**, 64–74.

Ahmadi, L., Young, S.B., Fowler, M., Fraser, R.A., Achachlouei, M.A. (2015) A cascaded life cycle: reuse of electric vehicle lithium-ion battery packs in energy storage systems. International Journal of Life Cycle Assessment. **22**(1), 111–124.

Ahmadian, A., Sedghi, M., Elkamel, A., Fowler, M., Aliakbar Golkar, M. (2018) Plug-in electric vehicle batteries degradation modeling for smart grid studies: Review, assessment and conceptual framework. Renewable and Sustainable Energy Reviews. **81**(July 2016), 2609–2624.

Ambrose, H., Gershenson, D., Gershenson, A., Kammen, D. (2014) Driving rural energy access: a second-life application for electric-vehicle batteries. Environmental Research Letters. **9**(9), 094004.

Amine, K., Kanno, R., Tzeng, Y. (2014) Rechargeable lithium batteries and beyond: Progress, challenges, and future directions. MRS Bulletin. **39**(05), 395–401.

Amirault, J., Chien, J., Garg, S., Gibbons, D., Ross, B., Tang, M., Xing, J., Pi, I.S., Kaminsky, P., Tenderich, B. (2009) The Electric Vehicle Battery Landscape : Opportunities and Challenges. , 42.

Amit, R., Zott, C. (2012) Creating value through business model innovation. MIT Sloan Management Review. **53**(53310), 41–49.

Antikainen, M., Valkokari, K., Mcclelland, J. (2016) A Framework for Sustainable Circular Business Model Innovation. Technology Innovation Management Review. **6**(7), 5–12.

Armand, M., Tarascon, J.-M. (2008) Building better batteries. Nature. **451**(7179), 652–657.

Arthur D. Little (2005) How leading companies are using sustainability-driven innovation to win tomorrow’s customers.

Babu, B.R., Parande, A.K., Basha, C.A. (2007) Electrical and electronic waste: a global environmental problem. Waste Management and Research. **25**, 307–318.

Bakas, I., Fischer, C., Harding, A., Haselsteiner, S., McKinnon, D., Kosmol, J., Leonadis, M., Plepys, A., Tojo, N., Wilts, H., Wittmer, D. (2014) Present and potential future recycling of critical metals in WEEE. Copenhagen, Denmark.

Baldassarre, B., Calabretta, G., Bocken, N.M.P., Jaskiewicz, T. (2017) Bridging sustainable business model innovation and user-driven innovation: a process for sustainable value proposition design. Journal of Cleaner Production. **147**, 175–186.

Balde, C.P., Kuehr, R., Blumenthal, K., Fondeur Gill, S., Kern, M., Micheli, P., Magpantay, E., Huisman, J. (2015) E-waste statistics - guidelines on classification, reporting and indicators. Bonn, Germany: United Nations University.

Barré, A., Deguilhem, B., Grolleau, S., Gérard, M., Suard, F., Riu, D. (2013) A review on lithium-ion battery ageing mechanisms and estimations for automotive applications. Journal of Power Sources. **241**, 680–689.

Beer, S., Gómez, T., Dallinger, D., Momber, I., Marnay, C., Stadler, M., Lai, J. (2012) An economic analysis of used electric vehicle batteries integrated into commercial building microgrids. IEEE Transactions on Smart Grid. **3**(1), 517–525.

Berckmans, G., Messagie, M., Smekens, J., Omar, N., Vanhaverbeke, L., Mierlo, J. Van (2017) Cost projection of state-of-the-art lithium-ion batteries for electric vehicles up to 2030. Energies. **10**(9).

Beverungen, D., Bräuer, S., Plenter, F., Klör, B., Monhof, M. (2016) Ensembles of context and form for repurposing electric vehicle batteries: an exploratory study. Computer Science - Research and Development. **32**(1–2), 195–209.

Bloomberg (2016) Here’s how electric cars will cause the next oil crisis. [online]. Available from: https://www.bloomberg.com/features/2016-ev-oil-crisis/ [Accessed January 15, 2017].

Bloomberg New Energy Finance (2018) Energy Storage is a $620 Billion Investment Opportunity to 2040. [online]. Available from: https://about.bnef.com/blog/energy-storage-620-billion-investment-opportunity-2040/#_ftn1 [Accessed February 2, 2019].

Bloomberg New Energy Finance (2017) Global storage market to double six times by 2030. [online]. Available from: https://about.bnef.com/blog/global-storage-market-double-six-times-2030/ [Accessed February 15, 2018].

BMW (2016) Battery storage system electrified by BMW i announced at EVS29 in Montreal. [online]. Available from: https://www.press.bmwgroup.com/usa/article/detail/T0261314EN_US/battery-storage-system-electrified-by-bmw-i-announced-at-evs29-in-montreal?language=en_US.

BMW (2014) BMW i Batterien werden als „Second Life Batteries“ flexible Speicher für erneuerbare Energien und sichern die Stabilität des Stromnetzes. [online]. Available from: https://www.press.bmwgroup.com/deutschland/article/detail/T0193200DE/bmw-i-batterien-werden-als-second-life-batteries-flexible-speicher-f%E3%BCr-erneuerbare-energien-und [Accessed August 18, 2016].

Bocken, N.M.P., de Pauw, I., Bakker, C., van der Grinten, B. (2016) Product design and business model strategies for a circular economy. Journal of Industrial and Production Engineering. **33**(5), 308–320.

Bocken, N.M.P., Short, S.W., Rana, P., Evans, S. (2014) A literature and practice review to develop sustainable business model archetypes. Journal of Cleaner Production. **65**, 42–56.

Bocken, N.M.P., Short, S.W., Rana, P., Evans, S. (2013) A value mapping tool for sustainable business modelling. Corporate Governance. **13**(5), 482–497.

Bocken, N.M.P., Weissbrod, I., Tennant, M. (2016) Business Model Experimentation for Sustainability. In R. Setchi, R. J. Howlett, Y. Liu, & P. Theobald, eds. Sustainable Design and Manufacturing. Cham, Switzerland: Springer International Publishing, pp. 297–306.

Bocken, N.M.P.M.P., Rana, P., Short, S.W.W. (2015) Value mapping for sustainable business thinking. Journal of Industrial and Production Engineering. **32**(1), 67–81.

Bohnsack, R. (2013) Car firms and low-emission vehicles: The evolution of incumbents’ strategies in relation to policy developments. Doctoral Dissertation, University of Amsterdam, Netherlands.

Bohnsack, R., Pinkse, J., Kolk, A. (2014) Business models for sustainable technologies: Exploring business model evolution in the case of electric vehicles. Research Policy. **43**(2), 284–300.

Bonges, H.A., Lusk, A.C. (2016) Addressing electric vehicle (EV) sales and range anxiety through parking layout, policy and regulation. Transportation Research Part A: Policy and Practice. **83**, 63–73.

Boons, F., Lüdeke-Freund, F. (2013) Business models for sustainable innovation: state-of-the-art and steps towards a research agenda. Journal of Cleaner Production. **45**, 9–19.

Boons, F., Montalvo, C., Quist, J., Wagner, M. (2013) Sustainable innovation, business models and economic performance: An overview. Journal of Cleaner Production. **45**, 1–8.

