A Data Driven Approach for Efficient Re-utilization of Traction Batteries

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***Abstract*— As electric cars become more and more affordable to broader parts of our society the number of new registrations start to increase. Inevitably, an increased number of resources consuming cars bring new challenges to raw material supply and electrical power networks based renewable sources. Traction batteries are used in electric cars for power. An approach to solve both issues is second -life applications for used traction batteries. Second-life applications are a way of reusing traction batteries, which cannot be used in electric cars anymore due to challenging requirements. One way of using the traction batteries in their second-life is to use them for maintaining a fixed frequency on electrical networks even if peaking demand cannot be matched by a sufficient supply. As high availability in these power networks requires suitable storage. It lowers material consumption for otherwise newly produced battery systems and reduces costs for the second-life applications users. Nevertheless, the current state of recycling and identification of potential second-life batteries are highly cost intensive but can be improved by usage and combination of data. In this paper, we explore an approach for using data to increase efficiency and reduce the cost of second-life applications of traction batteries in electric cars. But in order to move to a data driven approach for re-utilization of traction batteries, there are various challenges in the existing system. We identify these challenges and propose solutions.**

Keywords-recycling; electric-vehicles; traction batteries; data driven; blockchain

I. INTRODUCTION

The current change of mobility concepts from conventional to electric-cars leads to several upcoming challenges. First of all, the composition of the entire vehicle itself differs vastly from current vehicles as electric powertrains depend on rare and expensive raw materials. Just to name tantalum, nickel and lithium [1]. Furthermore, societies endeavor to alter their power supplies away from centralized and ecologically damaging power plants to smaller, decentralized and emission friendly technologies [2]. In order to maintain safe and reliable power supply, vast amounts of storage capacity have to be available. This is due to the nature of most renewable energy sources as they highly depend on wind or sun exposure. An approach to solve the lack of high available storage power is to use batteries in special facilities or even on a consumer level. The high cost for the batteries itself plays a big role in the economic feasibility and slower the spread of this approach.

One way to reduce costs and improve ecological impact is to reuse traction batteries after the vehicle or the battery exceeded an end of life criteria. Traction batteries are responsible to supply the electric powertrain with energy. They operate in high voltage spectrum. Since material consumption for producing new batteries can be avoided. This so called second-life approach which lowers the initial investment costs for battery-based power storage solutions and improves a net present value up to 33% after 20 years following for business orientated use [2]. Core process for a sufficient implementation of a second-life concept is the identification of traction batteries and their current state of health in order to be able to determine their potential for another use case or a safe recycling route. The current state of battery health can be determined by the battery impedance and the battery capacity [3]. Both information is saved in the battery management system of each battery but can so far only be accessed by the original equipment manufacturer. Third parties must rely on own measurements which involves a big workload and therefore costs for a save and reliable categorization. Just to name the process of capacity determination, it involves tempering each battery on a set temperature and load the battery till no more loading is possible. In a next step, the battery must be discharged, and the current has to be measured which results in a value for the available capacity. While present amounts of returning electric vehicles remain relatively low, compared to conventional vehicles, current dismantling processes and categorizing of each traction battery strongly relies on OEMs [4]. But with, further increasing flows third parties can be expected to play a big role in the whole dismantling industry.

During the life of an electric vehicle, a lot of data is generated by several participants, which, after being used for its initial purpose, is not being collected and put into relation to each other. An approach to increase the efficiency of the recycling industry is to improve the information exchange between all the stakeholders, which are part of the circular economy [5]. Especially second-life applications are using the data of the traction batteries throughout its lifecycle in order to define their further areas of application. If the battery could be tracked in its entire lifecycle the relevant data from it can be used to optimize the dismantling process and to determine the second-life applications of traction batteries. However, there are some challenges in the existing systems. We identify these challenges, such as access to the battery data, difficulties in estimating the batteries health easily and providing a secure and trusted platform for storing and accessing data.

The rest of the paper is structured as following. Section II. gives a brief overview of related work. The lifecycle of traction battery and the stakeholders are shown in Section III. Section IV. presents the identified challenges. An approach to solve the identified problems is described in Section V. In Section VI. an example of application scenario is presented. Section VII. shows the evaluation plan. Finally, Section VIII. concludes and gives insights of the future work.

