Integrating Sustainability Information in Configurators

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Abstract. Consumers are increasingly demanding sustainability information for products. Thus, pressure on companies increases to evaluate the sustainability of their products and supply the information in an appropriate way. The complexity of sustainability assessments, especially in the ecological dimension, poses a specific challenge for Smart and Medium Enterprises (SMEs), which only increases in the context of Mass Customization (MC) products due to the large number of variants. Product configurators hold the potential to answer both challenges of sustainability assessment and presentation of its results by taking advantage of the product model knowledge.

For this, we suggest extensions of the classical configurator architecture in the areas of data integration, processing, and user interfaces to expand configurator functionalities for sustainability information integration. The assessment process, illustrated by the example of the Ecological Scarcity Method (ESM), is guided by ISO standards for Life Cycle Assessment (LCA), but is not strictly adhered to, as there are currently no procedures for specifically assessing MC products. The extension of the configurator enables the modeler to perform the LCA directly within the configurator. Allocation of sustainability values is a main challenge both regarding assessment of product characteristics and comprehensibility of results for users. Configurators can aid in providing sustainability information to users for MC products during the configuration process, but many questions related to the assessment of large product variant spaces remain.

1 INTRODUCTION

Sustainability is understood as a principle of action in which resources are only used to the extent that their natural regenerative capacity is not restricted [19]. This ensures that future generations will also be able to meet their needs by means of the available resources [26]. A large proportion of environmental problems result directly or indirectly from people's consumption behavior [30]. Therefore, consumers can make a significant contribution to environmental protection by deciding to buy more environmentally friendly products. However, this requires companies to provide information about the sustainability of their products. Unfortunately, this is still not widespread nowadays.

For companies that produce standardized mass products, the assessment of sustainability is limited to a few products. In the area of Mass Customization (MC), on the other hand, a single product has a large number of variants [32]. Therefore, assessing the sustainability of each possible product variant is necessary. However, due to the high number of variants and the complexity of the methods, carrying out an individual sustainability assessment for each variant can hardly be considered feasible in practice, especially not for SMEs with limited resources [12].

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In the context of MC, product configurators are often used to determine feasible combinations of product components [13]. It seems appropriate to utilize these configuration solutions for the provision of sustainability information as well, since central information on the prod. However, these lack a methodology on how to deal with the complexity of conducting a sustainability assessment for MC products and to provide the results to the user in a comprehensible manner.

We address this question while adopting some limitations. Sustainability can be divided into three dimensions: economic, ecological, and social [20]. We focus on the ecological dimension by only considering the Ecological Scarcity Method (ESM) as a Life Cycle Assessment (LCA) method. The ESM has been developed in close cooperation with industry partners which makes it less complex than other LCA methods [2].

The paper proceeds by providing a theoretical background on the areas of LCA and the respective ISO norms, explains the ESM and how generic data is available in the sustainability database ecoinvent, and details the basics on product configurators. Then, an overview on the current state of research of configuration and sustainability is given. Building on these foundations, we propose an extension of classic configurator system architecture and outline how a sustainability assessment process within the system can be carried out. Based thereon, challenges related to mapping the sustainability values and LCA-related challenges are discussed in the context of MC product configuration.

2 THEORETICAL BACKGROUND

2.1 Sustainability Assessment

LCA is the best-known method for evaluating the environmental impact of a product system, taking into account its entire life cycle [22]. The result of an LCA supports decision-making, the improvement of products and processes, and communication regarding ecological aspects [10]. The publication of LCA information is mandatory since March 2017 for publicly traded companies with more than 500 employees according to the Corporate Social Responsibility Directive Implementation Act in Germany [4, 15]. The framework for conducting life cycle assessments are described in the ISO standards 14040 and 14044. According to these, an LCA is divided into four phases [10, 11]:

1. Goal and Scope Definition: the system to be investigated, its system boundary and the necessary level of detail are determined.
2. Inventory Analysis: all inputs and outputs of the system are specified.
3. Impact Assessment: based on the inventory analysis, the environmental impact of the system is determined in the form of indicator values.

4. Interpretation: the results of the inventory analysis and the impact assessment are discussed and recommendations are made on the basis of the initially defined objectives.

