Chapter 28

Depth and Detail or Quick and Easy? Benefits and Drawbacks of Two Approaches to Define Sustainability Criteria in Product Development

Matilda Watz and Sophie I. Hallstedt

28.1 Introduction

Despite an increasing awareness and interest, companies struggle to integrate life cycle sustainability considerations into product development [1]. The complexity of sustainability is a challenge for the identification of life cycle criteria that effectively guide toward increased socio-ecological sustainability performance of products and product service systems [2]. However, reducing the complexity by narrowing the scope of what sustainability means can lead to sustainability sub-optimization [3]. For instance, well-known sustainability aspects, such as reduction of greenhouse gas emissions from fossil fuels, may be selected ad hoc without a complete picture of sustainability in the specific design context. While reducing these emissions is critical to realize the slow-down of climate change, the solution could cause other negative sustainability impacts if the whole spectrum of sustainability is not taken into consideration. An example is the issue of electromobility, which provides a good opportunity to reduce the climate impact of the transport sector, but that relies on technologies that are dependent on metals that are sourced from limited and non-renewable supplies. Mining industry and its contribution to natural resource scarcity account for negative environmental impacts, for example, in form of air- and water pollution, and land use change, social issues, such as hazardous work conditions and conflicts. On a global system level, these ecological and social aspects also contribute to un-sustainability, just like greenhouse gas emissions from fossil fuels. And on a micro-level, companies need to account for the economic implications of these impacts in their business strategy development. Hence, to realize a sustainable

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M. Watz (✉) · S. I. Hallstedt
Department of Strategic Sustainable Development, Blekinge Institute of Technology, Karlskrona, Sweden
e-mail: matilda.watz@bth.se

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transport sector by the means of electromobility requires not only replacement of fossil fueled engines but also that aspects such as the minimization of toxic waste from battery production are ensured [4]. To provide a complete, and for the company relevant, picture of sustainability requires more than applying a well-known set of sustainability design criteria.

However, identifying the “right” set of sustainability criteria can be a challenging task within product developing companies today [5, 6]. Ideally, this task takes place at a very early stage of the product innovation process to mitigate risks for potential unintended consequences that can arise from a narrow focus on specific sustainability performance improvements without awareness of trade-offs with other sustainability aspects or design objectives [7]. In practice this means that most of the sustainability impacts of a product life cycle are determined already before the detailed design phase. But to identify social, ecological, and economic impacts of a not yet existing design solution, and calculating their magnitude, might be extraordinary cumbersome as these take place across the whole life cycle [8]. As it is rare that a company has access to all data that can be used to define the sustainability impact of an existing design solution, traditional life cycle assessment methods, from now on called “LCA” utilize aggregated historical life cycle data of materials and processes to analyze sustainability impacts in areas of the life cycle where a company has limited insight and control [9]. However, the questions about which data to assess, and which sustainability impacts to calculate remain. Therefore, companies might be attracted by standard sets of sustainability criteria to apply in all design projects, which from a sustainability and design perspective, is not ideal [10].

Against this background, the concept of leading sustainability criteria has evolved [5, 11]. Leading sustainability criteria (LSC) are defined using a strategic sustainability perspective and life cycle thinking. Together, LSC cover all life cycle phases and sustainability dimensions, address aspects that are difficult to change later in a design project, and are defined in a way that enables compliance assessment. However, current approaches for identifying LSC can be improved in terms of usefulness, usability and applicability, just like other sustainable design methods and tools [2, 12]. The aim of this study is to propose an approach to identify leading sustainability criteria that are applicable in many company contexts, without the need for expert facilitation. Guided by the research question “*What are some benefits and drawbacks with different approaches for defining leading sustainability criteria to guide definition of product requirements?*,” this chapter therefore compares and discusses the usefulness, usability and applicability of two approaches for identifying LSC.

28.2 Research Design

The research design is based on a comparative case study, for example, [13, 14], where the two approaches for identifying LSC are evaluated. Three use cases when the approaches have been applied are evaluated. The results and feedback from each use case are analyzed using the evaluation criteria usefulness, usability, and applicability [15].

28.2.1 Approaches to Identify Leading Sustainability Criteria

The two approaches for identifying LCS are described in this section.

