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Sustainability impact and effects analysis - A risk management tool for sustainable product development

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A B S T R A C T

Integrating a strategic sustainability perspective in product development requires that decision-makers can connect socio-ecological sustainability aspects to tangible business implications in the short- and long term. Only then will there be the driving forces necessary for adopting sustainable product development practices. A risk management approach can be used to enable strategic proactivity by exposing the potential consequences of sustainability-related decisions, for example in relation to reputation, legislative change, the ability to attract top talent, or meeting customer needs. Through an action research approach and by building on previous findings and existing tools and methods, this study presents the Sustainability Impact and Effects Analysis. This novel method and risk management tool combines the familiar format of the well-established Failure Mode and Effects Analysis with a strategic sustainability perspective. Designed to be applicable in early stages of the product innovation process, this tool aims to increase decision-makers' awareness of sustainability risks and provide them with a practical way for how to identify, assess, and treat such risks. The tool was developed in close collaboration with industry and tested in two different companies. The results indicate the effectiveness of the tool for identifying and analyzing sustainability risks, as well as deriving and monitoring strategies for how to manage them strategically, also leading to an increased awareness of the interconnections between socio-ecological sustainability aspects and business implications. Thereby, it can provide support for companies in how to work with product development in a way that contributes to society's transition towards sustainability, while benefiting the own organization.

1. Introduction

The necessary transition towards a sustainable society is dependent on product development and manufacturing companies taking leadership. It is in product development that the new business models, technologies, and products are envisioned and developed that shape society and its impact on ecological and social systems (Gaziulusoy et al., 2013). Since the transition towards a sustainable state requires drastic changes in all areas of society, it entails extensive uncertainty. Product development companies need to develop capabilities to connect macro-level societal change towards socio-ecological sustainability with tangible implications for the economic sustainability of their business to ensure relevance and competitiveness on changing markets (Schulte et al., 2020). Risk management can be used to identify and manage the threats and opportunities that society's transition towards sustainability entails, for example, stricter social and environmental legislation, changing customer demands, national and global litigation, effects on brand and reputation, ability to attract employees and investors, and availability and costs of resources, waste, and emissions (Gomez-Valencia et al., 2021; Chatzitheodorou et al., 2021). Ultimately, companies that fail to contribute or adapt to the inevitable transition towards a sustainable society, will not survive (Anderson, 2005). But it is not only the fear of failure that should motivate company action. As markets are becoming increasingly sustainability-driven, there is a self-interest for companies to be pro-active in relation to sustainability in order to benefit from the business opportunities that represent the upside of the risks (Robèrt and Broman, 2017). However, even though practitioners largely agree on the importance of sustainability risks, a survey by the World Business Council on Sustainable Development (WBCSD, 2017) found that 70% consider that risk management practices do not adequately address sustainability risks, among other things because of a lack of knowledge, guidance, and

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cross-functional collaboration, and because sustainability risks are difficult to quantify and require longer time horizons to be taken into account.

The early phases of the product innovation process, when strategies are created, requirements are formed, ideas are generated and concepts are selected, play a decisive role for sustainability risk management, as this is where the sustainability performance of a product across its life cycle largely are determined (Diaz et al., 2021; Poudelet et al., 2012). However, existing approaches for sustainability risk management have limitations in terms of (i) requiring detailed information that is not usually available in early phases; (ii) focusing on environmental sustainability instead of a full socio-ecological sustainability perspective; (iii) focusing on the connection between sustainability aspects and product cost instead of a broader stakeholder value perspective, including, but not limited to cost; and (iv) lacking of a long-term strategic perspective, which importance has been emphasized by an increasing number of studies (Broman and Robèrt, 2017; Hallstedt, 2017; Villamil et al., 2021).

In light of these gaps, this study presents the Sustainability Impact and Effects Analysis (SIEA), with the objective to provide support for how to systematically identify and assess sustainability risks and for how to strategically manage them in the early phases of the product innovation process. To make this possible in practice, SIEA builds on Failure-Mode and Effects Analysis (FMEA), because it is well-established in industry, provides a systematic yet easily customizable structure that covers the central steps of the risk management process described in ISO 31,000, and allows for the level of detail and complexity of the analysis to be adjusted. The contribution and novelty of SIEA is that (i) its scope is adjustable so that it can be used without quantitative data, making it applicable in the early phases of the product innovation process; (ii) it includes a full life-cycle and socio-ecological sustainability perspective; (iii) it connects such sustainability aspects to economic business implications through an instrumental stakeholder value perspective; and (iv) utilizing the Framework for Strategic Sustainable Development, it includes a strategic perspective by explicitly including different time perspectives and by enabling backcasting thinking from a vision framed by eight basic, first-order principles for sustainability (Broman and Robèrt, 2017). From a managerial perspective, being able to understand and systematically map the implications of a product's contribution or counteraction to society's transition towards sustainability on the economic sustainability of the company is decisive for several reasons. Firstly, it is a precondition for strategically maneuvering the uncertainty that the sustainability transition entails, secondly, it can support in trade-off situations to find the right pace for developing more sustainable products, and thirdly, it can create relatedness for decision-makers, which is a key ingredient for motivation (Ryan and Deci, 2000), by showing the relevance of sustainability aspects for their ability to achieve their objectives.

