Concepts of Product-Service Configurators for Repurposing used Electric Vehicle Batteries

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Abstract. The configuration of Product-Services Systems (PSSs) can be a complex task because of a large number of possibilities and dependencies that have to be considered. PSS configurators as a class of information systems can be used to support this task. To inform the design of a PSS configurator for the domain of repurposing used Electric Vehicle Batteries, a structured literature review on existing configurators is performed to identify underlying concepts and functionality. The results are discussed regarding their applicability in the specific domain of repurposing used EVBs. Additionally, the results are used to triangulate design choices made in the development of a first prototype.

Keywords: Product-service system, configurator, electric vehicle battery, repurposing, second-life

1 Introduction

Electric mobility is seen as one step towards reducing (locale) greenhouse gas emissions and therefore as a way to decelerate climate change and towards environmental sustainability [1]. However, in most countries, the diffusion of electric vehicles is still struggling. One of the reasons is the high initial costs when purchasing an electric vehicle. A significant share of these expenses is caused by the Electric Vehicle Battery (EVB) that is one of the reasons why electric cars are significantly more expensive than comparable conventional vehicles [2, 3].

The EVB is the component that stores and provides the energy necessary to propel the electric engine(s) of an electric vehicle. However, the currently used lithium-ion technology is suffering from degradation effects. In particular, the EVB's capacity (i.e., the amount of energy that can be stored) and power decreases over time and use. For the driver of an electric vehicle, this is notable in the range that can be driven without recharging and the loss of the capability to quickly charge the battery. Currently, it is assumed that an EVB should be removed from the car when the capacity has dropped to about 70%-80% of the original capacity [4, 5]. This is supposed to be reached after about eight years or 120.000 km driven [2].

In the EU the car and battery manufacturers are legally required to take back the used batteries. Therefore, with rising electric car sales the manufacturers will soon have to

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handle a large amount of old EVBs. Since the recycling of such large lithium-ion batteries is expensive [6] at the moment, it will be economically beneficial for the manufacturers to further use these batteries in different less demanding applications, the so-called *second-life applications* (SLAs).

Previous research has shown that used EVBs can be repurposed for various SLAs and marketed as part of product-service systems (PSSs) [2]. PSSs consist of a physical component and additional services and are suitable to provide customers with fitting offers for their individual needs [7]. In the case of repurposing of used EVBs, a PSS consists of one or more used batteries with additional services that can be required to settle certain drawbacks of the used battery (e.g., higher perceived risk of failure, classification as dangerous goods, unknown quality) or provide additional value to the customer.

Since every used battery has a different condition because of the degradation, their future performances will largely differ so that not every battery can be repurposed for every application [8]. Therefore, possible SLAs have to be determined for each used EVB individually [8]. Additionally, the SLAs have different technical requirements on the battery and additional (electrical) components that are needed for a safe operation [9]. Furthermore, the customers might have additional needs that should be addressed. Therefore, PSSs have to be configured for each customer specific application scenario individually.

Configuring PSSs that satisfy specific customer needs can be challenging. The configuration of PSSs is the process of selecting products and services, which solves an individual customer problem, from a set of predefined modules [10]. Because of a high number of possibilities and dependencies between product and service components this task is hardly possible to do manually. This calls for information systems (IS) to support this task. Since the whole domain of repurposing used EVBs is new, currently no specific PSS configurators for repurposing used EVBs exist. We set out to develop such a configurator as a component of a decision support system in a larger design science research project. We already presented a first prototype in [11]. However, its design is mainly informed by domain knowledge, and evaluation is still missing and challenging because practical application lies much into the further. Therefore, we strive to use knowledge on PSS configurators as a triangulation and to improve the design. To achieve this, in this article, we set out to identify the concepts and functionalities that underlie current configurators for PSS. Furthermore, we are interested in how these can be adapted for configurators for PSS consisting of used EVBs and additional services.

The following research questions are addressed in this paper:

1. *Which are the underlying concepts of existing configurators for PSS?*
2. *How should these concepts be adapted for the domain of repurposing used EVBs?*

To answer the research questions, we provide a systematic literature review of current configurators for PSSs. Based on this, we discuss the results for PSS configurators in the domain of repurposing used EVBs. Furthermore, we use the results to triangulate design decisions made when developing the first prototype.