28.2.1.1 The Sustainability Design Space Approach

The Sustainability Design Space (SDS) approach was developed for a product design team to identify and represent an acceptable, sustainability compliant, space for candidate designs [10]. A similar approach as the Set-Based Concurrent Engineering, set out by Sobek et al. [16], was used, in which the criteria should be used to set targets and guide the development of concepts and new innovations at the company. The main reason for the development of this approach was to avoid suboptimization as when sustainability-related criteria exist in product requirements today, they are often developed based on effects that are assumed to be desirable or not, along with being easy to assess.

The SDS aims to identify the prioritized life cycle sustainability aspects for the company products. It also gives answer to what a degree a concept performs in relation to a sustainable solution. The user should be familiar with the company product and production and there are three steps to create the complete sustainability design space, see Fig. 28.1. LSC are selected in an additional fourth step. Templates for each of these steps are available for the user. The four steps are:

Fig. 28.1 The three steps to create the complete sustainability design space [10]

1. Develop strategic sustainability criteria: These are the ideal long-term sustainability targets and something to strive for. The long-term criteria are developed using a principle-based definition of sustainability combined with backcasting [17, 18]. The user formulates these for one product life cycle stage at a time with the guidance question: What materials, production processes, and activities should you aim for or avoid in your future solutions that will contribute to a development which is in line with the overarching sustainability principles for a sustainable society.
2. Tactical Sustainability Design Guidelines: These are the prioritized sustainability aspects that support development toward the long-term strategic sustainability criteria. The user formulates 1–2 design guidelines for each criterion and connects these to any of the sources such as long-term strategic goals for industry; safety documents, recycling manual, key performance indicators—social and environment, material lists, code of conduct, environmental policy, environmental.
3. Develop Sustainability Compliance index (SCI) for each criterion: SCI is a metric that states the levels of compliance for each of the strategic sustainability criteria to operationalize the use of the criteria strategically and tactically. The user defines the SCI levels guided from a generic developed SCI scale, inspired by and adapted from other maturity or readiness scales such as the Technology Readiness Level [19], Sustainability Integration Stages [20], and Capability and Evolution Levels [21].
4. Select the Leading Sustainability Criteria (LSC): The LSC was added to the Sustainability Design Space approach in further research [11] as there is a need for a set of selected criteria to represent the most important sustainability aspects that can be accomplished within the time-constrained early design decisions. The increased data availability later in the design development, enables more detailed analysis and down-selection between fewer alternatives with improved certainty [22]. The user selects the LSC based on the characterizations of the leading criterion which are: possible to find data and information for SCI judgement; includes all dimensions of sustainability, that is, social perspective, environmental and, economical perspective (business perspective for the company); and, based on aspects that will affect the concept design directly or indirectly and that will be hard to change later on (or more costly).

The SDS has been conducted completely in one manufacturing company and partly in two other manufacturing companies in Sweden with facilitation from one or two researchers. Most of the work to complete and finalize the different steps of the Sustainability Design Space have been done by the researchers, as it was too cumbersome and time demanding for the users as it requires a workload of about 3–4 days. However, a completed SDS only needs to be updated approximately every other year.

28.2.1.2 The Leading Sustainability Criteria Workshop Approach

In the leading sustainability criteria workshop (LEASA), elements of the SDS approach and a Sustainable Product Development workshop for early design phases [23] have been combined. In a facilitated workshop, participants go through the three steps "to be," "as is," and "strategies" to identify possible design strategies and activities to leverage sustainability performance in their design projects. In this way, backcasting from an ideal sustainable solution, defined using a holistic sustainability and life cycle perspective, guides the criteria identification process. A final, fourth step aims to help participants select, and possibly combine, strategies and reformulate these to fit into the characteristics of LSC. Templates with guiding questions and checklists are used in each step to support discussion and help capture the results. At the end of the workshop, participants have a list of LSC for their specific design project. Table 28.1 gives an overview of the workshop steps, including examples of guiding questions. A more detailed description of step 1–3 can be found in Schulte and Hallstedt [23].

