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164 Sustainable and circular battery management - Conceptualization of an information model

Katharina Berger, Magdalena Rusch, Josef Peter Schöggl, Rupert J. Baumgartner

Christian Doppler Laboratory for Sustainable Product Management enabling a Circular Economy, Institute for Systems Sciences, Innovation- and Sustainability Research, University of Graz, Merangasse 18/I, 8010 Graz, Austria, katharina.berger@uni-graz.at .

Abstract

Circular value chains of electric vehicle traction batteries have the potential to offer benefits, such as securing the supply of raw materials, reducing environmental stresses, as well as enhancing social equity. For a linear value chain being able to transition towards a more circular one, value chain stakeholders are facing different decision-making situations for which they require high-quality data. Such data could be provided by digitalization and its respective information technologies, such as the digital twin, which could resume the function as driving technology for so-called digital battery passports. In this context digital twin-driven digital battery passports may serve as valuable data source for respective value chain stakeholders, who are facing different decision-making situations when pursuing sustainable and circular product management efforts. However, for a digital battery passport being a useful supporting tool, it needs to offer appropriate information to its users. This contribution provides a conceptual information model of a digital battery passport for an electric vehicle traction battery in the context of sustainable product management. The conceptual model was developed by conducting a stakeholder mapping according to SCOPIS, a systematic literature review, as well as three focus group workshops with industry experts. These steps allowed to pursue a conceptual battery passport due to firstly generating an understanding of potential passport users, respective use cases, as well as data needs and requirements. The concept presented in this work details information types and requirements for different use cases of sustainable and circular battery management. With respect to structure, the current concept iteration comprises four information categories: (1) battery, (2) sustainability and circularity, (3) diagnostics, maintenance, and performance, and (4) value chain actors. The concept further constitutes of seven underlying information levels to structure presented information in a more meaningful way. The conceptual battery passport contains next to sustainability and circularity performance-related information also in-depth information on product performance and electrical engineering-related properties, as well as battery health to provide potential users with support in their sustainable battery management efforts in the context of a circular economy. With respect to future research steps, the presented concept will be further enhanced by results derived from on-going follow-up interviews. The validated concept will serve as foundation for a comprehensive information model for a digital battery passport for an electric vehicle traction battery.

Keywords: digitalization, data management, sustainability, circular economy, digital battery passport

Introduction

The push of powertrain electrification for road transport decarbonization purposes is projected to lead to an increase in the demand of corresponding electric vehicle traction batteries (EVB) in the upcoming years (Olivetti et al., 2017; Slater et al., 2019). EVBs contain in general critical raw materials, such as lithium, natural graphite, and cobalt. Such raw materials are sourced in countries, such as Chile, Bolivia, DR Congo, and China (Ballinger et al., 2019; Mayyas, et al., 2019). From an European perspective, supplies of such materials have to be secured (Mayyas et al., 2019), which could be achieved by pursuing the transition from traditional linear to more circular value chains (Buruzs and Torma, 2017). Next to securing raw material supplies, more circular value chains hold the potential to offer relief of environmental stresses, as well as enhanced social equity (Millar, et al., 2019). This has been also recognized by policymakers, such as the European Commission who is demanding in their proposal for a new regulation for batteries and waste batteries a transition towards more sustainable and circular battery value chains (European Commission, 2020). Such a transition requires the involvement of value chain stakeholders, who are facing decision-making situations when pursuing such a transition (Honic et al., 2019c). However, to support aforementioned decision-making situations, high-quality data is needed (Ellingsen et al.,2017; Saidani et al., 2019). In this context, digital battery passports (DBPs) have the potential to serve value chain stakeholders as valuable data source (Heinrich and Lang, 2019; Honic et al., 2019b). In general, DBPs are said to be unique for each battery, and contain respective value chain and life cycle data (Lemos, 2020). Such applications could be driven by information technologies, such as the digital twin, due to its ability to collect, store, analyze and monitor real-time data of its physical counterpart (Jones et al., 2020). Thus, DBPs could yield the potential to resume the function as enablers of sustainable and circular value chains (Circular Economy Initiative Deutschland, 2020; Honic et al., 2019b). The potential of such applications has also been recognized by the European Commission, who is demanding the implementation of DBPs for industry batteries, as well EVBs by January 2026 (European Commission, 2020). However, for a DBP to be able to resume such a supporting function, it has to fulfil value chain stakeholders' respective data needs and requirements, thus providing stakeholders with appropriate information (Honic et al., 2019a,b). Therefore, this work addresses the following question: *What kind of information does a digital twin-driven DBP for an EVB has to offer to respective value chain stakeholders to support their sustainable product management efforts?*