2. Literature review

2.1. Sustainable product development

Companies increasingly recognize the importance of building capabilities for sustainability integration and implementation in product development for remaining competitive by meeting new demands from customers, legislators, and other stakeholders (Schulte and Hallstedt, 2017a; Willard, 2012). According to Hallstedt and Isaksson (2017), sustainable product development means that "that a strategic sustainability perspective is integrated and implemented into the early phases of the product innovation process, including life-cycle thinking". Such a strategic sustainability perspective implies that sustainable product development must contribute to society's transition to sustainability in a way that strengthens the own organization. A strategic perspective is crucial to make sure that efforts lead in the right direction and that the company neither is too passive nor too proactive in relation to sustainability. Being able to be strategic requires knowing the goal to be achieved, in this case, a definition of what is meant by sustainability. This definition must include a systems perspective of both the environmental and social dimensions of sustainability in order to avoid sub-optimization. An operationalizable, principle-based definition was presented as part of the Framework for Strategic Sustainable Development (FSSD) (Broman and Robèrt, 2017). These so-called sustainability principles (SPs) can be used to do backcasting to guide design activities and to come up with solutions that lead towards compliance with the principles over time. In contrast to the Triple Bottom Line (Elkington, 1997), which views the ecological, social, and economic dimensions as partly overlapping systems to be balanced, the FSSD considers the three dimensions as nested interdependent systems, Fig. 1. This means that the economy is part of and dependent on a functioning social system, which in turn is part of and dependent on the ecological system. From a societal perspective, the economic dimension of sustainability can be a means to achieve ecological and social sustainability, but it is not an end in itself. In practice in a product development context, the sustainability principles have, for example, been applied for Strategic Life-Cycle Assessment (SLCA) where a vision of a sustainable solution is developed and products' or technologies' hot-spots, i.e. impacts that are essential from a sustainability perspective, are identified to guide further analysis and improvement (Ny et al., 2006; Villamil et al., 2018). Hallstedt (2017) used the principles to develop a method for how a company's specific sustainability design space can be defined. It provides the company with leading sustainability criteria, which are the specific, high-priority, long-term criteria that product development should aim for and move towards.

For the integration and implementation of a sustainability perspective in product development to happen, changes in decision-making processes are necessary and a wide range of support tools have been developed, for example life-cycle assessment, environmental-QFD, checklists, and matrixes such as the MET-matrix (Materials, Energy, Toxic emissions) (Bovea and Pérez-Belis, 2012). In addition, there are approaches for including circular economy considerations into design decision-making, which also can contribute to sustainability (Dokter et al., 2021). However, while there is an abundance of methods and tools developed by academia, implementation in industry remains a major challenge and few tools are used in practice (Pigosso et al., 2015; Vanegas et al., 2018). In part, because the tools do not meet industry needs in terms of simplicity and ease of use (Peace et al., 2018). Another main reason is that the intended users do not see the clear benefit of including sustainability in oftentimes complex decision-making contexts where there are already many aspects to consider. Risk management has been pointed out as a potential lens that could catalyze sustainable product development (Zetterlund et al., 2016), primarily for two reasons: firstly, because risk management is a familiar language and well-established practice in industry (Gaziulusoy et al., 2013), and secondly, because it can help decision-makers to link socio-ecological sustainability aspects to economic business implications by highlighting potential effects on the achievement of company objectives (Schulte and Hallstedt, 2020).

2.2. Failure mode and effects analysis

First described by the United States Department of Defense in 1949, FMEA is a risk-based tool to identify, assess, and manage potential failures of a product or system in a structured way

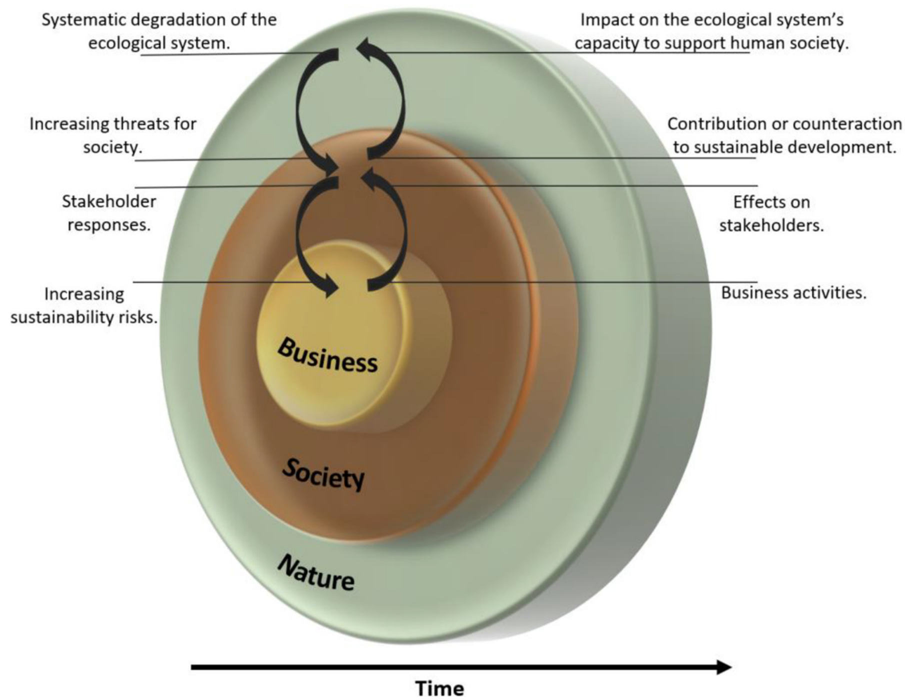

Fig. 1. Nested interdependent systems view of sustainability and its implications for company risk management.

