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Macro environmental analysis of the electric vehicle battery second use market

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Abstract—The end-of-life (EOL) strategy of repurposing degraded electric vehicle (EV) batteries in second use applications holds the potential to reduce first-cost obstacles of EVs. With a prospective EV market uptake, increasing numbers of retired batteries will be available soon for battery second use (B2U). But this emerging secondary market remains unclear from a business model perspective. This paper evaluated the evolving B2U market from a macro environmental perspective to comprehend key opportunities and threats in the future.

Index Terms—Battery Second Use; Macro-Environment; Business Strategy; Business Models; Electric Vehicle

I. INTRODUCTION

The global automotive industry appears to be on the tip of a revolution towards electric mobility, especially with regards to electric vehicles (EVs), which use chemical energy stored in rechargeable battery packs. However, today a wider market uptake of EVs is mainly hindered by the high costs of commercially installed battery packs [1]. Furthermore there exists the criticism that EVs are seen as ‘green washing’ as most vehicles are still charged with non-renewable electricity such as from coal and gas, which transfers emissions from the transport to the energy sector [2]. Simultaneously, there is an increasing concern over the quality and continuity of supply and a trend towards renewable energy production and decentralized generation such as photovoltaic and wind turbines, which all stress the importance for adequate electrical storage capacities in upcoming years [3].

EVs have recently attracted increased attention from the electricity markets as they can provide valuable services to the energy markets by offering grid services such as peak load shifting and integrating renewable energies [4], [5]. 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 [6], [7].

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 recapturing value from these batteries in alternative secondary applications could potentially be an engine for the transition towards a more sustainable transport sector [8], [9]. In this respect, repurposing 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 [10]. However, as these batteries still remain a state of health of around 70%-80%, one feasible solution to reuse 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 and back-up [11]–[14].

The global B2U market is predicted to grow from \$16 million in 2014 to \$3 billion in 2035 [15]. Many studies [10]–[13], [16]–[21] 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 [8], [18]–[21]. This means that degraded EV batteries may disrupt the current shape of the automotive and energy markets as they represent much cheaper electricity storage from renewables than is available today as well as

that EV manufacturers can charge less for their vehicles if their batteries prove to have value in a second life. Thus, 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.

The paper is organised as follows: Section II describes the research approach, Section III discusses opportunities and threats in the emerging B2U market from a macro environmental perspective, followed by conclusions and future research directions in Section IV.

II. RESEARCH APPROACH

This research aims to contribute to the scientific literature on business strategy in the case of EV B2U as very few authors [1] 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 [22]. 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 [23]. Finding the right business models at an early stage in emerging industries such as the B2U market is however still very rare [24].

Thus, novel business strategies around B2U have emerged such as the appearance of the start-up company Better Place that introduced the concept of battery swapping stations, which replace degraded EV batteries with a fully charged battery of the same type in less than 5 minutes [25]. 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 that current prevailing business models and strategies in the EV B2U industry might be considered under new approaches from product-based towards fully service driven [26].

Due to the complex and exploratory 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 [27]. 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 [28]. 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 (Fig. 1).

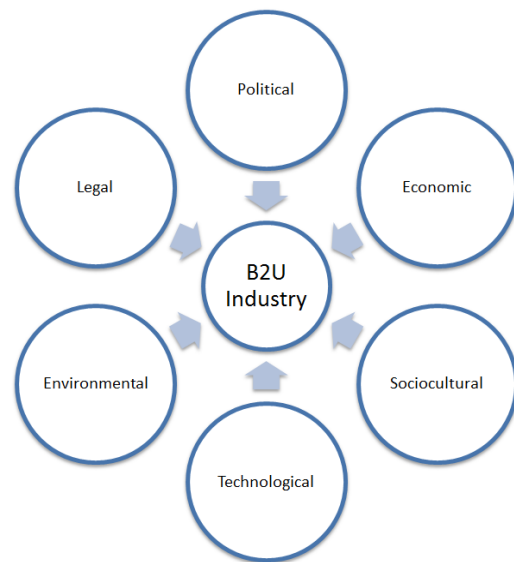


Figure 1. The PESTEL framework

The application of this strategic management tool allows comprehending the 'big picture' through 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 [29]. 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 [30]. 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.

III. 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 manufacturers evaluating how much value their batteries have in a second life through the development of pilot projects, as presented in Table I.

TABLE I. EXAMPLES OF B2U PILOT PROJECTS

Joint Ventures	Description	Location
Daimler GETEC/The Mobility House Remondis/EnBW	Battery storage unit with a total capacity of 13 MWh using degraded EV batteries from Daimler EV models	Luenen, Germany
BMW/PG&E	18-month pilot project to demonstrate EV smart charging and optimization grid efficiency with participation of 100 BMW i3 owners	San Francisco, USA
Nissan Sumitomo (4R Energy)/Green Charge Networks	System (600 kWh/400kWh): 16 Nissan Leaf LIBs regulate energy from a solar plant	Osaka, Japan
BMW/Vattenfall/ Bosch	2,600 battery modules from 100 electric cars, and provides 2MW of output and 2.8MWh of capacity	Hamburg, Germany
Renault/Connected Energy Ltd	“E-STOR”: on-grid providing energy storage that prevents power grid overload and balances supply and demand	United Kingdom, Europe
Mitsubishi/PSA EDF/Forsee Power/ MMC	Bi-directional battery energy consumption optimization from retired batteries	Paris, France
General Motors/ ABB	5 Chevrolet Volt LIBs, 74 kW solar array & two 2 kW wind turbines to power a GM office building site	Michigan, USA

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.