Bräuer, S. (2016) They not only live once – towards product-service systems for repurposed electric vehicle batteries. In Multikonferenz Wirtschaftsinformatik, MKWI 2016, 9-11 March 2016. Ilmenau, Germany, pp. 1299–1310.

Bräuer, S., Monhof, M., Klör, B., Plenter, F., Siemen, C., Beverungen, D. (2016) Residential energy storage from repurposed electric vehicle batteries market - overview and development of a service-centered business model. In IEEE 18th Conference on Business Informatics, 29th August - 1st September 2016. Paris, France: IEEE, pp. 143–152.

Broman, G.I., Robèrt, K.-H. (2017) A framework for strategic sustainable development. Journal of Cleaner Production. **140**, 17–31.

Budde Christensen, T., Wells, P., Cipcigan, L. (2012) Can innovative business models overcome resistance to electric vehicles? Better Place and battery electric cars in Denmark. Energy Policy. **48**, 498–505.

Bunsen, T., Cazzola, P., Gorner, M., Paoli, L., Scheffer, S., Schuitmaker, R., Tattini, J., Teter, J. (2018) Global EV outlook 2018: towards cross-model electrification.

Burke, A. (2009) Performance, charging, and second-use considerations for lithium batteries for plug-in electric vehicles. Davis, University of California Davis, Report number: UCD-ITS-RR-09-17.

California Energy Commission (2012) UC San Diego and BMW are giving new life to used electric vehicle batteries by storing up to 108kW of electricity for a few hours inside each battery. [online]. Available from: http://www.energy.ca.gov/research/energystorage/tour/ev_batteries/ [Accessed February 18, 2016].

Carrillo-hermosilla, J., Könnölä, T. (2010) Diversity of eco-innovations : reflections from selected case studies. . **18**, 1073–1083.

Casadesus-Masanell, R., Zhu, F. (2013) Business model innovation and competitive imitation: the case of sponsor-based business models. Strategic Management Journal. **34**, 464–482.

Casals, L.C., Amante García, B. (2017) Second-Life Batteries on a Gas Turbine Power Plant to Provide Area Regulation Services. Batteries. **3**(1), 10.

Casals, L.C., Amante García, B., Aguesse, F., Iturrondobeitia, A. (2015) Second life of electric vehicle batteries: relation between materials degradation and environmental impact. The International Journal of Life Cycle Assessment. **22**(1), 82–93.

Casals, L.C., Amante García, B., Canal, C. (2019) Second life batteries lifespan: Rest of useful life and environmental analysis. Journal of Environmental Management. **232**(October 2017), 354–363.

Casals, L.C., Amante García, B., Cremades, L. V (2017) Electric Vehicle Battery Reuse : Preparing for a Second Life. Journal of Industrial Engineering and Management. **10**(2), 266–285.

Casals, L.C., Martinez Laserna, E., Amante García, B., Nieto, N. (2016) Sustainability analysis of the electric vehicle use in Europe for CO2 emissions reduction. Journal of Cleaner Production. **127**, 425–437.

Chang, J., Huang, X., Zhou, G., Cui, S., Hallac, P.B., Jiang, J., Hurley, P.T., Chen, J. (2014) Multilayered Si nanoparticle/reduced graphene oxide hybrid as a high-performance lithium-ion battery anode. Advanced Materials. **26**(5), 758–764.

Chang, R.-D., Zuo, J., Zhao, Z.-Y., Zillante, G., Gan, X.-L., Soebarto, V. (2017) Evolving theories of sustainability and firms: History, future directions and implications for renewable energy research. Renewable and Sustainable Energy Reviews. **72**, 48–56.

Chesbrough, H. (2010) Business model innovation: opportunities and barriers. Long Range Planning. **43**(2–3), 354–363.

Chesbrough, H., Rosenbloom, R.S. (2002) The role of the business model in capturing value from innovation : evidence from Xerox Corporation’s technology spin-off companies. Industrial and Corporate Change. **11**(3), 529–555.

Cicconi, P., Landi, D., Morbidoni, A., Germani, M. (2012) Feasibility analysis of second life applications for Li-Ion cells used in electric powertrain using environmental indicators. In International Energy Conference and Exhibition (ENERGYCON), 9-12 September 2012. Florence, Italy: IEEE, pp. 985–990.

Cobb, J. (2015) One million global plug-in sales milestone reached. [online]. Available from: http://www.hybridcars.com/one-million-global-plug-in- sales-milestone-reached/.

Communication from the commission (EC) – Europe 2020 – a strategy for smart, sustainable and inclusive growth, (2010), COM (2010) 2020 final.

Communication from the commission (EC) to the European Parliament, the Council and the European Economic and Social Committee – a European strategy on clean and energy efficient vehicles, (2010), COM (2010) 186 final.

Communication from the commission (EC) to the European Parliament, the Council and the European Economic and Social Committee of the Regions – Energy roadmap 2050, (2011), COM (2011) 885 final.

Council Directive 2000/53/EC of 18 September 2000 on end-of life vehicles. (2000). Official Journal of the European Union, L269.

Council Directive 2003/87/EC of 13 October 2003 on establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC, Official Journal of the European Union, L275/32

Council Directive 2005/64/EC of 26 October 2005 on the type-approval of motor vehicles with regard to their reusability, recyclability and recoverability and amending council directive 70/156/EEC. (2005). Official Journal of the European Union, L310/10.

Council Directive 2006/66/EC of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC. (2006). Official Journal of the European Union, L266/1.

Council Directive 2008/98/EC of 19 November 2008 – on waste and repealing certain Directives, Official Journal of the European Union, L312/3.

Council Directive 2009/28/EC of 23 April 2009 – on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, Official Journal of the European Union, L140/16

Council Directive 2009/72/EC of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC, Official Journal of the European Union, L211/55

Council Directive 2009/73/EC of 13 July 2009 concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC, Official Journal of the European Union, L211/94.

Council Directive 2010/31/EU of 19 May 2010 on the energy performance of buildings, Official Journal of the European Union, L153/13.

Council Directive 2012/19/EU of 4 July 2012 on waste electrical and electronic equipment (WEEE), Official Journal of the European Union, L197/38.

Council Directive 2012/27/EU of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC, Official Journal of the European Union, L315/1.

Council Regulation No 443/2009 of 23 April 2009 – setting emission performance standards for new passenger cars as part of the community's integrated approach to reduce CO2 emissions from light-duty vehicles, Official Journal of the European Union, L140/1.

Council Regulation No 347/2013 of 17 April 2013 on on guidelines for trans-European energy infrastructure and repealing Decision No 1364/2006/EC and amending Regulations (EC) No 713/2009, (EC) No 714/2009 and (EC) No 715/2009, Official Journal of the European Union, L115/39

Cready, E., Lippert, J., Pihl, J., Weinstock, I., Symons, P. (2003) Technical and economic feasibility of applying used EV batteries in stationary applications. Albuquerque, Sandia National Laboratories, Report number: SAND2002-4084.

Curry, C. (2017) Lithium-ion battery costs and market. [online]. Available from: https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF-Lithium-ion-battery-costs-and-market.pdf [Accessed July 7, 2017].

Daimler (2016a) E-mobilty thought to the end.

Daimler (2016b) World's largest 2nd-use battery storage is starting up. [online]. Available from: http://media.daimler.com/marsMediaSite/en/instance/ko/Worlds-largest-2nd-use-battery-storage-is-starting-up.xhtml?oid=13634457 [Accessed October 13, 2016].