The remainder of this article is structured as follows. In Section 2 we provide an overview of the research background regarding the repurposing of used EVBs and Product-Service Systems. Afterwards, we present the used methodology, followed by the results of the literature analysis in Section 4. In Section 5 the identified principles are discussed for the domain of repurposing used EVBs. Section 6 concludes the paper and suggests some opportunities for further research.

2 Research Background

2.1 Product-Service Systems

A Product-Service System is the combination of physical products and additional services that are marketed together as an integrated solution that fulfills the needs of individual customers [12]. Some authors, esp. in earlier publications on PSSs, additionally highlight the aspect of environmental gains that have to be achieved through PSSs (e.g., [7]), but this aspect is not present in all definitions (e.g., [12]).

PSSs can be classified into different types that are distinguished by the level of integration of services. Tukker [13] identifies eight types of PSS in the three categories product-oriented, use-oriented, and result-oriented PSS. While the product-oriented PSSs focus on selling a product with additional services that increase the value for the customer, in use-oriented PSS the products remains the property of the provider and only the access to the products is offered. This includes the leasing or renting of products to one customer as well as pooling in which several customers use the same product simultaneously. The result-oriented types include payment per service unit (e.g., per hour) as well as the functional result (e.g., savings on the energy bill) [13]. Since the product remains the property of the seller in use- and results-oriented PSSs, the seller is responsible for the correct function and takes the risk of malfunction.

For the offering of PSSs, it is necessary to design them. Typically, such designs are modular and have to be configured for the specific customer needs [14, 15]. Configurators (also called configuration systems) are ISs that support during the configuration process.

2.2 Repurposing used Electric Vehicle Batteries

Electric vehicle batteries (EVBs) are one of the main components of electric vehicles, like electric passenger cars. They are needed to store and provide the necessary energy to propel the vehicle. Since the current lithium-ion battery technology suffers from degradation within time and use, the performance of batteries decreases. Currently, it is assumed that an EVB should be removed from the vehicle when its capacity has dropped to around 70%-80% of the original capacity [4, 5]. However, since the automotive use is very demanding, even the degraded batteries are still good enough to be repurposed and further used in less demanding applications [16, 17], such as buffer storage for renewable energy or grid stabilization [18, 19]. Because of the high prices for EVBs, marketing for SLAs can be beneficial by bringing in additional revenues

[20]. Furthermore, there are savings in recycling costs, since currently it is expensive to recycle large lithium-ion battery packs [6], but is supposed to drop in the future because of economies of scale. Additionally, currently, very few companies are even able to handle higher amounts of large battery packs. The demand for batteries will also increase because of the rising share of renewable energy (i.e., wind and solar energy) that cannot be leveled as combustion based energy sources (i.e., coal or gas). So, batteries can be used to store energy when there is an overproduction of renewables that can then be used when the demand is higher than the production [21]. One other effect of this transformation towards renewable energy is the increase in the number of energy generators. Larger power plants are replaced by smaller, decentralized ones thus far as that private households with photovoltaic panels feed energy into the grid. This upcoming decentralization of supply needs for additional storage for stabilization [21].

While the technical feasibility of different SLAs is intensively under research ([9, 22]), the economic perspective is mostly reduced to calculations if certain applications are economically feasible (e.g., [23–25]). There is nearly no research on markets for used EVBs or their marketing. Consequently, research on IS support is still scarce.

Previous research from our research group shows that used EVBs can be offered as PSSs consisting of one or more used EVBs and additional services. PSSs are a way to reduce the customer's risk of acquiring used EVBs that arises from the fact that the potential customer is not able to assess the quality of the offered used EVBs and estimate their future degradation [2]. Furthermore, PSSs can improve the value for the customer by including services that are required for a safe start-up and operation as well as additional services that improve the customer experience. Additionally, PSSs can improve the cost-efficiency for the customers [2].

The solutions offered to a customer have to satisfy certain dependencies. First, there are dependencies between the components of the PSS (i.e., services and products). For example, a particular type of used battery might require a specific service. Second, there are dependencies to the specific SLA scenario of a customer. For example, a battery that is repurposed for the usage in a private household has to be complemented by different services and electrical components than a larger storage that is run by a company with battery experts. However, the specific dependencies are unknown and are likely to change with developments in the technology.

The repurposing of used EVBs will likely be done by specialized companies that receive the EVBs from the manufacturers and configure the PSSs for the customers [26]. On a high level the decision process consists of the following steps: Identify technically feasible batteries for given customer requirements, configure different PSSs that solve the customer problem, and offer them to the customers [11].