On the one hand, this work provides a conceptual DBP for an EVB in the context of sustainable product management (SPM). The presented conceptual DBP elaborates on an early version (Berger et al., 2021) by including the findings from empirical validation. On the other hand, the paper reports first theoretical and empirical insights into a DBP's data needs and requirements, potential data sources and implementation barriers. The empirical findings were derived in a set of focus group workshops with 22 stakeholders from the EVB value chain. The term SPM is defined as product management, which strives to minimize negative environmental and social impacts, whilst pursuing value chain-loop closing pathways.

Methods

The conceptual DBP presented in this work was developed in three research steps: (1) a stakeholder mapping according to the supply chain orientated process of identifying stakeholders (SCOPIS) (Fritz et al. , 2018), (2) a systematic literature review according to PRISMA (Moher et al., 2009), as well as (3) conducting three stakeholder focus group workshops (total n = 22). The stakeholder mapping served to identify potential users of a DBP. The consequently conducted systematic literature review built on the results derived from the SCOPIS and served to develop potential use cases for a DBP. This in turn allowed to derive potential information requirements a DBP has to fulfil in the context of sustainable product management. To identify suitable references for the SCOPIS and systematic literature review, the database Scopus, as well as search engines (Google Scholar, Ecosia) were used. With respect to selection criteria, publications in the English and German language were considered. A time horizon between 2010-2021 was chosen due to electric vehicles entering the mass market in 2009 (Tsakalidis and Thiel, 2018). Publications were not excluded based on their geographical context due to EVB value chain's being global ones (Mayyas et al., 2019; Rafele et al., 2020). With respect to publication types, both, peer-reviewed journal articles, as well as grey literature was considered. An exemplary list of employed keywords for the SCOPIS and PRISMA approach are provided in Table 1.

Table 1. Exemplary list of keywords for the SCOPIS and the literature review according to PRISMA

traction battery" AND "value chain"	"traction battery" AND "supply chain"	"lithium battery" AND "value chain"	"lithium battery" AND "supply chain"
"lithium battery" AND "second life"	"battery" AND "value chain"	"battery" AND "supply chain"	"digital battery passport"
"battery" AND "state of health assessment"	"battery" AND "stathe of health indicator"		

The literature review for research step one (SCOPIS) and two (stand-alone systematic literature review) was conducted between October 2020 and January 2021. The derived sample for both research steps led to an initial sample of 1140 peer-reviewed articles and 50 grey literature references. This sample was then subjected to several screening processes (i.e., title and abstract screening, full-text screening). References were excluded when they did not have any relations to the EVB value chain, EVB value chain actors, the EVB life cycle, EVBs in the context of circular economy, digital product passports, or potential use cases and respective data needs. Further references were identified during the full-text screening stage by applying a snowballing approach. The overall process resulted in 129 references that were used to develop the concept presented in this paper. A depiction of the sample development can be seen in Figure 1.