(United States Department of Defense, 1949). In practice, FMEA usually takes the form of a worksheet, listing possible failure modes for functions or components with their causes. These failure modes are then assessed on scales of, for example, 1–5 or 1–10, in terms of their likelihood, severity, and sometimes probability of detection. Multiplying these parameters results in a risk priority number, which indicates the importance of a failure mode, thus guiding the design team in where to focus. Actions in relation to failure modes, e.g. to make changes to the design, are then listed and a person is assigned responsible. By re-doing or updating FMEA, the product development team shall in the end have a design where remaining failure modes are known, mitigated, and of minor importance (Liu et al., 2013). Since its introduction, FMEA has received wide-spread attention in both industry and academia and a large number of ad-hoc extensions has been developed, as described in a review by Spreafico et al. (2017). The review also raises the criticism that most FMEA-related work has focused on incremental solutions for narrow and specific problems, while being unable to handle more general issues in the approach.

The idea of building on FMEA to support sustainable product development has been previously researched by, among others, Lindahl (1999) who presented Environmental-FMEA (E-FMEA). It uses LCA results alongside internal and external environment-related requirements as inputs to identify product life-cycle activities, connected environmental aspects, and the impact caused by these aspects. This is then evaluated based on three criteria, (i) controlling documents, (ii) public image, and (iii) environmental consequences, to calculate an Environmental Priority Number. Also considering improvement possibility, the final step is to list recommended actions to improve the design. Other adaptations of FMEA were described by Rozak et al. (2015) and Nguyen et al. (2016), in this case for sustainable manufacturing. More recently, Bertoni (2020) presented Circularity Impact and Failure Analysis. It builds on FMEA structure, but focuses on potential circularity issues in early design, which was demonstrated based on the case of a bicycle V-brake.

2.3. Risk management and sustainability

In ISO 31,000, risk is defined as the “effect of uncertainty on objectives” (ISO, 2018). Sustainability risk was first defined as risks that are due to environmental or social justice issues (Anderson, 2006) and a rich variety of different ways for how businesses can be affected was described by Anderson (2005). This includes, for example, legislative issues such as taxes on emissions and regulation of manufacturing processes, reputational issues such as boycotts and negative media attention, and litigation issues such as fines and lawsuits. In the meantime, there are also companies, e.g. 3 M, IBM, Tesla, and Electrolux, that exploited sustainability-related opportunities and anticipated market changes, resulting in substantial competitive advantage and financial gains (Robèrt, 2002; Willard, 2012). Palousis et al. (2008) classified sustainability risks in six categories: physical, regulatory, litigation, competitive, reputational, and supply chain risks.

In 2014, Hofmann et al., applied an instrumental stakeholder theory perspective to conceptualize sustainability risks in a supply chain context. They proposed to define sustainability risk as “a condition or a potentially occurring event that may provoke harmful stakeholder reactions” and argued that two factors are critical to precipitate such action: firstly, stakeholders must notice the sustainability issue, and secondly, stakeholders have to interpret the situation as unacceptable and consider the company as responsible. Based on this understanding of sustainability risks, Hofmann et al. (2014) presented a concept for sustainability-oriented supply chain risk management and Hajmohammad and Vachon (2016) and Majumdar et al. (2021) described strategies for how to mitigate supply-chain sustainability risks. In the product development context, the Sustainability Risk Assessment (SRA) framework (Palousis et al., 2010) is most notable. It proposes to do a life-cycle assessment (LCA) of a product, then to do a sustainability risk assessment, and finally, to study the effects of these risks using activity-based life-cycle costing. Anand et al. (2016) and Gargalo et al. (2016) also focused on early-stage design and proposed sustainability risk assessment frameworks. Recently, the use of quantitative approaches for evaluating sustainability risks in product design was studied by Enyoghasi et al. (2020) and Sezer and Selim (2021) proposed the use of risk-oriented system dynamics modeling to analyze product sustainability. Schulte and Hallstedt, 2020 defined sustainability risks as “risks that are due to an organisation’s contribution or counteraction to society’s transition towards strategic sustainable development”. Thereby, they highlighted that the sustainability risks a company is facing (left part of Fig. 1) are directly dependent on the actions of the company when it comes to sustainability (right part of Fig. 1). In line with Hofmann et al. (2014), the study stressed that sustainability risks should be managed in relation to effects on internal and external stakeholder value creation, including, but not limited to cost.

3. Methods

The following research question guided the research methodology: How can a strategic sustainability perspective be integrated into risk management practices in the early phases of the product innovation process? Given the study’s objective of understanding and improving practice, which requires both strategic innovation and systematic reflection, an action research approach was chosen. Action research is particularly useful for solving real-world problems by examining a practical situation, making a change, and studying the consequences of that change (Savin-Baden and Major, 2013). In contrast to case studies, where the researcher has the role of an observer of a phenomenon with limited or no participation, action research is at its core about the researcher being in close collaboration with the study participants and involved in the situation, allowing for first-hand experience of the problem, its context, interventions, and their effects (Brydon-Miller et al., 2003). This characteristic makes action research particularly valuable for studying sustainability aspects in organizational contexts with the aim of developing interventions that can facilitate change in practice (Bastas and Liyanage, 2019; Pigosso and McAloone, 2021; Wu et al., 2021). The action research approach applied in this study was participatory in the sense that the people who were subject of the study took part in defining the problem and needs, developing and testing a solution, evaluating the outcomes, and taking action to change the situation. Over a two-year period between 2019 and 2021, the academic researcher engaged in close and interactive collaboration with a large engine component manufacturer in the aerospace industry, located in Sweden (Company A). This company was selected, because it has been actively working on increasing its capabilities for sustainable product development and on integrating a strategic sustainability perspective in its decision-making processes for more than 10 years (Hallstedt and Nylander, 2019). In this work, challenges were encountered as to how to connect socio-ecological sustainability aspects more specifically to economic aspects. There was a need for a structured approach for how to systematically identify the business threats and opportunities that come with solutions that are performing well or badly from a sustainability perspective. Risk management was early on pointed out as a key leverage point (Zetterlund et al., 2016) and a descriptive study (Schulte and Hallstedt, 2020) was performed at the company to investigate current risk management practices and preconditions, resulting in 10 hypotheses for sustainability integration. Building on these findings and the long-term relationship and trust between the company and the academic researchers, an action research study was initiated, Fig. 1. An academic researcher took the role of an outside agent, primarily facilitating the action and reflection within the company, while a risk management professional working at the company had the role of an inside agent, as such being able to provide primary and secondary access to information and other functions within the company (Coughlan and Coghlan, 2009).