The inventory analysis records all material and energy flows that cross the system boundary and are thus added to or removed from the system [16]. In order to make the inventory analysis practically applicable, individual inputs and outputs may be neglected under certain conditions [10]. The extent to which this is allowed depends primarily on the objective as well as on the required level of detail of the LCA and is defined by *cut-off criteria*. These indicate which inputs and outputs of the LCA are negligible due to their low influence on the result. ISO 14044 lists mass, energy, and environmental relevance as possible cut-off criteria.

In practice, inputs and outputs often cannot be allocated to a single product, but must be distributed among several products [11]. For this purpose, *allocation methods* are used. ISO 14044 specifies a clear procedure in three steps for the allocation of inputs and outputs that cannot be clearly assigned [10]. First, if possible, allocation should be avoided. In this case, the product system can either be further detailed or extended. Second, if allocation cannot be avoided, inputs and outputs should be allocated to products based on their physical relationships. A frequently used physical relationship is the mass distribution of products [12]. Third, if an allocation on the basis of physical relations is not possible, other relations should be searched. One possibility is the economic value of products [3].

The LCA must be understood as an iterative process in which system boundaries, influencing parameters, assumptions, and methods are continuously adjusted in order to ultimately achieve the most accurate estimate of environmental impact possible [11]. However, its user-friendliness in practice is controversial [12]. SMEs in particular often lack the human and financial resources to perform detailed LCAs of their whole product portfolio [12]. Therefore, Feifel et al. [12] see the LCA in a conflict of objectives between the scientifically required accuracy and the feasibility and communicability of the results in practice. Furthermore, the LCA methodology leaves room for interpretation, so that several LCAs of the same product can come to different results [7].

2.2 Ecological Scarcity Method and Ecoinvent

A particularly important phase of an LCA is the impact assessment: this is when the the examined system's influence on the environment is evaluated. ISO 14044 does not specify a particular impact assessment method, but merely states the requirements that such a method must fulfill [10]. An overview of all scientifically recognized assessment methods can be found in [16].

In the context of this work, the ESM was chosen. A major reason for this decision was that ESM has been developed specifically for use in industry, which makes it stand out from other assessment methods due to its simpler applicability [2]. It also meets the high scientific demands placed on impact assessment in accordance with ISO 14040 [1]. Furthermore, awareness of the method and its dissemination are increasing. For example, ESM is already used by legislators in Switzerland to assess sustainability activities and grant tax relief based on the results [17].

ESM regards the environment as a limited resource. Every consumption of resources or emission of pollutants leads to a scarcity. For an examined region, the scarcity situation is determined by its current demands on the environment as well as its environmental policy goals. In Germany, environmental policy goals are set both at the national level by the Federal Environment Agency, and at the supranational level by decisions of the European Union [1]. The scarcity situation of the environment in a region is described by eco-factors, which represent weightings for resource consumption or pollutant emission [25]. Typical eco-factors are, for example, the consumption of energy resources or the emission of greenhouse gases [17]. By multiplying the inputs and outputs determined during the inventory analysis with their corresponding eco-factors, their environmental impact is determined. Thus, the result is provided in a single value: Eco-Points (EP). The more resources are consumed or pollutants emitted, and the more acute their local scarcity situation is, the higher are the EP.

A significant advantage of the ESM is the simple handling of EP. These can be aggregated as desired, similar to business cost theory, and allow structuring in hierarchies [1]. Aggregation is possible because the EP are to be considered equivalent, as they provide information about the "relative deterioration of the scarcity situation" [2, p. 6]: according to ESM, 10 EP resulting from the consumption of freshwater have the same relevance for the environment as 10 EP resulting from the emission of radioactive substances into the air. Thus, by means of the EP, a simple comparison of alternatives under ecological aspects can be carried out, which makes ESM highly attractive for the application in the context of product configuration.

Another advantage of ESM is, that generic EPs for a large number of materials and activities are available in the ecoinvent database [31]. In its current version 3.6, which was published on September 12, 2020, the database contains 18,121 data records [8]. Each data record describes an activity that can occur in the life cycle of a product. Data is offered as inventory analysis data as well as fully evaluated LCA data. The ESM data belongs to the latter: for each activity, a generic impact assessment has been performed and thus the environmental impact has been quantified.