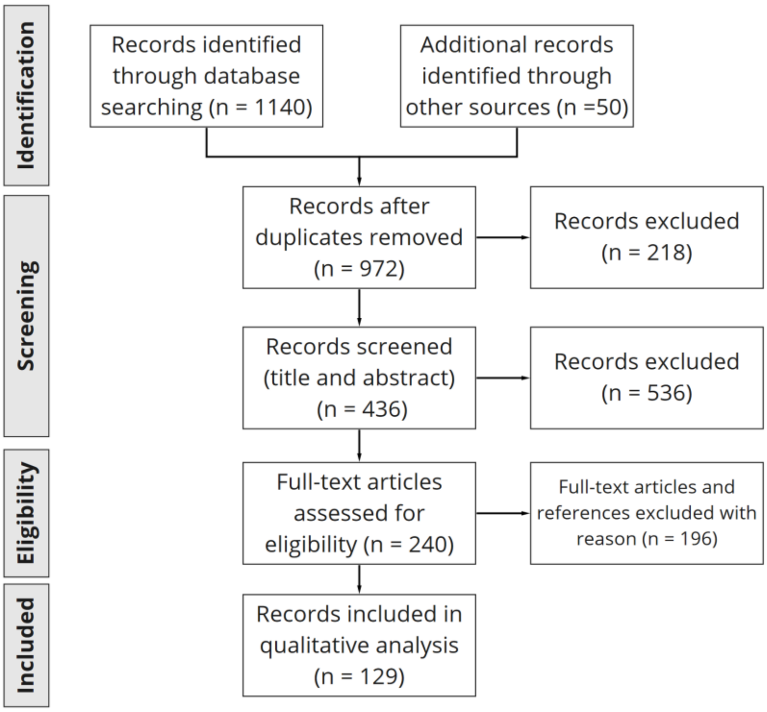

Figure 1. Literature sample development according to the PRISMA guidelines (Moher et al., 2009) in research step one and two.

After carrying out the stakeholder mapping and the systematic literature review, the respectively derived information served to develop a preliminary conceptual DBP. Therefore, identified data needs and requirements were compiled and grouped into information categories, which resulted in a preliminary conceptual DBP. This preliminary concept was subjected to a validation by conducting three online focus group workshops with industry experts. The focus group workshops served to generate deeper knowledge about the EVB value chain and its constitution, data needs and requirements a DBP should fulfil, as well as potential DBP implementation barriers. In total 20 EVB value chain representatives participated in the focus group series. With respect to participant selection criteria, as industry experts were considered who had affiliations to the EVB value chain, as well as minimum of five years of experience in the field. In addition, further participants were nominated by already recruited ones. Thus, the expert recruiting process was carried out in a systematic sampling approach.

Results and Discussion

This section contains the so far derived conceptual DBP, as well as its respective discussion. The proceeding content is structured as follows: Firstly, the conceptual DBP and its current structure is presented. Secondly, a discussion about data needs and requirements, thus what kind of information does a DBP of an EVB has to offer to its potential users, is provided. Subsequently, potential DBP data sources, as well as implementation barriers are discussed.

Results: Conceptual digital battery passport - overview

The conceptual DBP presented in this work consist currently of four main information categories, namely (1) battery, (2) sustainability and circularity, (3) diagnostics, maintenance, and performance, and (4) value chain actors. Those main categories further comprise respective sub-information categories. Therefore, the conceptual DBP was further structured by introducing underlying information levels, which contain respective sub-information categories. The pursuit of a “level” or “layer” logic was pursued to present a structured, and more meaningful conceptual DBP. However, the information levels do not indicate the degree of confidentiality. An overview of the developed concept and its first three information layers is provided in Figure 2. A more detailed description on the developed categories’ content and function, as well as discussions are provided in the proceeding sub-sections.