3 Research Method

In this study, a systematic literature review on configuration systems for PSS is conducted in line with Webster & Watson [27] and vom Brocke et al. [28]. First, a keyword search in three databases was performed. The review is exploratory to identify concepts and functionalities of current PSS configurators. Therefore, we queried scientific databases using a search string[1] that combines the different objects of investigation (i.e., PSS, product, and service) with various terms for configuration systems. Additionally, the term "knowledge-based configuration," which is mainly used in the context of artificial intelligence, was included. The databases and corresponding hits of the search that was performed in 08/2017 are shown in Table 1.

Table 1. Database query configuration and results

Database	*Configuration*	*Hits*	*Cleaned*	*Relevant*
Scopus	Article title, Abstract, Keywords	9	7	0
AISeL	All Fields	125	18	4
Google Scholar	No patents, no citations	204	15	9

The raw results were cleaned by first removing invalid entries (e.g., complete proceedings) and screened regarding their relevance based on the title and abstract. Additionally, articles from non-peer reviewed outlets were deleted. In a second step, the full texts of the remaining papers were read regarding whether they deal with configuration systems for PSS or service bundles. Since some configurators were described in more than one article, in the end, 13 articles were considered relevant for this study and nine configuration systems for service bundles and product-service systems were identified. Table 2 provides an overview of the identified configurators, referring articles, and whether they are supposed to be used for configuring PSSs or service bundles. In some of the articles, the term PSS is not explicitly used but describe the same construct [10, 15, 29].

Table 2. Overview of configurators and corresponding articles

ID	*Sources*	*Type*
C1	[10, 15, 29]	PSS
C2	[30, 31]	Service bundles
C3	[32, 33]	PSS
C4	[34]	Service bundles
C5	[35]	PSS
C6	[36]	PSS
C7	[37]	PSS
C8	[38]	PSS
C9	[39]	PSS

Afterwards, the results of the literature analysis are discussed regarding their suitability in the targeted domain.

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1 (("service bundle" OR "product service system" OR "hybrid product" OR "product" OR "service") AND ("configurator" OR "configuration system" OR "choice navigator") OR "knowledge-based configuration")

4 Product-Service System Configurators

In the analyzed literature, several concepts and functionalities of configurators can be identified (Table 3). All configurators have a knowledge base that contains information on whether a configuration is valid or not. Typically, this knowledge base is represented as one or more ontologies [30–33, 36, 39] (C2-C4, C6, C9) or using a specific modeling language or meta-model [29, 38] (C1, C8). For the other two, the structure of the knowledge base is not described in the analyzed articles.

In these knowledge bases, different types of dependencies are considered to describe valid configurations and are represented as configuration rules [29, 35]. The dependencies differ in the elements between which the dependencies occur and the type. For example, a certain product component might require the inclusion of a specific type of services Basic dependency types are "require" and "incompatible" [33]. For example, the inclusion of a certain product in the PSS might require or prohibit the inclusion of the particular type of service. Most configuration systems additionally allow the definition of other relationships between the different elements to enable more detailed configuration rules (C1-C4, C6, C9), such as "enhancing," "substitutes," or "supporting." For the others, it is unknown how the dependencies are modeled.

One concept in which the configurators differ is the targeted type of user. Most common is a technical or sales representatives of the vendor that configure PSSs for a specific customer (C1, C4, C7) or the customer can itself be the user of the system (C1, C5, C7, C8). Depending on the targeted group of users, the user interface and the amount of decision support that has to be offered differs. Especially in a complex domain, the customers will not have the necessary knowledge to configure a solution on their own if the support provided by the system is low [15]. Therefore, configurators include several functionalities that aid the user in the configuration task. Most commonly is the validation of configurations using the knowledge base (C1-C6, C9).

Some of the configurators additionally can identify valid solutions for customer preferences (C1-C4, C9). A prerequisite for this is that the customer can state its preferences, that the preferences are represented in the system, and that a matching between the preferences and the PSS elements can be made. To allow automatic configuration, the preferences have to be related to the PSS elements All configurators use explicitly stated relations between preferences and outcomes that can be realized by either product or service components (C1, C2, C3, C4, C9).

To provide further assistance, configurators can include recommender systems that recommend services or outcomes that are likely to be needed by the customer. For example, one configurator includes a collaborative filtering recommender (C1) [10]. Such recommender systems can be based on data gathered from previously sold PSSs or data acquired during the use in a SLA. Even if no recommender system is included in the configurator, a feedback mechanism for such data is reasonable to improve the PSS offerings (C6, C8) [35, 38].