3.1. Method and tool development

Action research is based on iterative cycles. The first two steps of the action research cycle presented by Coghlan and Brannick (2005), i.e. understanding of the context and purpose and diagnosing, were largely informed by previous studies at the company (Schulte and Hallstedt, 2020). At the center was the need to connect environmental and social sustainability aspects to economic implications for the business by applying a risk management perspective to make the driving forces for considering sustainability aspects in decision-making more tangible. However, existing risk management tools did not include a sustainability perspective. A specific case, which involved the design and manufacturing of a turbine component on the warm side of the engine, i.e. after combustion, was selected for the action research study. This product is currently made in a superalloy that contains critical elements from a sustainability perspective, such as cobalt. As it is made with subtractive manufacturing methods, the product has a high buy-to-fly ratio, meaning that only a small share of the raw material that is bought ends up in the final product, while a major share is becoming waste. Given high raw material costs and the company’s sustainability-related ambitions, a suggestion for an alternative concept was developed. It uses partly different materials and builds on the use of additive manufacturing (AM) with the potential to achieve a significantly lower buy-to-fly ratio. Fig. 3 provides a chronological overview of the study.

As indicated by Fig. 2, the research was highly collaborative and iterative to ensure both the academic researcher’s familiarity with the real-world context and practitioners’ sense of ownership of the research process and outcome. After the creation of a joint understanding of the situation, the academic researcher developed a first idea of a method for sustainability risk management. The term ‘method’ is here used to refer to “a specification of how a specified result is to be achieved”, e.g. what information that is used as input, what actions are to be performed, how, and in which sequence (Gericke et al., 2017). Drawing on the challenges and hypotheses described in the previous studies with Company A (Schulte and Hallstedt, 2020), requirements for the prescriptive support were developed, Table 1. While most of these requirements are mutually supportive, there are also trade-offs that had to be managed. For example, a balance had to be found between, on the one hand, including a full sustainability perspective, considering threats as well as opportunities, and considering a long-term perspective, and on the other hand, not requiring expert knowledge, simplicity, and applicability in early phases. Combining these requirements with strengths from existing approaches for sustainability risk management, described in Section 2.3, resulted in the development of the first prototype of the sustainability impact and effects analysis.

In parallel to the method development, a prototype of a tool was developed to facilitate the application of the method in practice. The term ‘tool’ is here used to refer to “an object, artefact, or software that is used to perform some action […]” (Gericke et al., 2017). The development and maturing of the method and tool took then place through iterations and tests with the company. Dependent on the stage of the study, weekly or bi-weekly meetings were held between the academic and the company researcher. Additional company employees from different functions were regularly included in the iterations to provide input or feedback. Once a functioning prototype existed, two workshops were run with a group of four company employees and two academic researchers, mostly focusing on the rationale of the method, the overall design of the tool prototype, and pointing out the direction for the next development steps. After further work and iterations in smaller groups, a second prototype version of the tool was finalized.

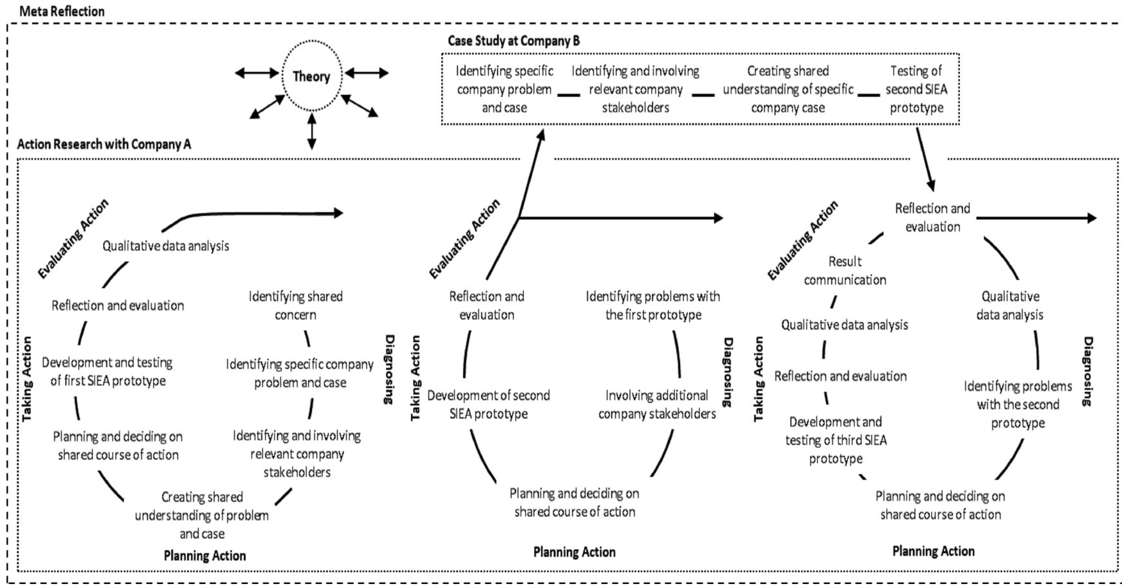

Fig. 2. The action research approach applied in this study.