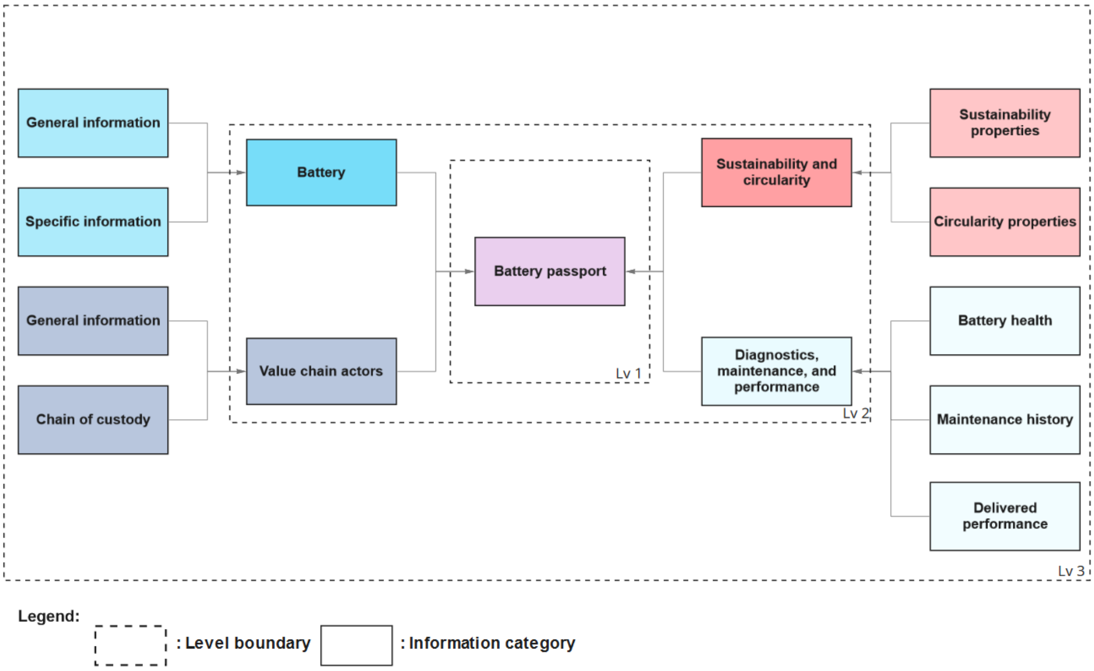

Figure 2. Concept of a Digital Battery Passport for an EVB (own depiction). Lv = level.

Results: Conceptual digital battery passport - battery

The main information category *battery* serves to provide value chain stakeholders with information that allows them to clearly identify the EVB at hand. Such information can be perceived as prerequisite when sustainable product management efforts are pursued (Honic et al., 2019b). Otherwise, value chain stakeholders might lack understanding of the product of interest, which in turn may complicate the pursuit of suitable actions to improve upon the sustainability and circularity performance of an EVB (Honicet al., 2019b).

Therefore, the main information category *battery* contains product-related information, which can be further divided into two sub-categories: *general product information*, and *specific product information* (see Figure 2). The sub-category *general product information* provides information on the battery type (e.g., a battery for an electric vehicle, a battery for energy storage purposes), battery chemistry, battery identifier (e.g., serial number, batch number), as well as battery manufacturer-related information (e.g., name of manufacturer, location of production site). The sub-category *specific product information* provides information on overall battery performance-related indicators (e.g., driving range, lifespan, charging times, energy consumption), as well as employed materials and substances (e.g., material/substance type, function). In addition, this sub-category contains information with respect to pack, module and cell level on electro and electrochemical engineering-related specifications (e.g., energy density, power density, energy content), as well as battery structure (e.g., number of modules, number of cells, employed assembly processes).