For the vendor of PSSs, it is important to determine how much a certain PSS will cost and which price can be asked for. Therefore, some of the configurators include functions to propose prices (C1, C4, C5, C6) and to provide the possibility to calculate the costs for the vendor (C1). Different pricing schemes, such as path auctions [34] or willingness-to-pay and competitor price analyses [10], are used.

Apart from the configuration task itself, it can be reasonable to provide the customer with different variants of configured PSSs. Therefore, some configurators include the functionality to oppose and contrast different variants. C1 provides the possibility to generate total cost of ownership calculations for various PSSs [15]. An additional feature incorporated by one configurator (C8) is collaborative work that allows the involvement of different actors in the design and configuration of PSSs [38].

Overall, while there are few advanced configurators (C1, C4), some are only rudimentary implemented in generic rule engines to demonstrate ontologies on which the configurators are based on (C3, C6, C9). The configurators C5 and C7 are described on an abstract level so that some conclusions cannot be made regarding all concepts.

It is noticeable that even though some configurators are especially for PSSs, none of them explicitly incorporates the distinction between the different types of PSS.

Table 3. Concepts of PSS Configurator design

Concept	*Form*	*Configurator(s)*
Knowledge-representation		
	Ontology	C2 – C7, C9
	Meta-model	C1, C8
Dependencies		
	Between services and products	C1, C9
	Between products	C1, C2, C5, C9
	Between services	C2, C3, C4, C6
Targeted User		
	Vendor	C1, C4, C7
	Customer	C1, C5, C7, C8
Functionality		
	Validation of configuration	C1-C6, C9
	Matching needs	C1-C4, C6, C9
	Recommendation of services	C1
	Feedback mechanism	C1, C5, C8
	Costing	C1
	Pricing	C1, C4 – C6
	Comparison of variants	C1
	Collaborative work	C8

5 Principles for PSS Configuration Systems for Repurposing EVBs

Various challenges arise for configuring individual PSSs consisting of used EVBs and additional services. First, a technically suitable battery has to be found satisfying some of the customer’s requirements. Additionally, services have to be identified which either are mandatory or provide additional value for the customer.Also, the PSS can contain additional hardware (e.g., for monitoring) that is not required for the operation but can be used for optimization or to enable different revenue streams [40].

In the literature, various dependencies were identified. Dependencies can occur between the different elements of a PSS (i.e., products and services). However, in the domain of repurposing used EVBs additional dependencies between the PSS elements and the SLA scenario exist. For example, if a single used EVB is installed as buffer storage in a house with photovoltaic panels there are other additional product components needed than for application in a larger energy storage in that many used EVBs are connected. Therefore, the knowledge base has to account for this specific type of dependencies.

In current configurators two ways of knowledge representation are used, ontologies and specific meta-models. Potentially both can be utilized in the domain of repurposing used EVBs. There is a lot of different dependencies inside and outside the PSS that because of the newness of the domain cannot be specified exactly. Therefore, the representation has to be flexible regarding additional constraints.

Because of the complexity of the used good, a customer is likely missing knowledge to configure the solution on its own. Therefore, a technical sales representative of the vendor should configure the solution in cooperation with the customer or by itself based on the preferences articulated by the customer [15]. When the whole domain of repurposing used EVBs becomes more mature, and the products are standardized an e-commerce like setting might become feasible in that the customers can configure their solutions by themselves. For both settings, validation of configurations regarding the dependencies is a functionality that is inevitable for strong support in the configuration task and should be incorporated in configurators for used EVBs.

Automated matching between needs and requirements of the customer and the SLA scenario would bring additional support. However, this requires formalization of those needs and an assignment between needs and the PSS elements have to be formulated. Because of the newness of the domain, such a formalization currently does not exist. Furthermore, because of the complexity of the domain, the customer might not even be aware of its particular needs. Until this additional knowledge is present, the configuration has to be done by sales representatives. Another possibility is the incorporation of recommender systems as present in one configurator. In particular, a collaborative filtering approach that recommends services based on PSSs that previously were successfully sold to similar customers is proposed. This concept can be extended towards similar SLA scenarios and similar used EVBs [11]. Using this approach the person who configures the PSS gets recommendations regarding services that are likely to be successfully sold. This approach works around the problem of not having formalized knowledge about the relationship between specific needs and PSS elements. Such a recommender system also can be used to generate different variants that can be offered to the customer [11].