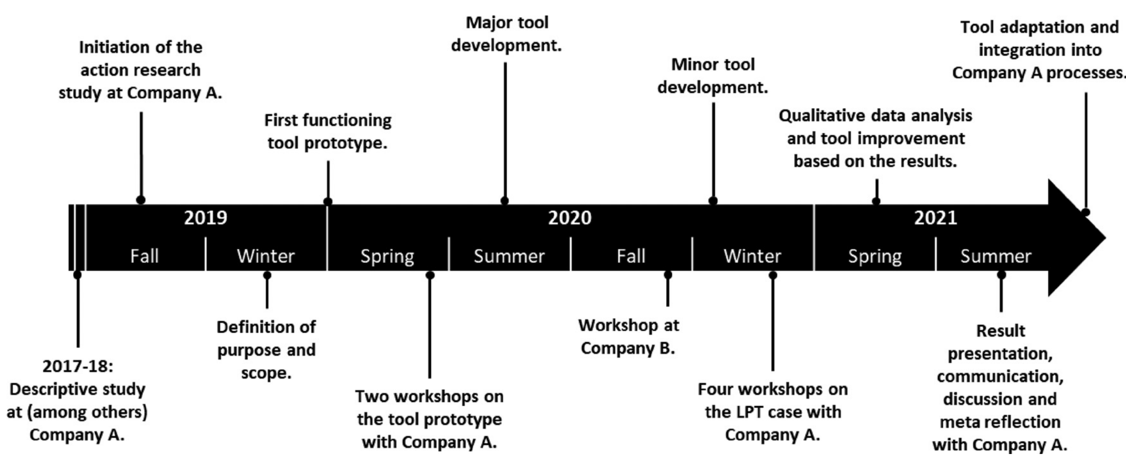

Fig. 3. Chronological overview of main events and milestones in the study.

Table 1
Requirements that were applied in SIEA development and how they were realized.

Requirement	SIEA Design
Include a holistic socio-ecological sustainability perspective and make sustainability risks tangible for product developers.	Based on basic principles for both social and ecological sustainability.
Build on the ISO31000 definition of risk and include not only threats, but also opportunities.	Both threats and opportunities are considered in all steps by looking into both positive and negative effects on stakeholder needs.
Establish the connection between a product's contribution or counteraction to strategic sustainable development of society and its potential implications for the company from a business perspective.	Sustainability impact of a product is linked to implications for the company from a business perspective by applying an instrumental stakeholder theory perspective.
Include a long-term time perspective.	A short-, mid-, and long-term time perspective are included in the sustainability risk analysis and evaluation.
Provide guidance for how to mitigate sustainability-related threats and exploit opportunities.	Includes a risk treatment section, where responses to the risks are listed.
Integrate a sustainability perspective into existing, mostly qualitative tools.	Builds on the widely used FMEA structure; quantitative data is not required.
Increase the awareness of the existence and importance of sustainability risks through rough but simple methods.	The level of detail and complexity is adjustable based on company needs and capabilities.
Do not require expert knowledge since sustainability risks are unfamiliar to many people in product development.	Guiding questions and a step-by-step approach support tool application. However, training or a facilitator is required.
Be applicable in the early phases of product development.	The tool does not require detailed or quantitative information that is unavailable in early phases.

Table 2
List of roles of company employees that participated in at least one workshop.

Company A	Company B
Project Lead	Global Environmental Manager and Sustainability Coordinator
Business Lead	Manager Product Development & Engineering
Supply Chain Lead	Global Product Manager
Design Lead	Technical Product Manager
Manufacturing Lead	Technical Product Engineer
Product Cost Manager	
Risk Management Methods Specialist	
R&T Cost and Sustainability Specialist	

3.2. Case study, testing, and evaluation

To get an early indication of the generalizability of SIEA, the second prototype version was tested with a medium-sized company in the industry construction, and vehicle and machinery equipment sector, located in Sweden (Company B). Together with company experts, a case for the testing of the tool was defined, which was about sustainability-related threats and opportunities with replacing brass, which contains lead, with a low-lead material in some of the company's sealing products. A workshop session was then conducted with five company experts and one academic researcher. A written document and a video recording explaining the purpose, company case, and the tool were provided to all participants prior to the workshop. At the workshop, the tool was tested, and feedback was gathered in a semi-structured way, see Appendix A.

Based on the experience gathered with Company B, refinements of the tool were made through further iterations with Company A. The latest version of the tool was then fully tested for the engine component case. Four workshop sessions were conducted with nine company employees and two academic researchers, see Table 2. The participants were selected based on (i) familiarity with the specific case; and (ii) function at the company, with the aim to create multifunctional groups where roles regarding product management, engineering, sustainability, and cost should be represented. Three of the sessions focused on applying the tool and one session was dedicated to gathering feedback. For both Company A and B, a questionnaire (Appendix B) was sent to all participants after the workshops to give an opportunity to provide additional and anonymous feedback on the tool's usefulness, usability, effect potential, and future development interests.