The preliminary category development was carried out by consulting peer-reviewed articles in the context of EVBs and EVB performances (e.g., Chen et al., 2019; Philippot et al., 2019; Stampatori et al., 2020), structure (Bai et al., 2020; Coffin and Horowitz, 2018; Jussani et al., 2017), as well as digitalization and circular economy (Wang & Wang, 2019). Furthermore, material passport-related research served for concept development purposes (Honic et al., 2019a,b,c). In addition, grey literature in the context of EVBs and circular economy (Brudermüller, 2020; Circular Economy Initiative Deutschland, 2020; Koller, 2020), as well as material passports provided inspiration for the concept development (Heinrich and Lang, 2019). In addition, publications provided by policymakers, such as the European Commission were consulted, due to them demanding the disclosure of certain product-related information on DBPs in the years to come (European Commission, 2020).

The preliminary information content of this category was further validated by industry experts in an online focus group workshop setting. The workshop participants came to the consensus that the information content of this category can be perceived as backbone of a DBP due to being needed to clearly identify the product at hand.

Results: Conceptual digital battery passport - sustainability and circularity

When facing decision-making situations related to sustainable product management, information about the product's sustainability and/or circularity performance (i.e., status quo, as well as life cycle performance) will be required. Such information serves to formulate and define targets for performance improvement purposes, as well as respective strategies and measures to reach said targets. In addition, such information may serve to identify potential life cycle hotspots, thus potential areas of improvement.

The main category *sustainability and circularity* provides information related to an EVB's sustainability and circularity performance. Category respective information can be further split into two sub-categories: *sustainability properties*, and *circularity properties* (see Figure 2). The sub-category *sustainability properties* provides information on an EVB's environmental and social impact. Hence, this sub-category contains information on respective indicators, corresponding impact categories, calculation methods, used inventory data for social and environmental assessment purposes, as well as applied standards and impact assessment methods. Furthermore, this sub-category provides information on employed material (e.g., hazardous, critical, primary/secondary). The sub-category *circularity properties* provides information on the EVB's circularity performance. In terms of structure and content, this sub-category follows the same logic as the preceding described sub-category. In addition, this sub-category provides information with respect to battery module and pack assembly processes, disassembly instructions, as well as pursued product design types (e.g., design for recycling, design for disassembly).

The preliminary category development was carried out by consulting peer-reviewed literature on material passports (Honic et al.,2019a,b,c), digitalization and sustainable supply chain management (Kouhizadeh et al., 2021; Nandi et al., 2021; Saberi et al., 2019; Wang and Wang, 2019), sustainability and circularity assessments (Ellingsen et al., 2014; Parchomenko et al., 2019; Saidani et al., 2019), as well as EVBs and EVB structure (Bai et al., 2020; Jussani et al., 2017). In addition, grey literature related to EVBs and the circular economy (Circular Economy Initiative Deutschland, 2020; Koller, 2020), product and material passports (Brudermüller, 2020; Heinrich and Lang, 2019), as well as regulatory papers (European Commission, 2020) were consulted.

The information content of this category was further subjected to expert validation in an online focus group workshop series. In general, focus group participants agreed upon the importance of environmental impact-related information on a DBP. With respect to information on an EVB's social, as well as circularity performance some experts approved of such information being available on a DBP, whilst others did not perceive them as critical, thus important compared to information on environmental performances. In addition, most experts did not perceive the other described information aspects (e.g., information on indicators used, respective impact categories, calculation methods) as must have information on a DBP.

Results: Conceptual digital battery passport - battery diagnostics, maintenance, and performance

When an EVB retires it may still qualify for entering a second battery life, thus allowing the potential pursuit of value chain loop-closing pathways other than recycling (Koller, 2020). To identify appropriate loop-closing pathways respective value chain stakeholders, such as waste battery collectors, require information on the EVB's health status (Bai et al., 2020; Circular Economy Initative Deutschland, 2020; Koller, 2020).