II. STATE OF THE ART

As mentioned in the motivation of this paper the current number of new electric car registrations is strongly increasing in countries such as Germany. Nevertheless, remains relatively low compared to the number of conventional car registration [6]. Nevertheless, the prospects are seemingly good for battery-based mobility concepts and therefore a sufficient process for occurring waste streams should be conducted. An approach for a possible solution can be seen in China. Due to high amounts of emissions in local cities, policies were focusing and emphasizing electric vehicles over the last years. In order to obtain an efficient recycling route for upcoming amounts of waste streams, China introduced a first traceability management platform for traction batteries [7]. It aims to trace the whole lifecycle of a battery and use the data for a better recycling track. Not only original equipment manufacturers but also battery producers and recycling companies need to register themselves on the platform and each battery is tracked using a unique identification number.

Another corresponding approach in keeping track of used materials in the car industry is the International Material Data System [8] (IMDS). Currently 35 OEMs and around 120.000 suppliers provide data of used materials in their products. The IMDS is than for example the basis for an EU type approval.

Furthermore, there are already existing solutions for circular economy concepts. For end-of-life vehicles are existing already strategic planning and optimization approaches to find optimal network configurations [9]-[10].

In other industries, an increase in efficiency through the targeted use of data has long been established. A good example for this is logistic. Since the introduction of Enterprise Resource Management System, the efficiency was increased highly [11].

III. TRACTION BATTERY LIFECYCLE

Defining a relevant lifecycle for traction batteries used in electric cars is challenging. In order to keep a simple overview of the lifecycle, in this paper we present only the core relevant stakeholders. Figure 1 illustrates the adopted lifecycle of a traction batteries with previously mentioned stakeholders in focus.

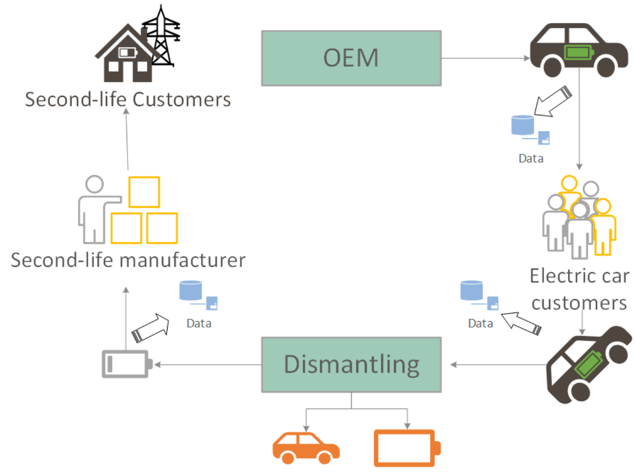

Figure 1: Lifecycle of traction battery.

The **Original Equipment Manufacturer** (OEM) can be seen as the starting point of the life of a traction battery and electric vehicle. First market design, production and sales are executed by the OEM. In this process a set of data such as installed battery technology, set up of battery management system and unique vehicle identification number is being generated but not accessible without the OEM's interfaces.

The next step of the examined lifecycle are the vehicle **customers**. Depending on the individual use case a vehicle can be transferred to numerous owners. Currently the only safe way to keep track of ownership are the corresponding vehicle registration documents. This data is sometimes not digital and therefore lost for other use cases. Furthermore, while being used the vehicle generates vast amounts of data. This includes data concerning the current state of health of a battery or general usage profiles. This data can if only be accessed by the OEM or associated partners and not by other participants.

After being used to a certain degree an electric vehicle will be brought back to a suitable dismantling process. Currently only the OEM's are qualified to dismantle high voltage systems from their own electric cars in a greater scale. It is to be assumed that with greater amounts of returning vehicles this process will be executed by third parties such as qualified **dismantlers**. Comparable solutions are already in place for conventional vehicles since many years. The dismantler needs to identify certain groups of batteries in order to decide for a different track. Either the batteries qualify for a second-life application or merely a recycling process. As explained in the motivation the data for a fast and reliable decision is only to be accessed by solutions provided by an OEM or must be conducted through a time and cost consuming process of measuring and evaluation each battery manually.