Daniel, C. (2008) Materials and processing for lithium-ion batteries. Jom-Us. **60**(9), 43–48.

Darbar, K.G., Suthar, M.S. (2014) Study of the ANSI/SPARC Architecture. International Journal of Modern Trends in Engineering and Research. **1**(3).

Demil, B., Lecocq, X. (2010) Business model evolution: in search of dynamic consistency. Long Range Planning. **43**(2–3), 227–246.

Deng, D. (2015) Li-ion batteries: basics, progress, and challenges. Energy Science & Engineering.

3(5), 385–418.

Dentchev, N., Rauter, R., Jóhannsdóttir, L., Snihur, Y., Rosano, M., Baumgartner, R., Nyberg, T., Tang, X., van Hoof, B., Jonker, J. (2018) Embracing the variety of sustainable business models: A prolific field of research and a future research agenda. Journal of Cleaner Production. **194**, 695–703.

Derousseau, M., Gully, B., Taylor, C., Apelian, D., Wang, Y. (2017) Repurposing used electric car batteries : a review of options. The Minerals, Metals & Materials Society. **69**(9), 1575–1582.

Despeisse, M., Yang, M., Evans, S., Ford, S., Minshall, T. (2017) Sustainable Value Roadmapping Framework for Additive Manufacturing. Procedia CIRP. **00**, 594–599.

Dinger, A., Martin, R., Mosquet, X., Rabl, M., Rizoulis, D., Russo, M., Sticher, G. (2010) Batteries for electric cars - challenges, opportunities, and the outlook to 2020. [online]. Available from: http://www.bcg.com/documents/file36615.pdf [Accessed September 27, 2016].

Dunn, J.B., Gaines, L., Sullivan, J., Wang, M.Q. (2012) Impact of recycling on cradle-to-gate energy consumption and greenhouse gas emissions of automotive lithium-ion batteries. Environmental Science and Technology. **46**(22), 12704–12710.

Eco2Charge (2014) A project designed to accelerate the deployment of electric vehicles. [online]. Available from: https://www.nexans.com/eservice/Corporate-en/navigatepub_320017_-33937/Eco2charge_a_project_designed_to_accelerate_the_de.html [Accessed October 25, 2015].

Eddahech, A., Briat, O., Vinassa, J.M. (2014) Determination of lithium-ion battery state-of-health based on constant-voltage charge phase. Journal of Power Sources. **258**, 218–227.

Eisenhardt, K. M. (1989) Building theories from case study research. AMR, 14(4), 532-550.

Elkind, E.N. (2014) Reuse and repower: how to save money and clean the grid with second-life electric vehicle batteries. Berkely, University of California Berkeley Law.

Elkington, J. (1997) Cannibals with forks: the triple bottom line of the 21st century business. Oxford: New Society Publishers.

Ellingsen, L.A.W., Majeau-Bettez, G., Singh, B., Srivastava, A.K., Valøen, L.O., Strømman, A.H. (2014) Life Cycle Assessment of a Lithium-Ion Battery Vehicle Pack. Journal of Industrial Ecology. **18**(1), 113–124.

Engert, S., Rauter, R., Baumgartner, R.J. (2016) Exploring the integration of corporate sustainability into strategic management: a literature review. Journal of Cleaner Production. **112**, 2833–2850.

España. Real decreto 1699/2011, de 18 de noviembre, por el que se regula la conexión a red de instalaciones de producción de energía de pequeña potencia. Boletín Oficial Del Estado, 8 de diciembre de 2011(295), 130033-130064.

España. Real decreto 900/2015, de 9 octubre, por el que se regulan las condiciones administrativas técnicas y económicas de las modalidades de suministro de energía eléctrica con autoconsumo y de producción con autoconsumo. Boletín Oficial Del Estado, 10 de octubre de 2015(243), 94874-94917

Etacheri, V., Marom, R., Elazari, R., Salitra, G., Aurbach, D. (2011) Challenges in the development of advanced Li-ion batteries: a review. Energy Environ. Sci. **4**(9), 3243–3262.

European Commission (2016a) 2020 climate & energy package.

European Commission (2016b) 2030 Energy Strategy.

European Commission (2015) Directives and regulations on motor vehicles, their trailers, systems and components. [online]. Available from: http://ec.europa.eu/growth/sectors/automotive/legislation/motor-vehicles- trailers/index_en.htm.

European Commission (2013) EU Energy, Transport and GHG Emissions – Trends to 2050.

European Commission (2018) European Commission tackles barriers to innovation: the second Innovation Deal focuses on batteries for electric vehicles. [online]. Available from: https://ec.europa.eu/info/news/european-commission-tackles-barriers-innovation-second-innovation-deal-focuses-batteries-electric-vehicles-2018-mar-12_en [Accessed March 18, 2018].

European Environment Agency (2016) Explaining road transport emissions. [online]. Available from: http://www.eea.europa.eu/publications/explaining-road-transport-emissions.

Eurostat (2017) Eurostat - your key to European Statistics. [online]. Available from: https://ec.europa.eu/eurostat/data/database.

Evans, S., Fernando, L., Yang, M. (2017) Sustainable value creation - from concept towards implementation. In R. Stark, G. Seliger, & J. Bonvoisin, eds. Sustainable manufacturing: challenges, solutions and implementation perspectives. Cham, Switzerland: Springer, pp. 203–220.

Evans, S., Rana, P., Short, S.W. (2014) Final set of tools & methods that enable analysis of future oriented, novel, sustainable, value adding business-models and value-networks. Cambridge, University of Cambridge, Report number:Deliverable D2,6.

Evans, S., Vladimirova, D., Holgado, M., Van Fossen, K., Yang, M., Silva, E., Barlow, C.Y. (2017)

Business model innovation for sustainability: towards a unified perspective for creation of sustainable business models. Business Strategy and the Environment. **26**(5), 597–608.

Faria, R., Marques, P., Garcia, R., Moura, P., Freire, F., Delgado, J., De Almeida, A.T. (2014) Primary and secondary use of electric mobility batteries from a life cycle perspective. Journal of Power Sources. **262**, 169–177.

Fischhaber, S., Regett, A., Schuster, S.F., Hesse, H. (2016) Second-Life-Konzepte für Lithium-Ionen-Batterien aus Elektrofahrzeugen: Analyse von Nachnutzungsanwendungen, ökonomischen und ökologischen Potenzialen. Frankfurt, Schaufenster Elektromobilität (BuW).

Foster, M., Isely, P., Standridge, C.R., Hasan, M.M. (2014) Feasibility assessment of remanufacturing, repurposing, and recycling of end of vehicle application lithium-ion batteries. Journal of Industrial Engineering and Management. **7**(3), 698–715.

Gaines, L., Cuenca, R. (2000) Costs of lithium-ion batteries for vehicles. Energy. **48**(3), 73.

Gaines, L., Sullivan, J. (2010) A review of battery life-cycle analysis: state of knowledge and critical needs. Argonne, Argonne National Laboratory. ANL/ESD/10-7.

Gaines, L., Sullivan, J., Burnham, A., Belharouak, I. (2011) Life-Cycle Analysis for Lithium-Ion Battery Production and Recycling. In Transportation Research Board (TRB) 90th Annual Meeting, 23-27 January 2011. Washington, D.C., USA: TRB, pp. 23–27.