2.3 Product Configurators

A *product configurator* is a software solution for the individual composition of a product from a set of predefined components [32]. A configurator presents all possible components and applies rules to check whether the current selection is feasible. During the configuration process, components can be selected according to the user's individual requirements towards the product.

Configurators are used wherever variant manufacturing is the predominant production type [13]. In variant manufacturing, each product belongs to a product family, which is characterized by a high degree of similarity between its products [23]. Product families rely on a modular design: their products have a common basic structure, which can be customized with modules [14]. The high number of possible combinations results in a high level of complexity. Configurators make this complexity manageable while at the same time exploiting the potential of customized products. In this context, the term mass customization (MC) is often used [14].

Product configurators typically aim at users with a limited technical understanding. Thus they are confronted with the ambivalence that, on the one hand, they must enable the user to configure the product easily and, on the other hand, they must describe a product in a technically complete manner so that it can be manufactured in production [32]. Therefore, the product model often consists of a sales model and a technical model [29]. The *sales model* is visible to the user. It includes all features that can be configured by the user. The t*echnical model*, on the other hand, is not visible to the user. It includes all features that are necessary to describe a product, but which cannot be selected directly by the user. The selection of these characteristics is implemented over predefined rules, which represent the relationship between sales and technical characteristics [29]. Regarding the configuration interface, the two models are referred to in the following as the sales view and technical view.

Product configurators usually consist of several basic components, which are described based on [13].

The *knowledge base* brings together the domain knowledge from the various specialist areas and stores it in a product model. The product model forms the basis for configuration. It contains the product structure in the form of components as well as rules on their compatibility [24].The components are described by features and their characteristics [28]. For example, the component 'seat' has the features 'size' and 'color', whereof the latter has the characteristics 'black' and 'blue'. Rules can describe both technical and economic relationships. Components with a common basic structure can be represented in an inheritance hierarchy, in order to reduce complexity and adjustment expenditure [28].

The *solver* receives the product model from the knowledge base on which the product configuration is to be performed. The task of the solver is to compute valid configurations [32]. A configuration is valid if it does not contradict any rules of the product model.

On the *configuration interface*, the user creates a configuration by selecting components and specifying their characteristics. This configuration is then sent to the solver for verification and the result is returned. Thus, the user gets direct feedback on their configuration and can - if necessary - adjust it directly.

The *modeling interface* offers modelers the possibility to manage the knowledge base. They bring together domain knowledge from the areas of product management, sales, and marketing, and thus enrich the product model [14].

3 Literature on Configuration and Sustainability Assessment

The topic of sustainability information within product configuration is starting to gain traction. There are a few works that specifically deal with the integration of systainability information into product configurators. In the most cases, the works deal with integrating a specific indicator into the configuration [18, 27]. For example, Ganter et al. [18] propose an approach to include information on Life Cycle Costs (LCC) in product configuration for product-service-systems. LCC belong to the economic dimension of sustainability. The approach allows users to consider their desired maintenance interval in addition to technical requirements during product configuration.

In addition to price as an economic indicator, Rousseau et al. [27] integrate the Global Warming Potential (GWP) as an ecological indicator in their configurator for 3D printing applications. The implemented product model is a 3D printed ship with variations to material, print quality, and number of items. After entering all relevant input, the user is presented GWP for different time horizons and the price. Regarding the low complexity of the product, it remains open how well this approach can be transferred to products with a larger number of variants.

Erdle et al. [9] extend a configurator by a sustainability view. They identify eight relevant sustainability indicators covering all three sustainability dimensions, that they assess as suitable for an SME context. Within the product configuration it is then possible to weight the importance of the different indicators according to the individual preferences. They neither report where the sustainability information is obtained from, nor how it is assigned to the product model.