Following the end of first lifecycle, after being dismantled and potentially grouped in a qualified track, the batteries are being used by **second-life manufacturers** to build new products. In this process data of the state of health and potential use scenarios of each battery is needed and is, in an ideal case, provided by the dismantling shareholder.

The final second life product is than being used by a second life customer in a suitable use case. Vastly in a fixed location and till a second end of life criteria will be matched.

IV. IDENTIFIED CHALLENGES

Second-life applications of traction batteries have many advantages. Once the battery is no longer usable in the vehicle, they can be implemented in other systems such as maintaining electric networks. We identify that using the data of the battery lifecycles can help all the stakeholders in the chain. Mainly the second life manufacturer as they can easily determine the battery's health by seeing the data of its lifecycle. This on one hand reduces the cost of manufacturing second life applications and on other hand increases the efficiency of second life application as the health of the battery is well recognized. But there are various problems in the existing systems for the required data flow. We identify the following challenges as the main challenges for this paper.

1. Tracing of the batteries - In order to determine a precise battery health, it is very important to collect data about it through its entire lifecycle. The batteries cannot be easily traced currently throughout its lifecycle, thus it’s very expensive to retrieve the battery health data when required.
2. Access to the data- Currently, it's not easy to access the battery data. The data is produced or collected by all the stakeholders but it's difficult for the other stakeholders to access it. Also, in most cases the batteries must be manually checked in order to access the health data from the battery management systems.
3. Secure platform to store and access data- The system should be able to store and give access to the data securely. The system should guarantee data security, i.e., the data is always secure from unwanted authorized users.
4. Trusted Platform- In the lifecycle of a traction battery, data is generated by various sources and stakeholders. In order to use data for efficient re-utilization of traction batteries the accuracy of the data is very important. If the data is not accurate or is tampered at any point the results of actual battery health state changes. Thus, the platform should be able to guarantee data integrity and trust, i.e., the data is consistent, accurate and not changed at any point in time.

Current technologies, such as RFID, do not fulfill all aspects in order to match the identified challenges. First of all, the maximum storage capacity of an RFID-Chip is limited and depending on the amount of data stored not sufficient enough. Furthermore, RFID does not offer a complete solution for sharing data while maintaining security and data integrity. Lastly in case of a damaged RFID-Chip all data would be gone and can’t be retrieved.

V. PROPOSED SOLUTION

In order to reduce the costs and make the second-life applications of traction batteries more efficiently, we realized the health of the battery should be tracked through its entire lifecycle. The data about the battery's health can be used to optimize the dismantling process and to determine the second-life application of the battery based on its health. Thus, tracking the batteries through its lifecycle reduces the cost and error rather than checking it manually.

The first requirement for tracking a traction battery is that it should be unique. As a result, we propose that during the production, batteries should get a “unique address”. Once the battery has a physical unique address this address must be stored somewhere as digital copy so that more data about it can be added as the batteries moves through various steps in its lifecycle. One way for keeping this digital data of the batteries is adding this to a database. Nevertheless, in order to provide more security and trust to the digital data we propose tracking the batteries lifecycle using blockchain technology (see Figure 2). This enables the creation of a decentralized environment, where the cryptographically validated transactions and data are not under the control of any third-party. Any transaction ever completed is recorded in an immutable ledger in a verifiable, secure, transparent and permanent way, with a timestamp and other details [12].

A blockchain is a decentralized, distributed database that is used to maintain a continuously growing list of records, called blocks. Each block contains a timestamp and a link to a previous block. By design and by purpose blockchains are inherently resistant to modification of the data. Functionally, a blockchain can serve as an open, distributed ledger that can record transactions [13]-[14].