Geissdoerfer, M., Bocken, N.M.P., Hultink, E.J. (2016) Design thinking to enhance the sustainable business modelling process - A workshop based on a value mapping process. Journal of Cleaner Production. **135**, 1218–1232.

Geissdoerfer, M., Morioka, S.N., de Carvalho, M.M., Evans, S. (2018) Business models and supply chains for the circular economy. Journal of Cleaner Production. **190**, 712–721.

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J. (2017a) The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production. **143**, 757–768.

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J. (2017b) The Circular Economy – A new sustainability paradigm? Journal of Cleaner Production. **143**, 757–768.

Geissdoerfer, M., Vladimirova, D., Evans, S. (2018) Sustainable business model innovation: A review. Journal of Cleaner Production. **198**(July), 401–416.

General Motors (GM) (2015) Used Chevrolet Volt batteries help power new IT building. [online]. Available from:

http://media.gm.com/media/us/en/gm/news.detail.html/content/Pages/news/us/en/2015/jun/0616-volt-battery.html [Accessed January 17, 2016].

Genikomsakis, K.N., Ioakimidis, C.S., Murillo, A., Trifonova, A., Simic, D. (2013) A Life Cycle Assessment of a Li-ion urban electric vehicle battery Parameters Settings for EVs in. In 27th World Electric Vehicle Symposium and Exhibition (EVS27), 17-20 November 2013. Barcelona, Spain: IEEE, pp. 1–11.

Goodenough, J.B., Park, K.-S.S. (2013) The Li-ion rechargeable battery: A perspective. Journal of the American Chemical Society. **135**(4), 1167–76.

Goriparti, S., Miele, E., De Angelis, F., Di Fabrizio, E., Proietti Zaccaria, R., Capiglia, C. (2014) Review on recent progress of nanostructured anode materials for Li-ion batteries. Journal of Power Sources. **257**, 421–443.

Green Car Congress (2015) Mitsubishi joins PSA and other french partners in second-life batteries demonstration. [online]. Available from: http://www.greencarcongress.com/2015/07/20150710-mmc.html [Accessed January 17, 2016].

Gur, K., Chatzikyriakou, D., Baschet, C., Salomon, M. (2018) The reuse of electrified vehicle batteries as a means of integrating renewable energy into the European electricity grid: a policy and market analysis. Energy Policy. **113**, 535–545.

Hakimian, a., Kamarthi, S., Erbis, S., Abraham, K.M., Cullinane, T.P., Isaacs, J. a. (2015) Economic analysis of CNT lithium-ion battery manufacturing. Environ. Sci.: Nano. **2**, 463–476.

Halvorsen, H. (2016) Introduction to Database Systems. Notodden, Norway: University College of Southeast Norway.

Hawkins, T.R., Singh, B., Majeau-Bettez, G., Strømman, A.H. (2013) Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles. Journal of Industrial Ecology. **17**(1), 53–64.

Heelan, J., Gratz, E., Zheng, Z., Wang, Q., Chen, M., Apelian, D., Wang, Y. (2016) Current and Prospective Li-Ion Battery Recycling and Recovery Processes. The Minerals, Metals & Materials Society. **68**(10), 2632–2638.

Heymans, C., Walker, S.B., Young, S.B., Fowler, M. (2014) Economic analysis of second use electric vehicle batteries for residential energy storage and load-levelling. Energy Policy. **71**, 22–30.

Van den Hoed, R. (2005) Commitment to fuel cell technology? How to interpret carmakers' efforts in this radical technology. Journal of Power Sources. **141**, 265–271.

Hu, Y., Cheng, H., Tao, S. (2017) Retired Electric Vehicle (EV) batteries: integrated waste management and research needs. Environmental Science & Technology. **51**(19), 10927–10929.

Huat, S.L., Yonghuang, Y., Tay, A.A.O. (2015) Integration issues of Lithium-ion battery into electric vehicles battery pack. Journal of Cleaner Production.

Huisman, J. (2014) Database and WEEE classification listing: Deliverable 2.3. Bonn, Germa.

Huisman, J., Magalini, F., Kuehr, R., Maurer, C. (2007) Review of Directive 2002/96 on Waste Electrical and Electronic Equipment, Bonn, Germany.

International Energy Agency (2016) Global EV outlook 2016: beyond one million electric cars. Paris, International Energy Agency.

International Energy Agency (2017) Global EV Outlook 2017 - Two million and counting. Paris, International Energy Agency.

International Energy Agency (IEA). Global EV outlook 2019. Paris, International Energy Agency.

International Energy Agency (IEA) (2013) Global EV Outlook – understanding the electric vehicle landscape 2020. [online]. Available from: https://www.iea.org/publications/globalevoutlook_2013.pdf.

International Renewable Energy Agency (2017) Electric Vehicles - Technology Brief. Abu Dhabi, International Renewable Energy Agency.

Ivankova, N. V., Creswell, J.W., Stick, S.L. (2006) Using Mixed-Methods Sequential Explanatory Design: From Theory to Practice. Field Methods. **18**(1), 3–20.

Jaffe, S., Adamson, K. (2014) Second-life batteries : from PEVs to stationary applications. Navigant Research. RB-SLB-14.

Jiao, N., Evans, S. (2018) Business models for repurposing a second-life for retired electric vehicle batteries. In G. Pistoia & B. Liaw, eds. Behaviour of Lithium-Ion Batteries in Electric Vehicles. Cham, Switzerland: Springer International Publishing, pp. 323–344.

Jiao, N., Evans, S. (2017) Business models for sustainability: the case of repurposing a second-life for electric vehicle batteries. In 4th International Conference on Sustainable Design and Manufacturing, 26-28th April 2017. Bologna, Italy: Springer, pp. 537–545.

Jiao, N., Evans, S. (2016a) Business models for sustainability: the case of second-life electric vehicle batteries. Procedia CIRP. **40**, 250–255.

Jiao, N., Evans, S. (2016b) Market diffusion of second-life electric vehicle batteries: Barriers and enablers. World Electric Vehicle Journal. **8**(3), 599–608.

Jiao, N., Evans, S. (2016c) Secondary use of electric vehicle batteries and potential impacts on business models. Journal of Industrial and Production Engineering. **33**(5), 348–354.

Johnson, Gerry, Scholes, K., Whittington, R. (2008) Exploring Corporate Strategy. London: Financial Times Prentice Hall.

Johnson, M., Fitzpatrick, C. (2016) The development of a model to ascertain future levels of historic WEEE arising (historic WEEE). Wexford, Ireland.

Johnson, M.W. (2010) Seizing the white space: business model innovation for growth and renewal. Boston: Harvard Business Press.

Johnson, Mark W., Christensen, C.M., Kagermann, H. (2008) Reinventing your business model. Harvard Business Review. **86**(12), 57–68.

Joyce, A., Paquin, R.L. (2016) The triple layered business model canvas: A tool to design more sustainable business models. Journal of Cleaner Production. **135**, 1474–1486.

Kley, F., Lerch, C., Dallinger, D. (2011) New business models for electric cars: a holistic approach. Energy Policy. **39**(6), 3392–3403.

Klör, B., Beverungen, D., Bräuer, S., Plenter, F., Monhof, M. (2015) A market for trading used electric vehicle batteries – theoretical foundations and information systems. In 23rd European Conference on Information System (ECIS), 26-29 May 2015. Münster, Germany: ECIS, pp. 1–18.