3.3. Data analysis

All formal workshop sessions, in total 12 h, were recorded (audio and video) and transcribed verbatim. The participants were informed and gave consent prior to starting the recording. Qualitative data analysis, using Atlas.ti software, was done based on transcriptions, notes from other formal and informal meetings, the outcomes of the workshops in the form of filled in SIEA sheets, and questionnaire results. The main steps of the analysis are as follows:

1. Immersion in the data by repeatedly reading all data to achieve a high level of familiarity and to get a sense of the whole before starting to break apart and analyze the data (Savin-Baden and Major, 2013).
2. A first round of coding was performed, in which the codes were identified inductively, i.e., directly from the data from the workshops, meetings, and questionnaire. In an open coding process, data was read multiple times and tentative labels were created, which, throughout the process, iteratively developed into refined codes. To allow for multiple ways of restructuring the data, dual coding was allowed.
3. Axial coding was performed to restructure the data by first taking it apart and then putting it back together based on connections between the codes (Corbin and Strauss, 2008). Thereby, a frame and set of themes emerged, which the codes and incidents could be related to.
4. Based on the restructured dataset, a second round of coding was conducted. This led to data being restructured again, making relationships between codes emerge, and results and meaning becoming denser.
5. Multiple of the 13 tactics presented by Miles et al. (2014) for generating meaning from the data were then applied, such as clustering, noting patterns, contrast and comparison, subsuming particulars into the general, and making conceptual coherence.
6. The data was synthesized into short and dense descriptions based on the following eight themes that emerged: context and mindset, level of decision-making, success factors, potential, strengths, challenges, changes, and future.
7. The results of the analysis were compiled and discussed with employees at Company A to validate the conclusions and to allow for meta-reflection on the action research study and identifying directions for future research.

4. Results and discussion

Besides raising awareness for sustainability risks, the purpose of the Sustainability Impact and Effects Analysis (SIEA) is to provide support both for concept selection and for identifying actions to improve a concept by mitigating sustainability-related threats and exploiting opportunities. The specific purpose must be defined and described by the user prior to the analysis, e.g. whether different solutions are compared to each other or an existing solution is analysed to identify and manage related sustainability risks. The SIEA method consists of four main steps, Fig. 4. The first step, sustainability assessment, corresponds to understanding the right part of Fig. 1, i.e., the product's sustainability performance and related impacts on the ability to create stakeholder value. The second and third steps correspond to the left part of Fig. 1 and are about identifying and assessing sustainability risks, which have their source in potential stakeholder responses in light of the sustainability challenge and company action. Finally, the fourth step is about identifying strategic company action as responses to the risks, which again corresponds to the right part of Fig. 1, starting a new loop.

Each step, alongside excerpts of how it was realized in the SIEA tool, is further explained in the following sub-sections. The full tool, including detailed instructions, templates, examples, and more is available as supplementary material.

Step 1: Sustainability Assessment

According to the definition by Schulte and Hallstedt, 2020, the sustainability risks that are connected to a product, process, or technology are dependent on its contribution or counteraction to society's transition towards a sustainable society. Therefore, a sustainability assessment is the first step of SIEA. In order to identify hot-spots from a full socio-ecological sustainability perspective for each life-cycle phase, basic principles for sustainability (Broman and Robèrt, 2017) can be used as a lens to scan the life-cycle (Ny et al., 2006). At Company A, guiding questions were developed based on the leading sustainability criteria identified by Hallstedt (2017). Even though the sustainability assessment can be done directly in the SIEA tool, it is also possible to use the results of other sustainability assessment tools as input. Fig. 5 presents an

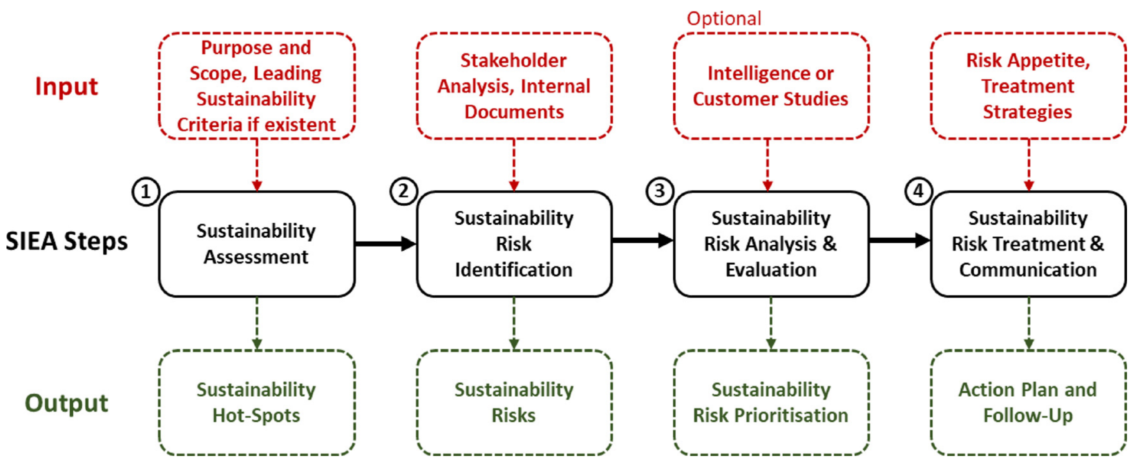

Fig. 4. The four steps of the SIEA method and related inputs and outputs.