In summary the blockchain is a distributed database existing on multiple computers at the same time. It is constantly growing as new sets of recordings, or ‘blocks’, are added to it. Each block contains a timestamp and a link to the previous block, so they form a chain. The database is not managed by anybody; instead, everyone in the network gets a copy of the whole database. Old blocks are preserved forever, and new blocks are added to the ledger irreversibly, making it impossible to manipulate by faking documents, transactions and other information. Blockchain is a transforming technology and can help the stakeholders on in the chain to securely trace the battery’s data and access data. Further some blockchain technologies (for example Ethereum [15]) are providing smart contracts. A smart contract is a self-executing script that reside on the

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blockchain. This contract could be used to manage the data exchange between the different parties in a blockchain to involve them in a contractual agreement [14] [16] . Figure 2 illustrates an outline of the overall approach to enable the data exchange.

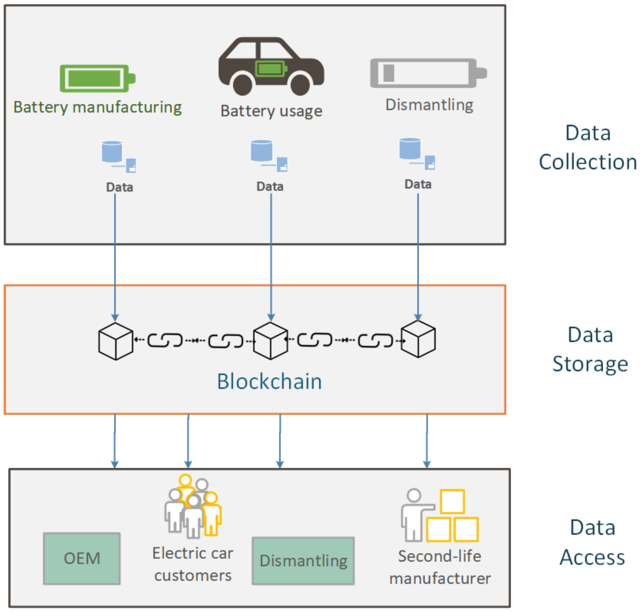

Figure 2: Overall approach.

As shown in Section IV. The proposed platform to store and access data should be secure and trustful. Data Integrity, i.e., guarantee that the data is consistent and accurate at every point is very important for using data driven approach for efficient re-utilization of traction batteries. The data could be changed by the stakeholders for benefits or can be accessed by unauthorized users and altered. Thus, the features of blockchain providing higher security, data integrity and immutability motivates us to use it as a database for tracking the lifecycle of traction batteries. Once the data is stored on blockchain it cannot be altered hence always providing accurate battery health.

In the moment the data is stored on blockchain it can be accessed from there whenever required. And as the data is stored on blockchain it becomes almost impossible to manipulate the data providing higher data integrity, i.e., it can be ensured that the data is accurate and consistent over its entire lifecycle.

Blockchains are mainly associated with cryptocurrencies but the its scope is far beyond just cryptocurrencies. There are various types of blockchains and a wide array of implementation approaches. It can be categorized in three types: Public, consortium and private.

A public blockchain is where anyone in the world can become a node in the transaction process. It is a completely open public ledger system. It is also be called permission less ledgers [17].

In private blockchains, the write permissions are with one organization or with a certain group of individuals. Read permissions are public or restricted to a large set of users [17].

Consortium blockchains let a group of people establish a distributed ledger. It can also be known as a permission private blockchain [17]. Thus, we propose using consortium blockchains for the tracking and data access of traction batteries as a distributed ledger between all the stakeholders is required.

Blockchain allows multiple competing parties to securely interact with the each other. It has shared immutable ledgers for recording transaction history and thus it can be used for tracking the batteries securely and lets the stakeholders access the data easily [18]. Thus, blockchain can be used as a standard interface to store and access data securely.

A uniform format should be sought for the data structure. An example of this would be the eCl@ss standard, which is the only worldwide ISO/IEC-compliant data standard for goods and services [19]. The advantage of one standard is that every stakeholder than finally has the same understand of the data and can use it easily.

VI. SCENARIO BASED ON PROPOSED SOLUTION

In this Section, we show a scenario of how data can be tracked with our proposed solution and be used for the re-utilization of traction batteries. Figure 3 shows the three layers- data collection, data storage and data access.