Knowles, M., Morris, A. (2014) Impact of second life electric vehicle batteries on the viability of renewable energy sources. British Journal of Applied Science and Technology. **4**(1), 152–167.

Korhonen, J., Nuur, C., Feldmann, A., Eshetu, S. (2018) Circular economy as an essentially contested concept. Journal of Cleaner Production. **175**, 544–552.

Lambert, F. (2016) BMW and Bosch open new 2.8 MWh energy storage facility built from batteries from over 100 electric cars. [online]. Available from: https://electrek.co/2016/09/22/bmw-bosch-energy-storage-facility-built-from-batteries-from-over-100-electric-cars/ [Accessed January 3, 2016].

Laurischkat, K., Viertelhausen, A. (2017) Business model gaming: a game-based methodology for e-mobility business nodel innovation. Procedia CIRP. **64**, 115–120.

Lee, B., Saunders, M.N.K. (2017) Conducting case study research for business and management students. Los Angeles: SAGE.

Leising, E., Quist, J. & Bocken, N.M.P. (2018) Circular Economy in the building sector: three cases and a collaboration tool. Journal of Cleaner Production, 176, 976–989.

Liebreich, M., McCrone, A. (2016) Electric vehicles – It's not just about the car. [online]. Available from: https://about.bnef.com/blog/liebreich-mccrone-electric-vehicles-not-just-car/ [Accessed November 13, 2016].

Lih, W.-C., Yen, J.-H., Shieh, F.-H., Liao, Y.-M. (2012) Second-use applications of lithium-ion batteries retired from electric vehicles: challenges, repurposing process, cost analysis and optimal business model. International Journal of Advancements in Computing Technology. **4**(22), 381–384.

Liu, C., Neale, Z.G., Cao, G. (2015) Understanding electrochemical potentials of cathode materials in rechargeable batteries. Materials Today. **19**(2), 109–123.

Lorentz, V.R., Wenger, M.M., Reiner, J., Martin, M. (2015) Electrification of the powertrain in automotive applications: 'technology push' or 'market pull'? In Electric Vehicle Business Models - Global Perspectives. Cham, Switzerland: Springer, pp. 35–51.

Lu, L., Han, X., Li, J., Hua, J., Ouyang, M. (2013) A review on the key issues for lithium-ion battery management in electric vehicles. Journal of Power Sources. **226**, 272–288.

Lüdeke- Freund, F. (2010) Towards a conceptual framework of business models for sustainability. In European Roundtable on Sustainable Consumption and Production (ERSCP) - Environmental Management of Sustainable Universities (EMSU), 25-29 October 2010. Delft, Netherlands: ERSCP, pp. 1–28.

Lüdeke-Freund, F., Dembek, K. (2017) Sustainable business model research and practice: emerging field or passing fancy? Journal of Cleaner Production. **168**, 1668–1678.

Lüdeke-Freund, F., Massa, L., Bocken, N., Brent, A.C., Musango, J. (2016) Business models for shared value: main report. Cape Town: Network for Business Sustainability South Africa.

Lux Research (2016) Reuse or Recycle: The Billion-Dollar Battery Question. [online]. Available from: http://www.luxresearchinc.com/content/reuse-or-recycle-billion-dollar-battery-question-0.

Majeau-Bettez, G., Hawkins, T.R., Stromman, A.H. (2011) Life cycle environmental assessment of lithium-ion and nickel metal hydride batteries for plug-in hybrid and battery electric vehicles.

Environmental Science and Technology. **45**(10), 4548–4554.

Manthiram, A. (2011) Materials challenges and opportunities of lithium ion batteries. Journal of Physical Chemistry Letters. **2**(3), 176–184.

Manzetti, S., Mariasiu, F. (2015) Electric vehicle battery technologies: From present state to future systems. Renewable and Sustainable Energy Reviews. **51**, 1004–1012.

Mariasiu, F. (2012) Energy sources management and future automotive technologies: environmental impact. International Journal of Energy Economics and Policy. **2**(4), 342–347.

Marra, A., Cesaro, A., Belgiorno, V. (2018) Separation efficiency of valuable and critical metals in WEEE mechanical treatments. Journal of Cleaner Production. **186**, 490–498.

Martinez-Laserna, E., Gandiaga, I., Sarasketa-Zabala, E., Badeda, J., Stroe, D.I., Swierczynski, M., Goikoetxea, A. (2018) Battery second life: Hype, hope or reality? A critical review of the state of the art. Renewable and Sustainable Energy Reviews. **93**(October 2017), 701–718.

Massiani, J. (2015) Cost-benefit snalysis of policies for the development of electric vehicles in Germany : methods and results. . **38**, 19–26.

Mazur, C., Contestabile, M., Offer, G.J., Brandon, N.P. (2015) Assessing and comparing German and UK transition policies for electric mobility. Environmental Innovation and Societal Transitions. **14**, 84–100.

Mock, P., Yang, Z. (2014) Driving Electrification: a global comparison of fiscal incentive policy for electric vehicles. ICCT - The International Council on Clean Transportation. [online]. Available from: http://www.theicct.org/sites/default/files/publications/ICCT_EV-fiscal-incentives_20140506.pdf [Accessed May 1, 2016].

Morgadinho, L., Oliveira, C., Martinho, A. (2015) A qualitative study about perceptions of European automotive sector ’ s contribution to lower greenhouse gas emissions. Journal of Cleaner Production. **106**, 644–653.

Morioka, S.N., Bolis, I., Evans, S., Carvalho, M.M. (2017) Transforming sustainability challenges into competitive advantage : multiple case studies kaleidoscope converging into sustainable business models. Journal of Cleaner Production. **167**, 723–738.

Murray, A., Skene, K., Haynes, K. (2017) The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. Journal of Business Ethics. **140**(3), 369–380.

Naor, M., Druehl, C., Bernardes, E.S. (2018) Servitized business model innovation for sustainable transportation: Case study of failure to bridge the design-implementation gap. Journal of Cleaner Production. **170**, 1219–1230.

Narula, C.K., Martinez, R., Onar, O., Starke, M.R., Andrews, G. (2011) Economic analysis of deploying used batteries in power systems. Oak Ridge National Laboratory, Report number: ORNL/TM-2011/151.

Nava, M. (2017) The Road Ahead for Electric Vehicles. USA.

Nelson, P.A., Gallagher, K.G., Bloom, I., Dees, D.W. (2011) Modeling the Performance and Cost of Lithium-Ion Batteries for Electric-Drive Vehicles. , 1–102.

Neubauer, J., Pesaran, A. (2011) The ability of battery second use strategies to impact plug-in electric vehicle prices and serve utility energy storage applications. Journal of Power Sources. **196**(23), 10351–10358.

Neubauer, J., Smith, K., Wood, E., Pesaran, A., Neubauer, J., Smith, K., Wood, E., Pesaran, A. (2015) Identifying and overcoming critical barriers to widespread second use of PEV batteries. National Renewable Energy Laboratory (NREL), Report Number: NREL/TP-5400-63332.

Neubauer, J., Wood, E., Pesaran, A. (2015) A second life for electric vehicle batteries: answering questions on battery degradation and value. SAE International Journal of Materials and Manufacturing. **8**, 21–23.