The main information category *diagnostics, maintenance, and performance* provides information related to an EVB's health status, carried out maintenance-related actions, and delivered performance. Category respective information can be further divided into three sub-categories: *battery health*, *maintenance history*, and *delivered performance* (see Figure 2). The sub-category *battery health* provides information on an EVB's health-related indicators, such as state of health, state of charge, and rest of useful life. The sub-category *maintenance history* provides information on carried out maintenance and repair work during the EVB's use phase, respective triggers of said work, as well as on the party who carried out respective work. The sub-category *delivered performance* provides information on an EVB's so far delivered performance in terms of, for example, charging/discharging cycles, covered mileages, provided operation time.

This main category was developed by consulting peer-reviewed articles with focus on battery diagnostics and battery second life (Canals Casals et al., 2019; Lipu et al., 2018; Richa et al. , 2017; Xiong et al., 2018). Furthermore, grey literature on EVBs and the circular economy (Circular Economy Initiative Deutschland, 2020; Koller, 2020), product and material passports (Brudermüller, 2020; Heinrich and Lang, 2019), as well as regulatory papers (European Commission, 2020) were used for concept development purposes.

The preliminary information content of this category was subjected to expert validation in an online workshop series. The majority of experts expressed the need of battery diagnostics-related information to ensure safe EVB handling, as well as to decide if an EVB may qualify for a second life. Some experts rejected the idea of providing operational EVB-related data (i.e. battery health-related data), thus any form of real-time dynamic data, on a DBP due to such data changing rather quickly, and given the lifespan of EVBs large data volumes would be the result. This in turn may lead to data collection, processing and storage issues.

Results: Conceptual digital battery passport - value chain actors

To ensure and enhance transparency along the entire EVB value chain, information on involved actors, as well as their respective roles and responsibility is required. Enhanced transparency, in turn, may further enhance and strengthen trust between value chain stakeholders, whilst supporting respective decision-making situations (Saberi et al., 2019).

The main information category *value chain actors* provides information, which allows to clearly identify actors with relations to the EVB of interest. Category respective information can be divided into two sub-categories: *general actor information* and *chain of custody* (see Figure 2). The sub-category *general actor information* provides information, which allows clear identification of actors related to the EVB during its entire life cycle, regardless to what extent (e.g., suppliers of active materials, manufacturers of cells, waste battery collectors). Therefore, information such as name of involved actors (e.g., company name), actor type and function (e.g., supplier of raw materials), location of value-adding activity (e.g., production site of cells), as well as actor identifiers (e.g., trade registration number) is affiliated to this sub-category. The sub-category *chain of custody* provides information that allows to clearly identify value chain actors' responsibilities related to the EVB of interest. This does not only include responsibilities of the physical product, respective components or related services, but also responsibilities with respect to sustainability and circularity-related performances.

This main category was developed by consulting peer-reviewed literature with focus on digitalization and manufacturing (Tao et al., 2018), as well as digitalization and sustainable supply and product management (Kouhizadeh et al., 2021; Nandi et al., 2021; Sarkis et al., 2020). Furthermore, regulatory papers (European Commission, 2020), and grey literature related to EVBs and circular economy were used for concept development purposes (Circular Economy Initiative Deutschland, 2020; Koller, 2020).

The preliminary information content of this category was subjected to expert validation in an online focus group workshop series. With respect to general information on value chain actors, workshop participants approved of such information being on a DBP. With respect to chain of custody-related information some participants did not see pressing need of such information being disclosed on a DBP (e.g., due to lack of regulatory pressure).

Discussion: Data needs and requirements

The proposed conceptual DBP provides in general information related to (1) the product itself, (2) the product's sustainability and circularity performance, (3) the product's health status, as well as (4) involved actors along the product's life cycle.

Product-related information has been identified as backbone of a DBP. This finding is based on literature (Bai et al., 2020; Chen et al., 2019; Circular Economy Initiative Deutschland, 2020; Coffin and Horowitz, 2018; Heinrich and Lang, 2019; Honic et al., 2019b,c; Philippot et al., 2019; Stampatori et al., 2020), which allowed to deduce the need of such information to enable DBP users to clearly identify the EVB at hand, thus providing contextualization. This has been further confirmed by industry experts who participated in the carried out online focus group workshop series.