In the research domain associated more closely to MC, sustainability in general has already received some attention. Three main research streams have been identified [20]: the impact of mass customization on sustainability, research on sustainable MC business models, and analyzing consumer decisions. The research and discussion on MC's impact on sustainability is mostly focused on whether MC products actually have a better or worse sustainability assessment than mass production objects [6]. A majority of works includes economic and social sustainability, while the ecological dimension is only considered in a third of the analyzed cases [20].

Few works actually deal with the question on how to assess the sustainability of MC products. Boër er al. [5] present a very detailed sustainability assessment model for MC products. It covers a multitude of indicators from all three sustainability dimensions. Due to the selection of indicators, there is a stronger focus on the production phase compared to other life cycle phases [20]. [5] present several use cases on how to apply the developed assessment model, where the main focus is on execution of the method, less on the technical perspective of supporting the assessment. Furthermore, it aims at evaluating the complete solution space of MC products, not at providing sustainability information on individual configurations from that solution space.

Hänsch et al. [21] present a preparatory approach for an LCA assessment of MC products with the help of Excel. They point out the importance to communicate the results of the sustainability assessment for example by use of a configurator, but the realization of this suggestion is not within the scope of their work.

In summary, the problem landscape of sustainability and configuration hast gained some attention in general, but few works have addressed the question on how to make the results available for individual product configurations for users. The need to make sustainability information available to users has been acknowledged [27], but insights on possible implementations are still scarce.

4 SUSTAINABILITY INFORMATION IN CONFIGURATORS

4.1 System Architecture

The basic system architecture of product configurators needs to be extended in order to include sustainability information. The proposed extensions are illustrated in Fig. 1. Basic system components that usually exist in a configuration solution, as presented in section 2.3, are marked with an asterisk. The suggestions for extension in the configurator system architecture were developed to allow an assignment of LCA data to the product model. It is based on the assumption that generic LCA data from a sustainability database, like the ESM activities in ecoinvent, are used for the assessment of the product model.

The same two *User* groups are addressed by the proposed extensions: modelers and users. The former build the knowledge base of the configurator, but now also perform the LCA within the configurator. Whether these tasks can be performed by the same person depends on the individual expertise with regard to product knowledge, modeling experience, and LCA expertise. Users benefit from the availability of LCA information during their configuration. It enables them to integrate sustainability information into their decision process during configuration.

A variety of *Data* is required for the integration of sustainability information into product configurators. This includes the product model, product life cycle data, and LCA data. The product model is already given by the product knowledge base in product configura-