Neubauer, J.S., Pesaran, A., Williams, B., Ferry, M., Eyer, J. (2012) A techno-economic analysis of PEV battery second use: repurposed-battery selling price and commercial and industrial end-user value. SAE International, Report Number: NREL/CP-5400-53799.

Nilsson, M., Nykvist, B. (2016) Governing the electric vehicle transition - Near term interventions to support a green energy economy. Applied Energy. **179**, 1360–1371.

Nissan (2017a) Leaf. [online]. Available from: https://www.nissan.co.uk/vehicles/new-vehicles/leaf/prices-specifications.html [Accessed May 14, 2017].

Nissan (2016) Nissan, Eaton and The Mobility House sign 10-year deal to make the world-famous Amsterdam ArenA more energy efficient with battery storage. [online]. Available from: https://newsroom.nissan-europe.com/eu/en-gb/media/pressreleases/426164259/nissan-eaton-and-the-mobility-house-sign-10-year-deal-to-make-the-world-famous-amsterdam-arena-more?preview=true&t=fb709602-e6a7-42d7-828d-666cbd2978ea [Accessed January 3, 2017].

Nissan (2017b) Xstorage. [online]. Available from: https://www.nissan.co.uk/experiencenissan/electric-vehicle-leadership/xstorage-by-nissan.html [Accessed May 15, 2017].

Nitta, N., Wu, F., Lee, J.T., Yushin, G. (2015) Li-ion battery materials: present and future. Materials Today. **18**(5), 252–264.

Notter, D.A., Gauch, M., Widmer, R., W??ger, P., Stamp, A., Zah, R., Althaus, H.J. (2010) Contribution of Li-ion batteries to the environmental impact of electric vehicles. Environmental Science and Technology. **44**(17), 6550–6556.

Nykvist, B., Nilsson, M. (2015a) Rapidly falling costs of battery packs for electric vehicles. Nature Climate Change. **5**(4), 329–332.

Nykvist, B., Nilsson, M. (2015b) Rapidly falling costs of battery packs for electric vehicles. Nature Climate Change. **5**(4), 329–332.

Osterwalder, A., Pigneur, Y. (2002) An e-business model ontology for modeling e-business. In 15th Bled Electronic Commerce Conference eReality: constructing the eEconomy, 17 - 19 June 2002. Bled, Slovenia, p. 12.

Osterwalder, A., Pigneur, Y., Christopher L Tucci (2005) Clarifying business models : origins, present, and future of the concept. Communications of the association for Information Systems. **15**, 1–125.

Osterwalder, A., Pigneur, Y., Smith, A., Movement, T. (2010) Business model generation: a handbook for visionaries, game changers, and challengers, Hoboken: John Wiley & Sons.

P3 Consulting Group (2016) Cost developments of battery systems. Coral Gables, USA.

Pasaoglu, G., Zubaryeva, A., Fiorello, D., Thiel, C. (2014) Analysis of European mobility surveys and their potential to support studies on the impact of electric vehicles on energy and infrastructure needs in Europe. Technological Forecasting and Social Change. **87**, 41–50.

Patala, S., Jalkala, A., Keränen, J., Väisänen, S., Tuominen, V., Soukka, R. (2016) Sustainable value propositions: framework and implications for technology suppliers. Industrial Marketing Management. **59**, 144–156.

Peterson, S.B., Whitacre, J.F., Apt, J. (2010) The economics of using plug-in hybrid electric vehicle battery packs for grid storage. Journal of Power Sources. **195**(8), 2377–2384.

Pillot, C. (2015) Battery market development for consumer electronics, automotive, and industrial: materials requirements and trends. In 5th Israeli Power Sources Conference, 21 May 2015. Herzelia, Israel, pp. 1–40.

Podias, A., Pfrang, A., Di Persio, F., Kriston, A., Bobba, S., Mathieux, F., Messagie, M., Boon-Brett, L. (2018) Sustainability assessment of second use applications of automotive batteries: Ageing of Li-ion battery cells in automotive and grid-scale applications. World Electric Vehicle Journal. **9**(2).

Porter, M., Kramer, M. (2011) Creating shared value. Harvard Business Review. **1**, 62–77.

Poulis, K., Poulis, E. (2017) International business as disciplinary tautology: an ontological perspective. Academy of Management Perspectives, 1–40.

Puckett, J., Byster, L., Westervelt, S., Gutierrez, R., Davis, S., Hussain, A., Dutta, M. (2002) Exporting harm, the high-tech trashing of Asia. [online]. Available from: http://www.ban.org/E-waste/%0Atechnotrashfinalcomp.pdf.

Punch, K.F. (2014) Introduction to social research – quantitative & qualitative approaches. 3rd ed. London: SAGE.

Ramoni, M.O., Zhang, H.C. (2013) End-of-life (EOL) issues and options for electric vehicle batteries. Clean Technologies and Environmental Policy. **15**(6), 881–891.

Rana, P., Short, S.W., Evans, S., Granados, M.H. (2017) Sustainable business models: theoretical reflections. In Jayantha P. Liyanage & Teuvo Uusitalo, eds. Value Networks in Manufacturing. pp. 95–109.

Rauter, R., Jonker, J., Baumgartner, R.J. (2017) Going one's own way: drivers in developing business models for sustainability. Journal of Cleaner Production. **140**, 144–154.

Rehme, M., Richter, S., Temmler, A., Götze, U. (2016) Second-Life battery applications - market potentials and contribution to the cost effectiveness of electric vehicles. In 5th Conference on Future Automotive Technology (COFAT), 3 - 4 May 2016. Fürstenfeld, Germany.

Reid, G., Julve, J. (2016) Second Life-Batteries as Flexible Storage for Renewables Energies. Hannover, Bundesverband Erneuerbare Energie e.V.

Reinhardt, R., Amante Garcìa, B., Casals, L.C., Gassó-Domingo, S. (2016) Critical evaluation of European Union legislation on the second use of degraded traction batteries. In IEEE, ed. 13th International Conference on the European Energy Market (EEM), 6-9 June 2016. Porto, Portugal.

Reinhardt, R., Amante Garcìa, B., Gassó-Domingo, S., Christodoulou, I. (2017) Macro environmental analysis of the electric vehicle battery second use market. In 14th International Conference on the European Energy Market (EEM), 6-9 June 2017. Dresden, Germany: IEEE.

Reinhardt, R., Christodoulou, I., Gassó-domingo, S., Amante García, B. (2019a) Towards sustainable business models for electric vehicle battery second use : A critical review. Journal of Environmental Management. **245**, 432–446.

Reinhardt, R., García, B.A., Casals, L.C., Gasso-Domingo, S. (2019b) A critical evaluation of cathode materials for lithium-ion electric vehicle batteries. In J. L. A. Muñoz, J. L. Y. Blanco, & S. F. Capuz-Rizo, eds. Project Management and Engineering Research. Cham, Switzerland: Springer, pp. 99–110.

Renault (2017a) Battery hire. [online]. Available from: https://www.renault.co.uk/renault-finance/battery-hire.html [Accessed October 12, 2017].

Renault (2017b) Electric Vehicle charging on highways with second-life batteries. [online]. Available from: http://press.renault.co.uk/Corporate/3a483d7c-2680-4733-987f-1c6581a69492.aspx [Accessed October 15, 2017].

Renewable Energy Association (2017) EV forward view: jobs, infrastructure, and a vision for the growth of electric vehicles in the UK. London, Renewable Energy Association.