Table 28.1 Overview of steps in the workshop approach to identify Leading Sustainability Criteria from which step 1–3 is adopted from the Sustainable Product Development workshop method [23]

Workshop steps	What	Type of support	Example
1. To be	Describing the characteristics of the ideal, sustainable, solution	Guiding questions	What functions are satisfied by a sustainable solution?
2. As is	Assessment of the current solution (if there is one), otherwise of current portfolio, in relation to the characteristics identified in step 1	Guiding questions	What are current sustainability challenges and opportunities to deliver those functions—Considering the life cycle phases: Raw materials, production, usage and maintenance, and end of life
3. Sustainable design strategies	Discussion and identification of possible actions and strategies to bridge the gap between the ideal solution (step 1) and the current (step 2)	Template	A blank template is provided for this step, in order to leave room for the participants' own experience and creativity
4. Leading sustainability criteria	Selection of strategies and actions from step 3 and reshaping of these into leading sustainability criteria	Checklist	The LSC: – Cover all life cycle phases and sustainability dimensions – Are measurable – Address aspects that cannot be changed later in the design process

28.2.2 *Comparative Quality Evaluation and Use Case Selection*

The comparative evaluation of the two approaches is enabled through the definition of quality evaluation criteria. In design research, quality can be described in terms of usefulness, usability, and applicability [15]. Usefulness refers to how well a method or tool lives up to its intended use, usability refers to how easy it is to use the method or tool as intended, and applicability refers to the scope of use contexts in which the method or tool can be used.

The indicators used in the quality evaluation and the selection of use cases are described below. Indicators for each of the quality criteria are defined to structure the comparative evaluation. To evaluate the usefulness of the two approaches, the accuracy of the identified LSC (in relation to the characteristics of leading sustainability criteria) in the different use cases is evaluated. The usability is evaluated through qualitative analysis of participant feedback, researcher memos, analysis of the materials used by the participants, as well as participant profiles. The applicability is evaluated by triangulating the accuracy of identified LSC, participant feedback, and the use case context, that is, type of industry and design project. An overview of the quality evaluation criteria can be found in Table 28.2.

The two approaches have been developed and tested together with industry and in engineering education in several cases. In this research, three use cases that represent different use contexts have been selected. The first use case describes the application of the SDS within an aerospace engine component development and manufacturing firm. The second use case describes the application of the SDS approach and the LEASA workshop at an industrial sealing solutions manufacturer, and the third use case describes the application of the LEASA workshop in a design engineering education context. Together, the three use cases summon perspectives of a wide range of user profiles and use context.

Table 28.2 Overview of quality evaluation criteria

Quality criteria	Evaluation aspect	Analysis method
Usefulness	Type of outcomes, accuracy of identified LSC	Qualitative content analysis
Usability	Type of facilitation, time, participant feedback, researcher memos, materials, participant profiles	Qualitative content analysis
Applicability	Participant feedback/use case context	Qualitative data triangulation

28.3 Evaluation of Use Cases

In this section, the results from the LSC identification in the three use cases are presented and structured according to the quality evaluation criteria. Hence, the results which were evaluated include a description of the approach for each use case, examples of LSC, summaries of participant feedback and researcher memos, descriptions of the templates used by participants, and a description of the use case context. An overview can be found in Table 28.3, and detailed results in the subsections.

Table 28.3 Overview of three use cases and workshop approach applications

Use case/ *approach*	Use context/*participant profiles and (number)*	Time/*researcher involvement*	Outcomes (*degree of implementation*)
1/*SDS*	(a) Aerospace engine component design, (b) construction equipment product design, / *specialists on engineering design and sustainability* (1 person per company)	Several days / In (a) *researchers responsible for all steps. In* *(b) researchers conducted step i and step ii and consulted company participants*	– Long-term sustainable design targets from step i – Tactical design guidelines from step ii – Sustainability compliance index (SCI) from step iii – Leading sustainability criteria from step iv *(a: Implemented in product development process, b: Used result in further research)*
2 -*SDS* -*LEASA workshop*	Industrial sealing solution component design / *sustainability manager, specialist on sustainable product development implementation (2)*	– SDS: Several months/*company representatives responsible for sustainability design space with support from researcher on occasion* – LEASA: 2 h/*researcher facilitation*	– Long-term sustainable design targets from step i – Tactical design guidelines from step ii (partly) – Leading sustainability criteria from step iv *(Used result in further research)*
3/*LEASA workshop*	Course projects (product service system and systems engineering design/*Master-level students (32)*	2 h/*researcher facilitation*	Leading sustainability criteria *(Used in course project and in further research)*