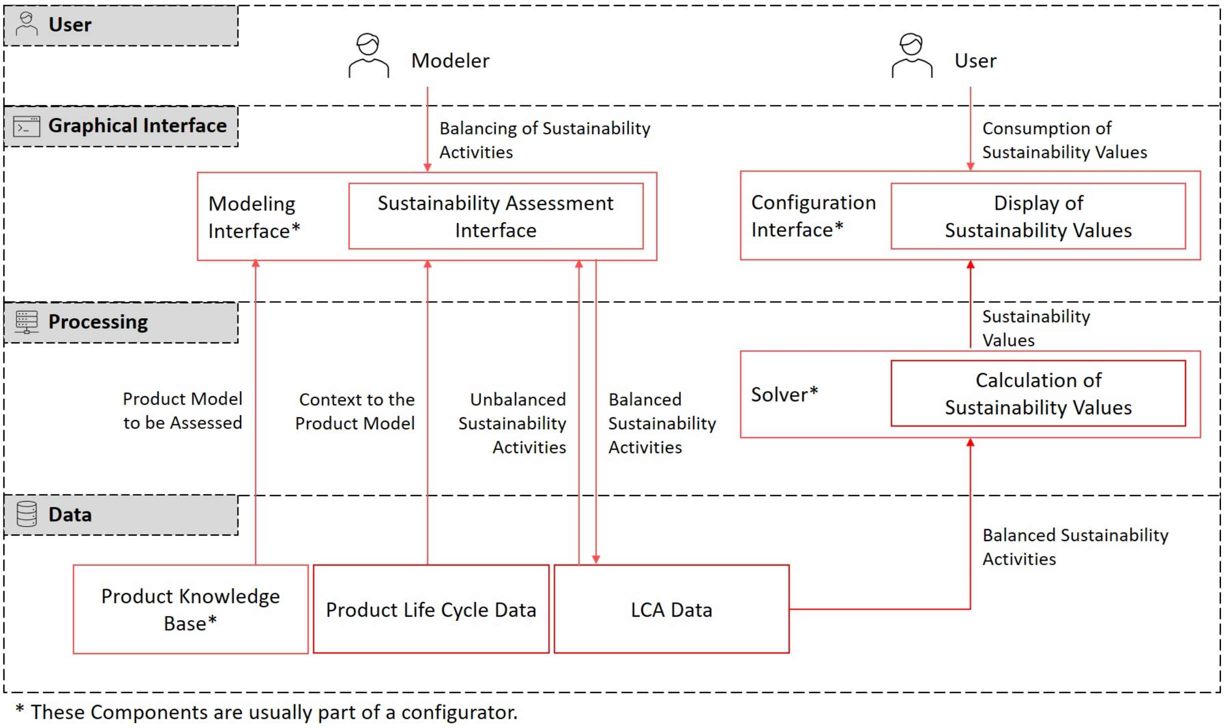

Figure 1. Extended configurator system architecture to enable sustainability assessment.

tors. It contains information about the product family with all its variants. It represents all modules that must be evaluated within the scope of the inventory analysis. The product life cycle data has the potential to enable the holistic assessment of a product from cradle-to-cradle by providing information on each product life cycle phase. This data can for example come from ERP or PLM systems, and consist of bills of materials or routings. The LCA data includes the sustainability activities that are used for inventory and impact assessment. It comes from sustainability databases, but can also be complemented with own sustainability evaluations.

The *Graphical Interfaces* include extensions of the user interfaces for modeling and product configuration. The extension of the modeling interface for the sustainability assessment allows the modeler to define the inputs and outputs of a module over the entire life cycle. The definition of inputs and outputs is based on the unbalanced sustainability activities provided by the sustainability database. The modeler identifies the most suitable activities and balances them by quantifying the flow of inputs and outputs that cross the system boundaries. The configuration interface needs to be extended to display sustainability information. Further research is needed on how this can be realized in a way that it actually supports the user. For example, as EP can be displayed as a single total value but also be decomposed into 18 dimensions, integrating sustainability indicators can add significant complexity to the information displayed in the configuration. For example, displaying several sustainability impact indicators from an LCA might be desirable from a holistic LCA perspective. However, for a user, the complexity of this information could be overwhelming.

The *Processing* assigns a sustainability value to each attribute in the product model. This value is calculated from the sum of the sustainability values of all balanced sustainability activities assigned to the attribute.

4.2 Process for LCA within a Configurator

The starting point for the process is that the modeler creates a product model in the configuration knowledge base. If product life cycle information from other systems is to be integrated in the assessment, a suitable mapping of data needs to be implemented. For example, in the case of an ERP system, a mapping can be achieved by including the material numbers in the configuration knowledge base.

By starting the LCA component, all relevant data from the knowledge base, product life cycle data from integrated systems and unbalanced sustainability activities from the sustainability database. Based on this data, the modeler performs an inventory assessment for modules of the product model over the entire product life cycle. Suitable sustainability activities are selected and balanced by entering the corresponding quantities. This is the main activity in the sustainability assessment process. After the modeler has created inventory analyses for the entire product model, impact assessments are conducted and the sustainability value for each characteristic is determined by aggregation. When a product is configured, the sustainability values are displayed in the the user interface and recalculated for every configuration step.

4.3 Mapping of Assessment to the Product Model

The aim of the sustainability assessment in the product configurator is to provide information on the sustainability of the configuration for the user. However, it must be taken into account that the sustainability assessment is carried out for features of both the technical and the sales model. But it must be considered that the consumption of sustainability information takes place exclusively for the features of