To train such a recommender system, a feedback mechanism is needed as proposed in three of the identified configurators. In this particular case data about previously sold PSS have to be stored. Apart from that feedback mechanisms are reasonable since the whole domain of repurposing used EVBs is still new and only little is known about successful SLA scenarios. While there are currently many research projects regarding the technical feasibility and battery degradation in different SLAs, there is not much on successful sales. With an evolving market, it will become beneficial for the vendors to track the usage of the battery and services to improve the product and service offering.

Determining costs and pricing of services is not easy because of the process and co-creation characteristics. In the domain of repurposing used EVBs, the services most likely will be provided by different service providers. Therefore, the aspect of costing could be transferred to the providers. That would require an interface to retrieve specific costs. Pricing is necessary only to allow profitable PSS. Therefore, such a functionality should also be present for repurposing used EVBs.

There are likely different possible PSSs that solve a specific customer's problem [14]. The customers should be able to choose between offers with different value propositions and costs. Therefore, it should be possible for the customer to oppose different variants. E.g., this could be operationalized using a web-based interface (C1).

Collaborative work is another functionality that is incorporated in one of the configurators. Different persons can design and configure PSSs simultaneously [38]. For repurposing used EVBs that will be required since several decisions makers might be involved in the decision process [11]. The selection of a suitable battery might be performed by a different person than the configuration of the PSS. Additionally, since a large amount of used EVBs will be available in the future, many PSSs will have to be configured, and therefore it is necessary to balance the task between different persons.

One concept that is not present in current configurators is the type of PSS. No configurator explicitly consider use- or result-oriented PSSs. Different types of PSSs should be explicitly supported by the configurator since the type has an influence on the functionality (e.g., pricing) and has to be represented by additional constraints in the knowledge base. For used EVBs this would be beneficial since use- and result-oriented PSSs are a way to reduce the risks for the customer and stimulate sales [2]. Battery aging is highly complex the estimation of future degradation is challenging, and profound knowledge of the batteries and their usage history are necessary [8]. For potential buyers of used batteries, it is not possible to identify the quality of the offered product. Furthermore, there is asymmetric information since the seller typically has more information on the quality. According to Principal-Agent Theory, this can lead to adverse selection. To solve this, the seller has to signal the battery's quality or risks market failure as demonstrated in the Lemon Market Theory [8]. One possibility to solve this issue is to transfer the danger of a "bad" battery to the seller. E.g., by providing warranties in a product-oriented PSS or offering use- and result-based PSSs.

The identified concepts and functionalities correspond with the principles identified from domain knowledge for the development of our first prototype [11]. Some of the concepts offer possibilities to extend the solution by incorporating new functionality. Specifically, the system should be adopted for use- and result-oriented PSSs to provide additional possibilities to solve the problem of potential adverse selection. Furthermore, an automatic matching of customer preferences and outcomes could be added. This requires certain information in the knowledge base that is not yet available but would enable customers to configure PSSs themselves. Pricing currently is only implemented rudimentary using a cost-based approach that uses costs for services.

6 Conclusion and Outlook

Product-Service Systems consisting of the used battery and additional services are a possibility to account for asymmetric information, reduce risks for the customer, and provide customers with individual solutions. The configuration of PSS can be complex. Therefore IS are needed to assist the vendor of such PSSs. To inform the design of such an IS, we first performed a structured literature review of existing systems. The results were discussed in a second step for their reasonability for configurators for repurposing used EVBs. Most of the identified concepts and functionalities can be adapted for this domain. However, due to missing knowledge about the future of the technology and specific services that will be required, some are not applicable right now.

In our design science research project the results will be used to refine and extend the design of the existing prototype in a next iteration. For other researchers, the results provide an overview of current research on PSS configurators and their concepts and functionality. Practitioners can use the results as a starting point for their design.

Limitations of the research are only considering existing configurators and methods for PSS development and configuration were neglected. Another limitation and opportunity for further research is that literature on product configurators and knowledge-based configuration is not systematically included in this study. While those two areas mainly deal with support in configuring product alternatives to enable mass-customization strategies, there are several similarities regarding the goals and concepts. Since product configuration is more researched than service or PSS configuration, it can be worth it to analyze which aspects and solutions in this area can be transferred.

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