The importance of sustainability and circularity-related information can be deduced through literature (Heinrich and Lang, 2019; Honic et al., 2019a,b,c), but has been also recognized by focus group participants. Participants have put emphasise on the importance on environmental impact-related information, such as information on an EVB's carbon footprint. This perception can be explained by provided incentives by policymakers (e.g., introduction of carbon footprint-related thresholds, which a product may not exceed when entering a certain market) (European Commission, 2020). However, sustainability encompasses not only an environmental perspective, but also a social one, which needs to be taken into consideration (Millar et al., 2019). This could be achieved if policymakers were to also emphasise the importance of the social dimension of sustainability, thus defining respective targets. Otherwise, value chain actors might focus on the environmental dimension of sustainability only, thus neglecting social sustainability-related issues. With respect to sustainability-related indicators, some participants focused on the importance of the carbon footprint. However, to manage the sustainability performance of an EVB, more than one indicator will be needed; be it to express environmental or social performances. Otherwise, at best one-sided sustainability-related improvements could be achieved, meaning that one indicator may indicate that the sustainability performance of the product of interest has improved. However, when considering other indicators, the performance may have remained the same, or even deteriorated. Concerning circularity performance-related information, literature (Parchomenko et al., 2019; Saidani et al., 2019) indicates its importance. However, focus group participants did not reach a consensus if such information is needed on a DBP. Some emphasised its importance, whilst others could not relate to this opinion due to them perceiving the concept of circular economy as being rather generic, thus leading to different possible scenarios (e.g., recycling of certain kinds of materials, repurpose activities). However, circularity performance-related information should be provided by a DBP to allow DBP users to get information of the status quo of said performance. Otherwise, respective decision-makers cannot tell if so far pursued circularity performance improvement efforts have been fruitful.

In general, knowledge about the performances mentioned above is needed when improvement is sought after. This, in turn, allows decision-makers to formulate and define respective targets and measures to achieve them. Workshop participants' reluctance could be explained by findings stemming from literature (Parchomenko et al., 2019; Saidani et al., 2019), which state that the assessment of circularity performances is rather new to practitioners compared to the assessment of environmental performances. As a result, practitioners are rather unfamiliar with tools and indicators that may assess circularity-related performances (Parchomenko et al., 2019; Saidani et al., 2019). In addition, compared to, for example, environmental impact assessment, there is a lack of standardization when it comes to circularity assessment. This could further explain why some workshop participants have not perceived circularity performance-related information as needed on a DBP. With respect to the information aspect related to used indicators, respective impact categories, used inventory data, applied assessment standards and calculation methods, most workshop participants did not perceive them as a pressing issue in the context of DBPs. However, it can be argued that such information is needed to ensure transparency of sustainability and circularity performance-related information provided by a DBP. In addition, such information may further enhance the meaning of provided performance results to DBP users (e.g., what does this result mean, how does it impact the environment).

To pursue appropriate EVB value chain loop-closing pathways (e.g., repair, repurpose, recycling) battery diagnostics-, performance-, maintenance-related information should be provided by a DBP. This information need can be deduced from literature (Circular Economy Initiative Deutschland, 2020; Koller, 2020). However, workshop participants provided mixed opinions on a DBP containing such information. While some participants opined that such information has to be on a DBP to enable the pursuit of appropriate value chain loop-closing pathways, some experts opposed this idea. The reasoning behind said opposition was the concern that adding dynamic data, in particular real-time data, (i.e. battery diagnostics and performance-related data) to a DBP, will enhance the complexity of DBP implementation. Real-time dynamic data, such as battery diagnostics-related data changes instantly during its use phase. Due to EVBs offering lifespans of at least eight years, it can be assumed that massive volumes of data would be generated during its use phase. Thus, experts raised the concern of data collection, processing and storage issues. In addition, some participants voiced the concern that battery health-related indicators are not straightforward to collect (e.g., due to the different calculation approaches) (Lipu et al., 2018). Keeping that concern in mind, when it comes to data types (e.g., static, dynamic, real-time), it needs to be taken into consideration when it makes sense to employ which kind of data type. In the case of battery diagnostic, maintenance and performance-related information, some workshop participants proposed that it could be sufficient to update respective data at specific points during the EVB's lifespan (e.g., during vehicle service, in case of changing ownerships).