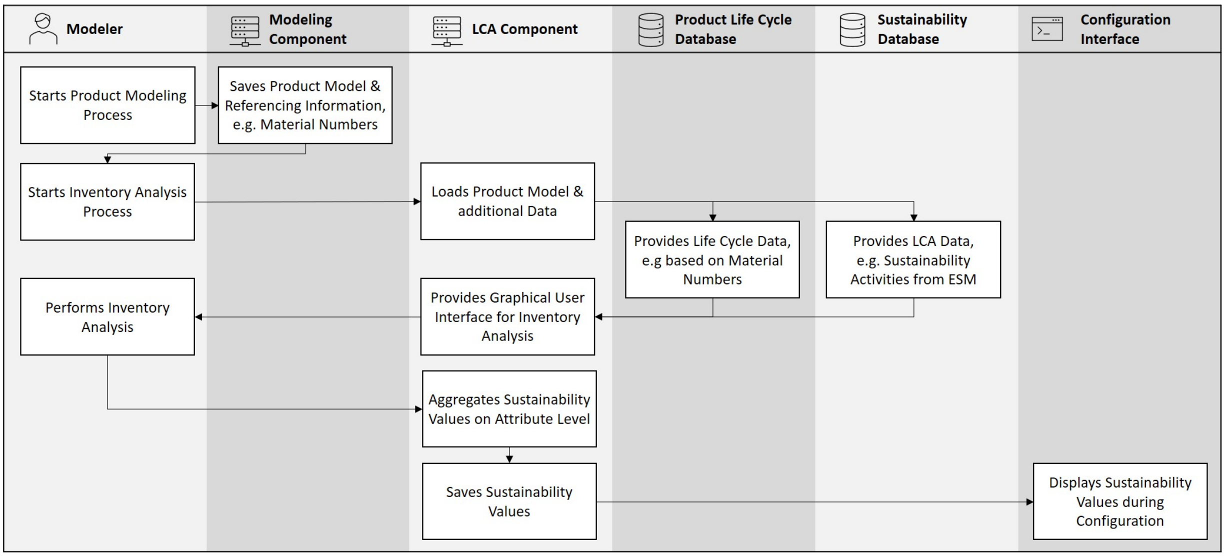

Figure 2. Process for LCA within a configurator executed by a modeler.

the sales model. The features and thus also the sustainability values of the technical model are not visible to the user. In order to make the complete sustainability assessment of a product configuration visible to the user, the sustainability values of the technical model must be transferred to the sales model.

In principle, there are two cases in which sustainability values are assigned to features. First, there is the case in which the sustainability values are directly available in the sales view. This is always applicable when an element is modeled directly in the sales view as a feature and therefore cannot be changed. This can, for example, apply to the selection of car tires. The user can choose between summer, winter and all-season tires. However, she has no option to configure the tread depth or the rubber compound. These properties are predefined for the characteristic.

In the second case, however, the assignment is not possible directly. In this case, the sustainability ratings refer to the technical view, which means that the sustainability values are not visible to the user. This case always occurs when a characteristic is only modeled in the technical model and its integration into the configuration is thus implemented via rules defining the relationship with the sales model. For example, the selection of a trailer coupling in the sales model leads to the installation of a reinforced instead of a standard chassis in the technical model in the background of the configuration. The question now arises how the sustainability ratings from the technical model can be assigned to the sales model and thus made visible and comprehensible to the user. Two principles can be identified for the assignment:

- *Causal Allocation:* Only those sustainability values may be allocated to a characteristic for which it is primarily responsible.
- *Comprehensible Allocation:* The user must be able to understand how the sustainability value for a characteristic is formed.

One possibility is to allocate the sustainability values of the technical characteristics to the sales characteristics by means of an allocation rule. This possibility must be rejected for three reasons. First, a user cannot understand the allocation. In order for users to understand the allocation of sustainability values from the technical model, the relationship between the different characteristics would have to be shown to them. This contradicts the idea of reducing the complexity of the sales-based model. However, if the user does not receive information about allocations of sustainability ratings that have been made, the sustainability values given can be incomprehensible and confusing. This is illustrated by the following example. Taken by itself, a trailer coupling has a significantly lower sustainability value than an engine. However, if the sustainability value of the chassis is fully allocated to the sustainability value of the trailer coupling, the trailer coupling suddenly has a significantly higher environmental impact than the engine. Secondly, when allocating the technical sustainability values, the question arises as to how an allocation should be made. In many cases, it is practically impossible to make an allocation that is fair to the cause. For example, it is questionable how the sustainability value of the engine should be allocated to its properties *fuel consumption* and *performance*. This would require an isolated consideration of the properties, which is hardly possible. Thirdly, ISO 14044 makes it clear that allocations - if possible - should be avoided [10].