Richardson, J. (2008) The business model: an integrative framework for strategy execution. Strategic Change. **17**(5/6), 133–144.

Richter, S., Rehme, M., Temmler, A. (2016) Second-life battery applications - market potentials and contributions of the cost effectiveness of electric vehicles. In 8th Wissenschaftsforum Mobilität, 29 Juni 2017. Universität Duisburg-Essen, Germany.

Ritala, P., Huotari, P., Bocken, N., Albareda, L., Puumalainen, K. (2018) Sustainable business model adoption among S&P 500 firms: A longitudinal content analysis study. Journal of Cleaner Production. **170**, 216–226.

Rohr, S., Wagner, S., Baumann, M., Muller, S., Lienkamp, M. (2017) A techno-economic analysis of end of life value chains for lithium-ion batteries from electric vehicles. In 12th International Conference on Ecological Vehicles and Renewable Energies (EVER), 11 -13 April 2017. Monte Carlo, Monaco: IEEE, pp. 1–14.

Rong, K., Shi, Y., Shang, T., Chen, Y., Hao, H. (2017) Organizing business ecosystems in emerging electric vehicle industry: structure, mechanism, and integrated configuration. Energy Policy. **107**(288), 234–247.

Saevarsdottir, G., Tao, P., Stefansson, H., Harvey, W. (2015) Potential Use of Geothermal Heat in

Lithium- Ion Battery Production. In World Geothermal Congress 2015. Melbourne, Australia, pp. 1–6.

Sakti, A., Michalek, J.J., Fuchs, E.R.H., Whitacre, J.F. (2015) A techno-economic analysis and optimization of Li-ion batteries for light-duty passenger vehicle electrification. Journal of Power Sources. **273**, 966–980.

Sarker, M.R., Pandzic, H., Ortega-Vazquez, M.A. (2015) Optimal Operation and Services Scheduling for an Electric Vehicle Battery Swapping Station. IEEE Transactions on Power Systems. **30**(2), 901–910.

Sathre, R., Scown, C.D., Kavvada, O., Hendrickson, T.P. (2015) Energy and climate effects of second-life use of electric vehicle batteries in California through 2050. Journal of Power Sources. **288**, 82–91.

Saunders, M.N.K. (2017) Doing research in business and management. Harlow: Pearson.

Sauvé, S., Bernard, S., Sloan, P. (2016) Environmental sciences, sustainable development and circular economy: Alternative concepts for trans-disciplinary research. Environmental Development. **17**, 48–56.

Schaltegger, S., Hansen, E.G., Lüdeke-Freund, F. (2016) Business models for sustainability: origins, present research, and future avenues. Organization & Environment. **29**(1), 3–10.

Schaltegger, S., Lüdeke-Freund, F., Hansen, E.G. (2012) Business cases for sustainability: the role of business model innovation for corporate sustainability. International Journal of Innovation and Sustainable Development. **6**(2), 95.

Scrosati, B., Garche, J. (2010) Lithium batteries: Status, prospects and future. Journal of Power Sources. **195**(9), 2419–2430.

Seale, C. 1999. The Quality of Qualitative Research. London: SAGE Publications.

Shankleman, J. (2017) The electric car revolution is accelerating. Bloomberg. [online]. Available from: https://www.bloomberg.com/news/articles/2017-07-06/the-electric-car-revolution-is-accelerating [Accessed October 25, 2017].

Song, M.K., Park, S., Alamgir, F.M., Cho, J., Liu, M. (2011) Nanostructured electrodes for lithium-ion and lithium-air batteries: The latest developments, challenges, and perspectives. Materials Science and Engineering R: Reports. **72**(11), 203–252.

Sonoc, A., Jeswiet, J., Soo, V.K. (2015) Opportunities to improve recycling of automotive lithium ion batteries. Procedia CIRP. **29**, 752–757.

Sperling, D., Gordon, D. (2009) Two Billion Cars Transforming a Culture. Transportation Research News. **259**, 3–9.

St.John, J. (2015) Nissan, Green Charge Networks turn ‘second-life’ EV batteries into grid storage business. [online]. Available from: https://www.greentechmedia.com/articles/read/nissan-green-charge-networks-turn-second-life-ev-batteries-into-grid-storag [Accessed June 15, 2015].

Standridge, C.R., Corneal, L. (2014) Remanufacturing, repurposing, and recycling of post-vehicle-application lithium-ion batteries. Mineta National Transit Research Consortium. Report Number: CA-MNTRC-14-1137.

Standridge, C.R., Hasan, M.M. (2015) Post-vehicle-application lithium-ion battery remanufacturing, repurposing and recycling capacity: modeling and analysis. Journal of Industrial Engineering and Management. **8**(3), 823–839.

Stubbs, W., Cocklin, C. (2008) Conceptualizing a ‘sustainability business model’. Organization & Environment. **21**(2), 103–127.

Swinkels, V., van der Ree, B., Ugarte, S. (2016) Bottlenecks for energy storage and how to address them? [online]. Available from: http://www.energypost.eu/bottlenecks-energy-storage-europe-address/.

Taneja, A. (2017) Database Management Systems.

Tang, Y., Zhang, Y., Li, W., Ma, B., Chen, X. (2015) Rational material design for ultrafast rechargeable lithium-ion batteries. Chem. Soc. Rev. **44**(17), 5926–5940.

Tarascon, J.-M., Armand, M. (2001) Issues and challenges facing rechargeable lithium batteries. Nature. **414**, 359–367.

Teece, D.J. (2010) Business models, business strategy and innovation. Long Range Planning. **43**(2–3), 172–194.

Thackeray, M.M., Wolverton, C., Isaacs, E.D. (2012) Electrical energy storage for transportation—approaching the limits of, and going beyond, lithium-ion batteries. Energy & Environmental Science. **5**(7), 7854.

Thompson, C. (2015) The fascinating evolution of the electric car. [online]. Available from: http://www.businessinsider.com/electric-automobile-history-2015-12/#it-wasnt-until-the-1960s-and-1970s-when-interest-in-electric-cars-began-to-grow-again-4 [Accessed March 1, 2016].

Törkler, A. (2014) Electrodes and cells manufacturing white paper: batteries refurbishing & reuse. Boulogne-Billancourt, European Li-Ion Battery Advanced Manufacturing (ELIBAMA).

Trigg, T., Telleen, P., Boyd, R., Cuenot, F. (2013) Global EV outlook: understanding the electric vehicle landscape to 2020. Paris, International Energy Agency.

Tukker, A. (2015) Product services for a resource-efficient and circular economy - A review. Journal of Cleaner Production. **97**, 76–91.

Tukker, A., Tischner, U. (2006) Product-services as a research field: past, present and future. Reflections from a decade of research. Journal of Cleaner Production. **14**(17), 1552–1556.

Tunn, V.S.C., Bocken, N.M.P., van den Hende, E.A., Schoormans, J.P.L. (2018) Business Models for Sustainable Consumption In The Circular Economy: An Expert Study. Journal of Cleaner Production. **212**, 324–333.

U.S. Department of Energy (2017) Cost and price metrics for automotive lithium-ion batteries. Washington, D.C., USA.

U.S. Department of Energy (DOE) (2014) The History of the Electric Car. [online]. Available from: http://energy.gov/articles/history-electric-car [Accessed April 1, 2016].