1. Sustainability Assessment			
Life-cycle phase	**Sustainability Principle**	**Guiding questions based on Leading Sustainability Criteria**	**Sustainability Hot-Spot**
Raw material extraction	1	Does the product or technology contain or use critical materials?	Yes, the alloys contain cobalt.
	2	Are there emissions of persistent or bio-accumulating chemicals?	No hot-spot.
	3	Is there physical degradation of nature, e.g. through mining?	Yes, there is open pit mining.
	4	Is there risk for child labour and bad working conditions?	Yes, primarily in relation to cobalt.

Fig. 5. Excerpt of the sustainability assessment step with examples from Company A.

excerpt of the sustainability assessment step in the SIEA tool with an example from Company A. At Company B, examples of hot-spots include the much lower lead content of the new solution, but also potential problems when it comes to recycling of the new low-lead material.

Step 2: Sustainability Risk Identification

As described by Palousis et al. (2008), Hofmann et al. (2014), and Schulte and Hallstedt, 2020, the mechanism that connects sustainability impact with business risks is stakeholder action. Two points are worth emphasizing: firstly, both internal stakeholders, e.g. employees or owners, and external stakeholders, e.g. customers or suppliers, must be considered; and secondly, stakeholder action can pose a threat, but also an opportunity for the company. For example, a product with a high sustainability impact can entail threats in relation to legislators' action, while a product that contributes to sustainable development can come with opportunities if the customer experiences a higher value and willingness to buy. The risk identification step of SIEA focuses on establishing such connections between the sustainability hot-spots identified in step 1 and stakeholder value creation and action.

To facilitate the risk identification activity, seven sustainability risk categories, Table 3, were created based on the categories proposed by Palousis et al. (2008) and Schulte and Hallstedt (2017b). There is overlap between the categories, for example, reputational damage can also cause competitive risks. However, the purpose of the categories is to trigger the identification of risks, while it is less important exactly which category a risk is assigned to. Also, as the connections between stakeholder needs and sustainability hot-spots are many, it is important to focus on key stakeholders and important risks.

A stakeholder list, which exists in different forms at many large companies, can be used as input. For Companies A and B, workshops were done prior to the SIEA application where the company's stakeholders were identified based on the stakeholder definition by Freeman (1984). The stakeholders were then mapped in relation to the attributes power, legitimacy, and urgency to better understand stakeholder salience (Mitchell et al., 1997). Finally, key stakeholders' needs and expectations on the company were identified and listed. The SIEA tool includes an optional sheet to facilitate such a stakeholder mapping in case no similar input exists. Looking at the list of stakeholders and their needs, the SIEA user then has to identify who could affect or be affected by the sustainability hot-spots from step 1. Once this connection between sustainability hot-spots and stakeholders is established, the sustainability risks are formulated. The first SIEA prototype included multiple columns for this step to first connect the sustainability hot-spots to stakeholder value creation and then to assign a sustainability risk category and formulate the sustainability risks. When testing this design with practitioners, it was found that this division was not supportive for sustainability risk identification as it did not align well with the lines of thought of the practitioners, who found it difficult to write down their results in the different columns. Therefore, the design was changed to only have one column in which the sustainability risks are described, Fig. 6.

Examples of sustainability risks identified at Company A include: (i) the use of critical elements like cobalt in the alloys causes risks in relation to reputation if media finds poor working environment in mines, legislation if stricter regulation on conflict minerals in put in place, and supply chain as critical materials are susceptible to supply chain disruptions; (ii) developing capabilities for AM will over time enable the design of light-weight structures,

Table 3
Sustainability risk categories and examples to facilitate sustainability risk identification.

Sustainability Risk Category	Examples
Reputational risk	Brand damage, negative publicity due to e.g., poor working environment in the value chain, unethical behavior, bribery and corruption, environmental destruction
Regulatory risk	Legislative change, e.g., ban of a material or manufacturing process, carbon tax, producer responsibility
Litigation risk	The organization is found responsible for human health issues or environmental destruction, lawsuits, fines
Competitive risk	Failure to innovate and meet changing customer needs, falling behind competitors, losing market share
Strategic risk	Misalignment with company vision, strategy, or Code of Conduct, the organization takes a path that is a blind alley in the long-term
Supply chain risk	Dependence on critical materials (limited availability, conflict materials, high environmental or social impact)
Competence and productivity risk	Ability to attract and retain talented employees and collaboration partners, employee motivation, loyalty and productivity, efficiency of organizational processes and practices, competence, and capability development

2. Sustainability Risk Identification **Sustainability Risk Category and Stakeholder Value Connection:** Who could affect or be affected by this sustainability hot-spot and how?
Competence and productivity risk: high capabilities in AM can help attract talented employees. Regulatory and reputational risk: the use of virgin raw materials that contain cobalt comes with higher risk for stricter regulation and negative media attention.

Fig. 6. Excerpt of the sustainability risk identification step with examples from Company A.

which leads to reduced fuel-consumption and operating cost of the aircraft in the use phase. This is highly valued by the customer and therefore represents a competitive risk (in this case an opportunity) for the company. Workshop participants from Company B identified sustainability risks, such as the increased price for the low-lead product, which could negatively affect customer demand, and opportunities related to enhanced brand value and reputation and increased employee motivation and loyalty.