28.3.1 *Use Case (1) Sustainability Design Space in Aerospace Engine Component Design and in Construction Equipment Design*

The SDS was the first time conducted in an Aerospace Engine component case company as the research and development department wanted to increase the capability to integrate a sustainability perspective in their decision-making system. In an action research-based approach, the SDS was developed as a novel approach in parallel to the development of the SDS for the company. The second time the SDS was conducted, a new company was selected that represented another industrial sector with a different product- and production process to validate its usefulness, usability as well as its generalizability. In both cases, a sustainable product development researcher led the work and consulted the company practitioners in several interactive activities. The work took place over a period of 6 months but the workload to conduct all four steps is estimated to about 4 days of concentrated work. An example of a LSC is provided in Fig. 28.2.

28.3.1.1 Usefulness, Usability, Applicability

The SDS approach can be considered to have high usefulness, as it provided the companies with a set of tools that could be implemented into several layers of their product development processes. This provides strategic management with long-term targets to guide the portfolio development. The tactical level is provided with

	Leading sustainability criteria
SCI	*Lifecycle phase: End-of-Life*
9	*All valluable materials/components are returned to the value chain for remanufacturing and recycling.*
6	*Recycling is monitored, and over 50% of the products are remanufactured.*
3	*Some materials/components are recycled but no systematic monitoring of recycling is performed (information is lacking about recycling).*
1	*No recycling/remanufacturing of components takes place at end of life.*
0	*Do not know if and how much recycling/remanufacturing of materials/components occur at the end of life.*

Fig. 28.2 Example of leading sustainability criteria for the life cycle phase “End-of-Life,” derived with the SDS approach. The SCI columns shows criteria for different levels of sustainability compliance. (Adapted from [10])

sustainability criteria and tactical guidelines to define the scope of sustainability improvements, guiding toward which analyses that must be made to progress in a design project. And the operational level can use the SCI scale to evaluate the sustainability performance against a targeted level. The usability can, however, be considered as moderate, due to the time requirements as well as the need for expert consultation. Access to a great variety of cross-disciplinary company documentation is needed, as well as competency in strategic sustainability thinking. The combination of these two aspects may require the involvement of a specialist group, rather than as in this case, a researcher. Hence, industrial application might be dependent on access to a high level of sustainability competency.

With respect to the evaluation criteria for usefulness, usability, and applicability, the SDS scores high in usefulness but can be considered to have limited usability and applicability.

28.3.2 Use Case (2) Combination of Sustainability Design Space and Leading Sustainability Criteria Workshop Within Industrial Sealing Solutions Design

A design engineer with responsibility for implementing sustainable product development in the product development process at the company was together with and a sustainability manager in the process of finalizing a SDS. Using the templates, and with limited support from a sustainable product development researcher, they had defined the long-term sustainability targets but not yet the tactical guidelines or the LSC. To enable participation in a study that require LSC as input, they therefore participated in a LEASA workshop. As a result, the participants became familiar with both the SDS and LEASA, and thus able to give feedback on the two. A 2-h LEASA workshop was organized and facilitated online by two researchers guided the participants through all steps.

28.3.2.1 Usefulness, Usability, Applicability

A combination of both the SDS and LEASA provided the opportunity for the company to reflect on both approaches.