A. The Macro Environment

A good starting point to comprehend this evolving industry from a business model perspective is to evaluate 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, as shown in Fig. 2.

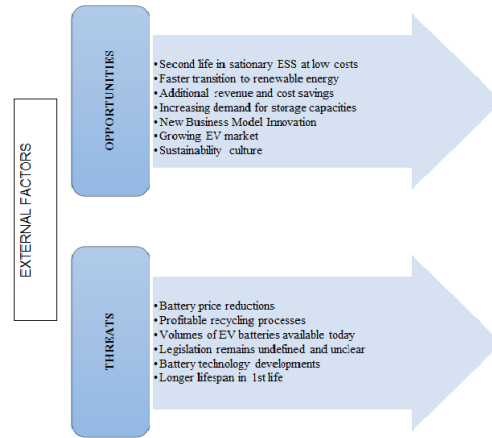


Figure 2. Opportunities and threats of battery second use industry

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 (Fig. 3). Essentially, B2U can help improve first cost hurdles of traction batteries and EVs respectively through implementing the principles of the circular economy approach that are to keep products and materials in a closed-loop life cycle by preserving natural capital, optimising resource yields and minimising system risks.

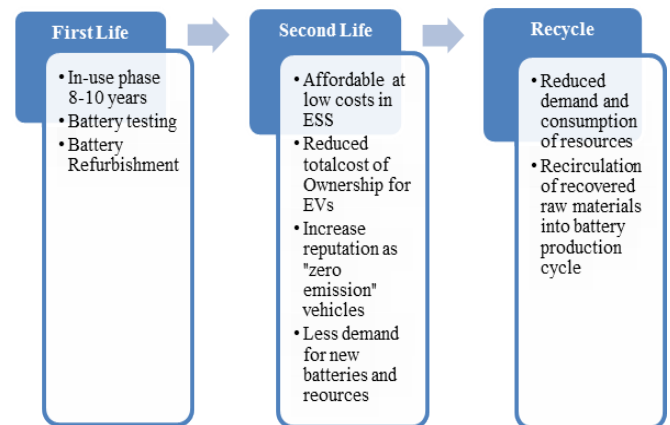


Figure 3. Battery second use process

A recent study [31], using EV sales forecasts as set out by [32] and considering average battery sizes between 24 kilowatt-hours (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 installed capacity of secondary batteries are predicted to reach 230 Gigawatt hours (GWh) in 2025 and an increase by four times to 1000 GWh in 2030 [31]. Previous studies [10], [33] estimate further 10 years of battery lifetime in B2U applications (after automotive service) with initial 80% capacity and an average decrease of 7.5% by year in their available capacity, reaching 50% at the end of their stationary life before undergoing recycling processes. Hence, B2U may generate additional revenues and decrease total cost of ownership and environmental impact of EVs.

There are two major business opportunities for degraded EV batteries, which are to create groups of battery packs for larger commercial/industrial applications (25kWh – 50 Megawatt hours) or for smaller applications such as residential related or commercial offices and buildings (3-4 kWh) [34]. From an economic point of view and given that the B2U industry is still in its infancy stage, it is less risky to invest in many small applications such as residential energy storage. This economic potential in smaller applications 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 [35]. 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 [36].

B2U may have 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. A study by [17], using different assumptions on battery degradation, repurposing costs and competitive technologies, estimated that B2U is economically viable for commercial and industrial end-users with payback periods of 7-10 years and a selling price of a repurposed EV batteries between \$38/kWh - \$132/kWh. But, these estimates may not include all possible energy storage market opportunities of B2U as well as that prospective cheaper and more technological advanced battery technologies may drive down the residual value of retired EV batteries.

From a business model perspective, within the emerging B2U and interrelated EV industry a mature business model is far off as the core elements of the traditional business model are still unclear such as to the value proposition, target customer segments and roles within the value network. Hence, business model innovation through the appearance of the sustainable technology B2U may create new sources of value and reconfigures the network of stakeholders involved in creating

while having a positive impact on the environment and society [37], [38]. This will lead to firms no longer acting autonomously but it is likely that in the future, specialised companies will repurpose and distribute retired EV batteries in close collaboration with automotive original equipment manufacturers [39].

2) Threats

In theory everyone can agree, that B2U in energy storage applications can increase total battery life time, address resource consumption and waste management issues and open 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, one study [40] 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 should 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 [41] 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 battery packs from leading EV manufacturers are predicted to be even lower, at around \$300/kWh. The authors suggest in a further study [42] 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 [43]. 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 [44]. 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 [45] 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 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.

IV. CONCLUSIONS AND FUTURE RESEARCH

This paper highlights that 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.

This paper further emphasizes that new relationships between the automotive and energy sectors are forming where it is likely that in the future inter-industry collaboration as part of business model innovation approaches is key to create additional sources of value.

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 sustainable competitive advantage as a strong research gap from a business model perspective remains for both industry and academics.

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