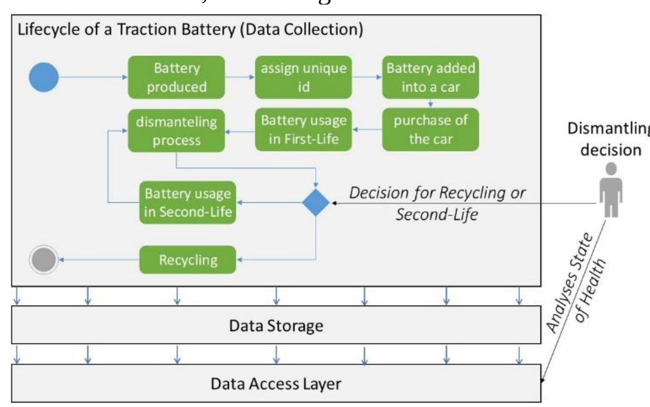

Figure 3: Example of an Application Scenario.

The data collection starts once the battery is produced. A timestamp of its production date is stored in the blockchain. The blockchain here is the data storage mechanism. While the battery is produced, we propose that the battery is given a unique id which can be used to track the battery. Thus, while production the battery's unique id and production timestamp is stored. After the production, the battery is added to the vehicle. The timestamp when the vehicle is sold can be added. During the battery's first life in the car, the health of the battery can be tracked through its charging cycles from various sources. One source to track the charging cycles is using the charging stations for it. This approach is benefiting from growing charging infrastructure provided by the OEMs

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themselves. All the data about the battery's health through charging cycles can be stored. After the battery is used in its first life it goes to the dismantling process where the decision whether it can be used for second life application or should be recycled is to be made. This decision can be easily made by analyzing the data of the battery's lifecycle, with our proposed solution as all the data is already stored and available rather than manually checking it. This reduces the cost of the process and helps in taking a precise dismantling decision. When the battery is still usable for a Second-Life application, data about its health can also be used to determine for which application, it can be used in. After the battery serves its second-life usage it returns to the dismantling process where a further use or recycling decision can be easily made by looking at the health data.

VII. EVALUATION PLAN

In order to implement the proposed solution suitable technologies and type of blockchain has to be selected. Public blockchains such as bitcoin and Ethereum are not suitable for this scenario. Thus, firstly we will evaluate the blockchains and related technologies. However, despite all the advantages of the Blockchain it does not make sense to store all the data in the Blockchain. Thus, depending on the size of data more advanced data storage mechanisms has to be selected. Possibilities are on-chain and off-chain data storage. In such as a mechanism only critical data such as timestamps and charging cycles data is only stored for access to everyone. Other data is stored in an off-chain system.

But further research in this is required. Also, a uniform format should be made for the data structure. An example of this would be the eCl@ss standard, which is the only worldwide ISO/IEC-compliant data standard for goods and services [19]. Currently, we are evaluating suitable blockchains, technologies and data structure for the proposed solution. The standard should be oriented on eCl@ss, which is the only worldwide ISO/IEC-compliant data standard for goods and services [19].

VIII. CONCLUSION AND OUTLOOK

In this paper we present a data driven approach for increasing efficiency of traction battery re-utilization by reducing related costs. In order to use data for this purpose we identified two major problems in the existing system. Primarily, there is no existing mechanism to track the battery's lifecycle and secondly the stakeholders who are a part of the chain do not have access to the data of the batteries. For this we propose a mechanism, using blockchain, through which the data throughout the battery's lifecycle can be tracked and accessed. Blockchain provides higher security, data integrity, transparency, immutability and trust. Once the record is saved on a blockchain it cannot be changed thus it can be ensured that the data is real and was not manipulated at any point. There are various ways to implement it, but in this scenario a public blockchain is not feasible. A shared database with authorized access is required. Consortium blockchains let a group of people establish a distributed ledger. Thus, we propose using a consortium blockchain for the stakeholders or partners who are a part of the battery's lifecycle. Currently we are evaluating the technologies and platforms to establish a permissioned blockchain for the scenario shown in this paper. Our next steps will be the implementation of the proposed solution for traction batteries.

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REFERENCES

[1] G. Zhao, *Reuse and Recycling of Lithium-Ion Power Batteries*. Singapore: John Wiley & Sons Singapore Pte. Ltd, 2017.