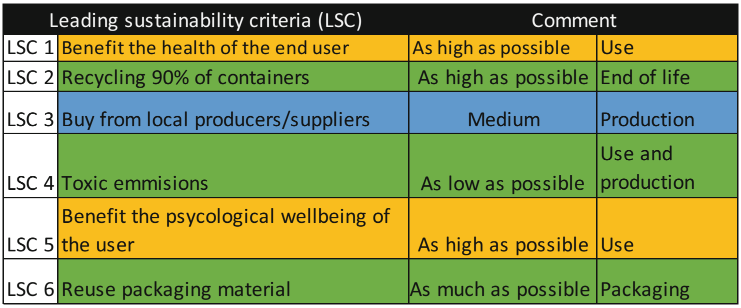
The SDS approach was considered to have high usefulness, as it forced the practitioners to assess the whole management structure of the company that could be related to product development and sustainability. In this way, the SDS provided an opportunity for the practitioners to gain deep knowledge about the extent to which sustainability is included in the decision-making processes that influence the product development process, for instance, what type of requirements, standards, and certifications that support a long-term vision for sustainability. Another useful aspect of the SDS was the opportunity to build cross-disciplinary in-house networks of competencies. The two practitioners conducting the SDS had to engage with other company functions to find all required company documents, and to learn in which way they were used. To ensure this level of expertise in the group of participants that are selected for a LEASA workshop can be difficult as it might not be possible to know beforehand which roles that possess the right competencies. The LEASA approach was considered useful, as it provided an opportunity to from the beginning direct the selection and formulation of LSC so that they could work effectively as criteria in concept development and selection. In this way, the LEASA approach was considered as time efficient. However, the participants acknowledged that their background knowledge provided by the SDS probably made the application of the LEASA approach smoother than in a context where participants are completely new to it. A combination of SDS and LSC can be considered as well-performing in respect to all quality criteria, that is, highly useful, usable, and applicable.

28.3.3 Use Case (3) Leading Sustainability Criteria Workshop in Engineering Design Education Projects

Students in two project courses in engineering design were given a workshop series in sustainable design as part of their project work. One of the courses was on product service system innovation (PSS) and given to 16 students in their second year of their master program, while the second course was on Systems Engineering (SE) and given to 25 students in their first year of their master. The LEASA workshop constituted as the first out of three 2-h workshops in the series and was held online in both courses. The students had been asked to refresh their memory on sustainability and sustainable design before joining the workshop and were at the beginning of the workshop sessions introduced to the purpose of the workshop and to the workshop templates. Thereafter, the students were sent to break out rooms in the online meeting, and the facilitating researcher moved between the rooms to support their discussions and to introduce each new step of the workshop. The PSS students were given the workshop series at the end of their course, just before making critical and final design decisions in their projects. The SE students, on the other hand, were given the workshop in the beginning of their projects, in a phase of need-finding and planning.

28.3.3.1 Evaluation of Usefulness, Usability, Applicability

With moderate supervision from the facilitating researcher, all nine teams were able to formulate a list of LSC at the end of the workshops. The checklist for LSC characterization helped ensure that all life cycle stages and all three sustainability dimensions were covered by the LSC, but not all teams managed to define LSC with respect to information availability and delimitation of the design space. However,



Leading sustainability criteria (LSC)		Comment	
LSC 1	Benefit the health of the end user	As high as possible	Use
LSC 2	Recycling 90% of containers	As high as possible	End of life
LSC 3	Buy from local producers/suppliers	Medium	Production
LSC 4	Toxic emmisions	As low as possible	Use and production
LSC 5	Benefit the psycological wellbeing of the user	As high as possible	Use
LSC 6	Reuse packaging material	As much as possible	Packaging

Fig. 28.3 Example of leading sustainability criteria developed in use case iii. The colors indicate sustainability dimension (green = ecological, yellow = social, blue = economic) and the comments indicate the desired performance level

with an extra hour of team discussion and supervision it is likely that the students would have been able to apply these characterization criteria as well. Taking only two and a half hours, it still led to valuable results, that is, sustainability criteria that the students used to guide concept development from a sustainability perspective in their design projects. Figure 28.3 shows an excerpt from a team template shows an example list of LSC.

As an education tool, the LEASA approach can hence be considered to score high in both usability and applicability but moderate level on a usefulness point of view.

28.4 Concluding Discussion

This study presents the result of a systematic comparison and assessment of the usefulness, useability, and applicability of two approaches to identify leading sustainability criteria and have discussed their benefits and drawbacks from an industrial, educational, and academic point of view. In brief, the SDS approach gives more detailed outcomes than the LEASA approach, but on the other hand demands more resources and time to conduct. To support a selection and implementation of support tools in industry, we propose aspects such as usefulness, usability, and applicability, as a standardized and objective way to present support methods and tools in an organized structure. This is in line with the research road map, presented by Faludi et al. [2], in which the identification of success factors and examples of needs in industrial cases is pointed out as key research area for enhanced implementation of support tools.