The second possibility is not to carry out an allocation, but to assign the sustainability values of the technical characteristics to a dummy feature created specifically for this purpose in the sales view. If only one such dummy exists for a product, which includes the sustainability values of all technical characteristics, the user can hardly understand how the sustainability rating of his product comes about. Therefore, the product is broken down into meaningful components, with each of these product components receiving its own dummy feature for allocation. This procedure is based on the system space extension recommended in ISO 14044 [10], since the sustainability rating of each technical characteristic is mapped to its corresponding sales-related product component. Thus, the allocation is cause-appropriate. At the same time, the decomposition of the product into components allows the user to better understand the full impact of a configuration step on the sustainability value based on the individual product parts. The extent to which detailing makes sense depends on the complexity of the product on the one hand and on the product knowledge and information requirements of the user on the other hand.

4.4 LCA-related Challenges

Due to the high complexity of LCA, there are several challenges that make it difficult to apply the methodology in configurators in practice. A key challenge is that a LCA must fully capture all inputs and outputs of a product over its entire life cycle. A typical product consists of thousands of sustainability activities, all of which must be captured [31]. Another challenge is allocating the sustainability value of processes involving multiple products. Solutions for these two complexities are presented below in the context of product configuration. As an aside, it should be noted that another challenge lies in the variety of enterprise processes possible in practice [31]. For example, several alternatives can exist for a process, which in the end lead to the same product, but which differ greatly in terms of their sustainability. Therefore, the use of process alternatives must be taken into account during the LCA. However, this aspect will not be dealt with in this paper.

4.4.1 Level of Detail in LCA

A major complexity in the LCA of a product is that, in general, all its inputs and outputs have to be considered. One way to reduce the complexity is to define the required accuracy for the LCA, where ISO 14040 allows mass, energy, and environmental relevance as cut-off criteria. Since the mass of individual materials is most probably available from an existing ERP system, it is obvious to use the cut-off criterion mass. If a material has a lower share in the mass of the product than the cut-off criterion specifies, no LCA needs to be performed for it. To verify the correct application of the cut-off criterion, a sensitivity analysis must be performed according to ISO 14044 [10]. For the modeler, such an analysis is very time-consuming and can be classified as difficult to implement with regard to the target group of SMEs. Therefore, automation of the sensitivity analysis should be considered in the future.

However, the cut-off criterion of mass cannot be used without further considerations for the evaluation in the product configuration. For products from mass production, the materials that go into the product are known. In the case of MC, the total weight cannot be determined before the configuration is completed. However, since the LCA is performed before the configuration is completed by the user, the question arises as to what total weight should be used. According to the strict guidelines of LCA, the total weight of the product variant with the lowest weight must be used. This is the only way to ensure that the cut-off criterion is used correctly for all variants.

4.4.2 Allocation Problems

LCA pursues the goal of assigning exactly that sustainability value to a product which corresponds to the environmental impact caused during its complete life cycle. However, if processes exist in which several products are involved, the question arises as to which product must be attributed which share of the environmental impact. For example, several products may be moved in a transport process. Likewise, a machine can manufacture different products and consume a certain amount of auxiliary materials, which must be allocated to the individual products.

The occurrence of such a case is an allocation problem. In principle, according to ISO 14044, an allocation should be avoided by detailing or expanding the product system [10]. The modeler can make such an adjustment in the product configurator by modifying the product structure stored in the product model. However, this procedure is not expedient for the examples described at the beginning. In these cases, the environmental impact must be allocated to the products involved. For this purpose, ISO 14044 prescribes an allocation according to the physical relationships between the products [10]. There are different physical relationships that can be considered for an allocation. Mass could be used because the information is probably available. Another possibility would be the use of volume, since this is usually also mapped in the ERP system. Which physical relation should be used for the allocation has to be decided by the modeler depending on the use case.