To enhance the transparency along the EVB value chain, value chain actors-related information is required, which in turn may enhance trust amongst value chain stakeholders. This finding can be deduced by literature (Brudermüller, 2020; Heinrich and Lang, 2019; Nandi et al., 2021; Sarkis et al., 2020). Focus group participants, in general, approved of basic value chain actor-related information being disclosed on a DBP. However, the concern was raised that some value chain actors are most likely to be reluctant to disclose their involvement due to perceived competitive drawbacks (e.g., loss of business to competitors, damage of reputation).

Discussion: Data sources and providers for a DBP

The conducted stakeholder mapping, as well as stand-alone literature review allowed to further deduce that value chain stakeholder are prone to resume the role as data providers for DBPs (Circular Economy Initative Deutschland, 2020; Heinrich and Lang, 2019; Honic et al., 2019c). The same information was provided by workshop participants, who emphasised that all EVB value chain stakeholders have a hold over data needed on a DBP. Some participants further provided that there are current uncertainties with respect to data needs and requirements in the upcoming years. Thus, as much data as possible should be collected and stored on a DBP. This uncertainty poses, in general, a challenge when digital product passport development efforts are pursued. On the one hand, if all kinds of value chain-related data were to be collected and stored on a DBP, it cannot be ruled out that a DBP's sustainable product support function might suffer due to it containing redundant data. On the other hand, if only data were to be collected on a DBP that is perceived as important from today's perspective, data could be overlooked, which might be of interest in the future (e.g., due to regulatory mandates).

Discussion: Potential DBP implementation barriers

The conducted desk research and focus group workshop series, further provided insights of potential DBP implementation barriers. From literature, implementation barriers in the form of information losses along value chains, due to insufficient documentation efforts, as well as scepticism regarding data sharing can be deduced (Honic et al., 2019 c; Saidani et al., 2019; Wang and Wang, 2019). Those findings have been confirmed by focus group participants, who named implementation barriers with respect to violation of intellectual property rights. Thus, some participants voiced the concern of potential competitive drawbacks if, for example, competitors were able to access sensitive information via DBPs. In addition, some participants raised concerns, which are linked to one often quoted benefit DBPs might offer: enhanced transparency along the value chain (Circular Economy Initiative Deutschland, 2020; Heinrich and Lang, 2019). In this context, it was provided that some value chain actors could be reluctant to share certain kinds of data due to potential reputation damages, as well as perceived loss of business to fellow competitors. Thus, one of the major challenges when it comes to DBP implementation is most likely to be the incentivization of value chain actors to share their data.

Conclusions

This work provides a conceptual DBP of an EVB, which outlined data needs and requirements a DBP should fulfil to support EVB value chain stakeholders in their sustainable EVB management efforts. The current version of the conceptual DBP was developed by conducting desk research, as well as by seeking out validation provided by industry experts. This allowed to explore theoretical potentials of a DBP in the context of sustainable product management. To further push the development of a more practical concept, next research steps comprise further validation efforts (e.g., by conducting follow-up interviews), as well as further deepen the understanding of data availability of needed data, thus further investigating power dynamics along the EVB value chain. In addition, further research will focus on developing a preliminary information model for a digital twin-driven DBP based on the final version of the conceptual DBP. Thus, questions with respect to, *inter alia*, EVB specifications that have to be abstracted, data model structures, as well as data types have to be pursued.

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