A standardized way of comparison can be of value for industry when selecting approaches with similar purposes and thereby they can more easily navigate between different choices for different organizational levels [24]. Today, many tool databases are available for practitioners, who can base their selection on whether they need support with, for example, idea generation, provision of generic information in checklists, or environmental design guidelines. However, there is still a lack of guidance which is complete and context-specific enough, that is, covering all three sustainability dimensions, easy to use and actionable, for industrial practitioners who can benefit from support that considers sustainability from early stage to late stage of product development process (e.g., in [25]). A standardized approach in assessing them would be supportive for industry and regulators to select the most appropriate tool for the task at hand. To strengthen the validity of findings, future comparative studies can also include results from tools applications free from researcher involvement.

In the next subsection follows a discussion on the identified benefits and drawbacks of the two approaches to identify LSC, and how these findings can be used to leverage improved usefulness, usability and applicability of other sustainable design tools and methods.

28.4.1 Benefits and Drawbacks with the Sustainability Design Space and the Leading Sustainability Criteria Workshop

In Sect. 28.3, we presented an evaluation of the SDS approach and the LEASA approach applied in three use cases. The SDS approach scored high in usefulness, while the LEASA approach performed better in usability and applicability. More specifically, the SDS approach was more successfully than LEASA supported the identification of sustainability criteria compliant to LSC- characteristics. Presence of relevant competencies and enough time in the last LEASA workshop step were pointed out as crucial factors to mitigate this limitation.

The usefulness of LEASA could therefore, potentially, be leveraged from usability improvements, for instance, through additional instructions with proposed time spending per step and role descriptions to guide participant selections. Such measures could also improve the usability of the SDS approach but does not change the fact that it requires time and dedication to reach a sufficient depth. This is the key strength of the SDS approach that provides the whole product development organization with more robust decision support, that is, long-term sustainability targets, tactical design guidelines, and, of course, LSC that can be reused. The LEASA approach is useful when such rigor background does not yet exist, or when there is time or competency limitations, as it does provide LSC, and if it is an acceptable risk that important information remains unknown.

The applicability of LEASA scored high as it can be used in several contexts, even as an educational tool. An organization could, hence, use the tool both operationally and to increase the sustainability competency of the employees. Raising the sustainability competency organization might then ease the implementation of the approach, as well as more detailed approaches such as SDS, in the product development process.

28.4.2 Depth and Detail Versus Quick and Easy

The general assumption may be that tools and methods that are easy-to-use and quickly generate results are less robust and advanced. However, there is no evident connection and clear answer to if a "quick and easy" tool will generate less "depth and detail", that is, limited quality of results. We argue, on the contrary, that the quality instead may depend on the rigidity of the approach that the tool applies, that is, whether it is based on a scientific verified framework and has been developed for the needs of the users. "Less is more" might apply in some contexts but should not neglect the important challenge to "simplify without reduction," regardless of whether the tool is quick and easy. This is particularly true for the area of sustainable development where it otherwise may result in suboptimization and investment that run the company into dead ends [26]. One important part is to select the right tool for the specific task or purpose. For companies that are uncertain of which approach they should select, we therefore propose a guiding support tool with questions that the project team at the company should ask themselves before selecting the tool, such as "why to use a tool"; "when to use it"; "who and how to use it"; "what is the data input"; or "what is the data output."

How can then sustainable design tools be designed for high usefulness, optimal usability, and through easy adaptability, also leverage high applicability in industry? In future research, we will explore this question further and collect examples and cases when support tools have been successful in terms of these three evaluation aspects. Additional questions: What are the success factors and how can academia and industry work together in order to reach success in purpose of sustainability implementation?; What role do regulators, governmental authorities, standard organizations play to allow for different types of support tools to enhance sustainability integration at different organizational levels in companies, with different needs?; and, How can these actors advise about support methods and tools for sustainable product development and steer the industry in the right direction for society to move faster in the sustainability transition? These are examples of questions that need to be further explored in future research.

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