If an allocation according to the physical relationships is also not possible, other relationships between the products must be found [10]. For this purpose, the economic value of a product can be used [3]. One way to determine the economic value would be to use prices. These are already available and easily accessible in sales-related product configurators. However, it should be noted that these are usually assigned to the sales perspective and often value product functions rather than technical modules. However, in order to use the prices to determine allocation, it would be necessary for the prices to be assigned to the individual technical modules, since it is for these that the assessment is performed. Therefore, in general, the use of the product configurator prices for allocation should be avoided. A better option is to use costs. These are also frequently mapped in sales-related product configurators for the purpose of margin calculation. In contrast to the prices, the costs are directly assigned to the technical modules. Therefore, the costs can be used for the allocation of sustainability values.

5 DISCUSSION

We analyzed integrating sustainability information into configurators in a way that enables SMEs to include sustainability information into their product configuration process. The considerations were based on the assumptions of an existing configuration solution integrated in the company's system landscape, ecoinvent as a sustainability database, and ESM as an exemplary impact assessment methodology. In addition, the examinations were aimed at being compliant with the state-of-the-art LCA standards as much as possible.

An important step is to verify the proposed configurator architecture in an industrial application scenario. This would enlighten whether the suggested components can realize the intended functionalities. The topic of system and, related to this, data infrastructure, has only been treated superficially. It is necessary to evaluate closer how the information needed for an LCA can be obtained in different infrastructure scenarios and what data is usually available for integration.

The choice of ESM as an LCA methodology is advantageous in the context of the proposed modular product assessment, as EP values of inputs and outputs related to one characteristic can simply be summed up. Application of the findings to indicators with other features is not possible on a one-to-one basis. For example, the recycling rate describing the share of recycled material in a part, cannot be summed up over all components and requires a different aggregation functionality. Future work should also strive for a holistic view of sustainability and expand the considerations to complementary sustainability indicators. For this purpose, the social and economic dimensions of product configurations should be considered in addition to the ecological dimension. For example, with regard to the economic dimension, an evaluation of the total cost of ownership for the customer could be helpful. This would enable the customer to take into account not only the purchase price but also the costs of using the product over its entire life cycle when making a purchase decision.

Concerning the execution of the LCA, concepts have to be developed that facilitate the handling of the identified complexities. The focus was laid on enabling SMEs to integrate sustainability information in their configurators, but the high complexity of both inventory analysis and impact assessment call for additional user support for a correct execution of the LCA. With regard to the variety of alternative business processes, it should be investigated how their environmental impact can be correctly assigned to products. With regard to the cut-off criteria, the extent to which the sensitivity analysis required by ISO 14040 can be automated should be examined, so that the modeler can concentrate on the actual LCA. For the handling of allocation problems, further research can shed light on how functionalities can be provided to support the modeler in the allocation of environmental impacts to several products. For the identification of possible solutions, an analysis of existing LCA software has the potential to provide valuable insights, since these already address the given problems for non-configurable products.

Seeing all these challenges, taking a step back to consider the role of the considered standards can be a reasonable step. So far, ISO 14040 and ISO 14044 only describe the assessment of products and services in general. However, it has been shown repeatedly in this work that the modular structure as well as the high number of variants in product configuration raise special requirements towards the execution of an LCA. Two main approaches can be followed: not supporting standard compliance or extending the standard to the area of MC products. The latter approach is probably the more desirable one, as it would create a uniform framework and increase the reliability of sustainability information for customers. It would also promote the exchange and comparison of LCA results for product variants.

Reliability points towards a more general issue: trust. The presented approach is based on the assumption that the offering companies themselves are performing the LCA. Currently, there is no independent party involved to check the correctness of the sustainability information provided in the configurator. Measures are needed to increase the trustworthiness of the presented information.

6 CONCLUSION

The integration of sustainability information in configurators aims at providing users with decision-relevant sustainability information in the context of MC products. The importance of this kind of information will probably significantly increase in the future. The sustainability assessment of MC products with a high number of variants poses a considerable challenge, especially for SMEs. Configurators can clearly support the undertaking by providing system integration, assessment functionality, and information display. But further research in this area is necessary.

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