Ugarte, S., Larkin, J., van der Ree, B., Swinkels, V., Voog, M., Friedichsen, N., Michaels, J., Thielmann, A., Wietschel, M., Villafafila, R. (2015) Energy Storage: Which market designs and regulatory incentives are needed? [online]. Available from: http://www.europarl.europa.eu/RegData/etudes/STUD/2015/563469/IPOL_STU(2015)563469_EN.pdf.

UL The Afterlife of Electric Vehicle Batteries. 2017. [online]. Available from: http://www.ul.com/inside-ul/the-afterlife-of-electric-vehicle-batteries/.

United Nations Secretariat (2018) The Sustainable Development Goals Report 2018. [online]. Available from: https://www.un.org/development/desa/publications/the-sustainable-development-goals-report-2018.html [Accessed January 31, 2019].

Upward, A., Jones, P. (2016) An ontology for strongly sustainable business models. Organization & Environment. **29**(1), 97–123.

Viswanathan, V. V, Kintner-Meyer, M. (2011) Second use of transportation batteries: maximizing the value of batteries for transportation and grid services. IEEE Transactions on Vehicular Technology. **60**(7), 2963–2970.

Warner, N.A. (2013) Secondary life of automotive lithium ion batteries: an aging and economic analysis. Doctoral Dissertation, The Ohio State University.

Wei-Pang, Y. (2017) Introduction to DBMS. Database Management Systems. [online]. Available from: http://opencourse.ndhu.edu.tw/ pluginfile.php/944/mod_resource/content/0/Advanced_Database_Management_System/unit1.pdf.

Wells, P., Nieuwenhuis, P. (2015) EV business models in a wider context: balancing change and continuity in the automotive industry. In D. Beeton & G. Meyer, eds. Electric Vehicle Business Models - Global Perspectives. Cham, Switzerland: Springer, pp. 3–16.

Whittingham, M.S. (2004) Lithium batteries and cathode materials. Chemical Reviews. **104**(10), 4271–4301.

Whittingham, M.S. (2008) Materials Challenges Facing Electrical Energy Storage. MRS Bulletin. **33**(04), 411–419.

Williams, B., Lipman, T. (2011) Analysis of the combined vehicle-and post-vehicle-use value of lithium-ion plug-in-vehicle propulsion batteries: task 3, second life applications and value of ‘traction’ lithium batteries. University of California, Berkley—Transportation Sustainability Research Center, Technical Report, Berkley, California, USA.

Williams, B., Lipman, T. (2010a) Strategy for Overcoming Cost Hurdles of Plug-In-Hybrid Battery in California. Transportation Research Record. **2191**(1), 59–66.

Williams, B., Lipman, T. (2010b) Strategy for overcoming cost hurdles of plug-in-hybrid battery in california - integrating post-vehicle secondary use values. Transportation Research Record: Journal of the Transportation Research Board. **2191**, 59–66.

Winslow, K.M., Laux, S.J., Townsend, T.G. (2018) A review on the growing concern and potential management strategies of waste lithium-ion batteries. Resources, Conservation and Recycling. **129**(November 2017), 263–277.

Wolfs, P. (2010) An economic assessment of ‘second use’ lithium-ion batteries for grid support. In 20th Australasian Universities Power Engineering Conference (AUPEC), 5 - 8 December 2010. Christchurch, New Zealand: IEEE, pp. 1–6.

Wood, D.L., Li, J., Daniel, C. (2015) Prospects for reducing the processing cost of lithium ion batteries. Journal of Power Sources. **275**, 234–242.

World Commission on Environment and Development (WCED) (1987) Our Common Future.

Oxford University Press: Oxford.

World Economic Fourm. 2019. The Global Risks Report 2019. Available at: https://www.weforum.org/reports/the-global-risks-report-2019 (Accessed 1st April 2019)

Worthington, I., Britton, C. (2003) The Business Environment. London: Financial Times Prentice Hall.

Xu, B., Qian, D., Wang, Z., Meng, Y.S. (2012) Recent progress in cathode materials research for advanced lithium ion batteries. Materials Science and Engineering R: Reports. **73**(5–6), 51–65.

Xu, J., Dou, S., Liu, H., Dai, L. (2013) Cathode materials for next generation lithium ion batteries. Nano Energy. **2**(4), 439–442.

Yang, M, Evans, S., Vladimirova, D., Rana, P. (2017) Value uncaptured perspective for sustainable business model innovation. Journal of Cleaner Production. **140**, 1794–1804.

Yang, Miying, Vladimirova, D., Evans, S. (2017) Creating and capturing value through sustainability. Research-Technology Management. **60**(3), 30–39.

Yang, M., Vladimirova, D., Rana, P., Evans, S. (2013) Developing the Sustainable Value Analysis Tool (SVAT). Institute for Manufacturing, University of Cambridge, United Kindom. (July 2016).

Yang, M., Vladimirova, D., Rana, P., Evans, S. (2014) Sustainable value analysis tool for value creation. Asian Journal of Management Science and Application. **1**(4), 312–332.

Yin, R.K. (1994) Case Study Research: Design and Methods. London: SAGE.

Yin, R.K. (2003) Case study research - design and methods. 3rd ed. London: SAGE.

Yin, R.K. 2011. Applications of case study research. London: SAGE.

Yip, A.W.H., Bocken, N.M.P. (2018) Sustainable business model archetypes for the banking industry. Journal of Cleaner Production. **174**, 150–169.

Yong, J.Y., Ramachandaramurthy, V.K., Tan, K.M., Mithulananthan, N. (2015) A review on the state-of-the-art technologies of electric vehicle, its impacts and prospects. Renewable and Sustainable Energy Reviews. **49**, 365–385.

Yun, L., Linh, D., Shui, L., Peng, X., Garg, A., Loan, M., Le, P., Asghari, S. (2018) Metallurgical and mechanical methods for recycling of lithium-ion battery pack for electric vehicles. Resources, Conservation & Recycling. **136**(April), 198–208.

Zackrisson, M., Avellán, L., Orlenius, J. (2010) Life cycle assessment of lithium-ion batteries for plug-in hybrid electric vehicles – critical issues. Journal of Cleaner Production. **18**(15), 1519–1529.

Zeng, X., Li, J., Ren, Y. (2012) Prediction of various discarded lithium batteries in China. In IEEE International Symposium on Sustainable Systems and Technology (ISSST), 16 - 18 May 2012. Boston, MA, USA: IEEE International Symposium, pp. 1–4.

Zhang, M., Tse, Y.K., Doherty, B., Li, S., Akhtar, P. (2018) Sustainable supply chain management: Confirmation of a higher-order model. Resources, Conservation and Recycling. **128**, 206–221.

Zheng, Y., Dong, Z.Y., Xu, Y., Meng, K., Zhao, J.H., Qiu, J. (2014) Electric vehicle battery charging/swap stations in distribution systems: comparison study and optimal planning. IEEE Transactions on Power Systems. **29**(1), 221–229.

Zott, C., Amit, R. (2010) Business model design: An activity system perspective. Long Range Planning. **43**(2–3), 216–226.

Zott, C., Amit, R. (2008) The fit between product market strategy and business model: implications for firm performance. Strategic Management Journal. **29**(1), 1–26.

Zott, C., Amit, R., Massa, L. (2011) The business model: recent developments and future research. Journal of Management. **37**(4), 1019–1042.