[2] S. Fischhaber, A. Regett, S. Schuster, and H. Hesse, “Studie: Second-Life-Konzepte für Lithium-Ionen-Batterien aus Elektrofahrzeugen. Analyse von Nachnutzungsanwendungen, ökonomischen und ökologischen Potenzialen.,” *Begleit. und Wirkungsforsch. Schaufenster Elektromobilität*, 2016.

[3] K.-B. Holve, “Auslegungsaspekte von Batteriepacks und Batteriemanagement-Systemen,” Universität Duisburg-Essen, 2018.

[4] J. Neubauer, K. Smith, E. Wood, and A. Pesaran “Identifying and Overcoming Critical Barriers to Widespread Second Use of PEV Batteries,” *Nrel*, no. February, pp. 23–62, 2015.

[5] C. Knieke, S. Lawrenz, M. Fröhling, D. Goldmann, and A. Rausch, “Predictive and flexible Circular Economy approaches for highly integrated products and their materials as given in E-Mobility and ICT,” *Circ. Econ. Mater. Components E-mobility – CEM*^{2}, 2018.

[6] “Neuzulassungen von Pkw in den Jahren 2008 bis 2017 nach ausgewählten Kraftstoffarten.” [Online]. Available: https://www.kba.de/DE/Statistik/Fahrzeuge/Neuzulassungen/Umwelt/n_umwelt_z.html?nn=652326. [Accessed: 12-Apr-2019].

[7] “National NEV Monitoring And Mangement-Traction Battery Recycling And Traceability Platform.” [Online]. Available: https://www.tbrat.org/. [Accessed: 12-Apr-2019].

[8] “IMDS | Internationales Material Daten System.” [Online]. Available: https://www.mdsystem.com/imdsnt/startpage/index.jsp. [Accessed: 12-Apr-2019].

[9] O. Püchert, H.; Spengler, T. S.; Rentz, “Strategische

Planung von Kreislaufwirtschafts- und Redistributionssystemen - Am Fallbeispiel des Altautorecyclings," *Zeitschrift für Planung, 7 (1), pp. 27–44.*, 1996.

[10] F. Schultmann, B. Engels, and O. Rentz, "Closed-Loop Supply Chains for Spent Batteries," *Interfaces*, vol. 33. INFORMS, pp. 57–71.

[11] A. Rizzi and R. Zamboni, "Efficiency improvement in manual warehouses through ERP systems implementation and redesign of the logistics processes," *Logist. Inf. Manag.*, vol. 12, no. 5, pp. 367–377, 1999.

[12] M. C. Bacescu, "The 13 th International Scientific Conference eLearning and Software for Education Bucharest , April 27-28 , 2017," *13th Int. Sci. Conf. eLearning Softw. Educ.*, no. April, pp. 369–376, 2017.

[13] A. S. Bruyn, "Blockchain an introduction Research paper," 2017. *University Amsterdam* [Online]. Avaible: https://beta.vu.nl/nl/Images/werkstuk-bruyn_tcm235-862258.pdf [Accessed: 12-Apr-2019]

[14] M. Finck, "Blockchain Technology," in *Blockchain Regulation and Governance in Europe*, 2018, pp. 1–33.

[15] "Ethereum Project." [Online]. Available: https://www.ethereum.org/. [Accessed: 12-Apr-2019].

[16] A. Kosba, A. Miller, E. Shi, Z. Wen, and C. Papamanthou, "Hawk: The Blockchain Model of Cryptography and Privacy-Preserving Smart Contracts," in *Proceedings - 2016 IEEE Symposium on Security and Privacy, SP 2016*, 2016, pp. 839–858.

[17] "Paul Valencourt & Samanyu Chopra & Brenn Hill [Paul Valencourt] - Blockchain Quick Reference (2018, Packt Publishing)." .

[18] M. Santos and E. Moura, *Hands-On IoT Solutions with Blockchain*. 2019.

[19] "home: ecl@ss." [Online]. Available: https://www.eclass.eu/en.html. [Accessed: 12-Apr-2019].