Step 3: Sustainability Risk Analysis and Evaluation

To be able to prioritize risk treatment and allocate resources, it is necessary to assess the identified risks in terms of their likelihood and consequences. As pointed out by Palousis et al. (2010), it is the social response that has to be assessed and Hofmann et al. (2014) provided more detail by explaining that it is about the likelihood of (i) the stakeholder noticing the sustainability issue; (ii) the stakeholder considering the issue as unacceptable (or desirable in the case of opportunities) and the company as responsible; and (iii) the stakeholder taking action. However, in practice, it was found challenging and not meaningful to try to assign distinct likelihoods for all three steps. For the sake of usability, SIEA only requires the assessment of a combined likelihood of a stakeholder noticing and acting upon a sustainability hot-spot. After that, it is assessed how severe the consequences of such action would be. Finally, a Risk Priority Number (RPN) is calculated by multiplying likelihood and severity, like in FMEA. Alongside the RPN, the SIEA user may indicate how easy it would be to mitigate the threat or exploit the opportunity, similar to the "improvement possibility" factor proposed by Lindahl (1999), see Fig. 7.

Since it is crucial for strategic sustainability risk management to include a long-term perspective, the SIEA user is asked to assess likelihoods and consequences for three time horizons. Which specific times that should be considered is dependent on the industry. The team at the aerospace company decided to consider a three- (short term), ten- (the UN SDGs end), and twenty-year (release of some solutions that are developed today) time horizon. Accordingly, three risk priority numbers are calculated: short-term (SRPN), mid-term (MRPN) and long-term (LRPN). By calculating the sum of these numbers, a total risk priority number (TRPN) can be obtained. It should be noted that the TRPN guides the user's attention towards the most important risks, independent of whether they are threats or opportunities. Different inputs can be used to facilitate the assessment, for example intelligence studies or studies on customer preferences.

3. Sustainability Risk Analysis and Evaluation (likelihood stakeholder notices and reacts & severity of that action)

Short-term Likelihood	Short-term Severity	Mid-term Likelihood	Mid-term Severity	Long-term Likelihood	Long-term Severity	RPN | Possibility to mitigate or exploit SRPN	MRPN	LRPN	TRPN
3	3	4	4	6	4	9	16	24	49

Fig. 7. Excerpt of the risk analysis and evaluation step with an example.

In the interactive work with Company A, it was found that this step of the process was particularly difficult, especially when it comes to putting numbers on the likelihood and severity of risks. For that reason, assessment scales, Table 4, were developed and two workshops fully dedicated to developing and testing the scales were conducted. Whether a 1–5 or 1–10 scale should be used was also discussed in depth. As both scales were found to have advantages and disadvantages, the newly developed assessment scales allow for both 1–5 or 1–10 to be used and it is recommended to use the same scale for this assessment as the company also uses for FMEA. The scales were developed to be applicable in most industries. Each company needs to make minor adjustments of the scales, e.g., in relation to specific percentages of number of years, since it will be different for different industries. The testing with Company B indicated that it is easy to adapt the scales to the specific company context. The adjustment only needs to be done once when the company adopts SIEA and not every time a team wants to apply the tool.

The assessments at Company A showed that high priority risks were related to, for example, (i) legislative change around critical virgin raw materials, especially in the long-term perspective; (ii) opportunities with developing capabilities and taking leadership in AM; and (iii) the initially higher weight of the new concept, due to changes in raw material. At Company B, opportunities in relation to legislation, reputation, and customer requirements that come with the lower lead content of the new solution were given high priority.

Step 4: Sustainability Risk Treatment and Communication

In the final step of SIEA, recommended actions are listed to treat the identified sustainability risks, Fig. 8. In general, traditional risk treatment options can be considered also for sustainability risks, i.e. transfer, mitigate, monitor, avoid, and accept for threats, and exploit, enhance, share, and accept for opportunities. However, a multitude of implicit and explicit mitigation strategies exists, such as preventive, reactive, responsive, adaptive, and resilience decision-making strategies (Hubbard, 2009). In addition, due to the deep uncertainty that characterises many sustainability risks, additional strategies should be considered, e.g. robust decision-making (Aven, 2013). Communication plays an important role in sustainability risk management, considering that the mechanisms by which they affect companies are based on stakeholder perception and action, as described by Hofmann et al. (2014). Hence, communication is a mediating factor that can affect likelihood and

Table 4
Excerpt of the scales that were developed to facilitate sustainability risk analysis and evaluation.

SIEA - Severity						
	Ranking			Reputational Risk	Regulatory Risk	Competitive Risk
OPPORTUNITIES	Game-Changing	5	10 9	The company is globally recognized as the world leader and first choice in its industry both amongst collaboration partners and customers. The brand creates a major value and is decisive for the customer selecting the company.	The company benefits strongly from being ahead of legislation, giving it a unique position on the market for a substantial amount of time.	The company makes a huge leap and becomes market leader, leaving competitors far behind for more than 2 years in a core business area. Customers consider the company's offerings to be most attractive and desirable and the first choice. There is a huge increase in customer demand for a very long time.
OPPORTUNITIES	Major	4	8 7	The brand is widely known and recognized for its good sustainability practices. The sustainability aspect is a major aspect considered by the customer and collaboration partners selecting the company.	The company has a major advantage by being well-positioned in the face of legislative change in relation to its competitors for a longer period of time.	The company gets a major lead and leaves competitors behind for 1-2 years is a core business area. There is a major increase in customer demand for a long time.
OPPORTUNITIES	Significant	3	6 5	The brand is clearly associated with good sustainability practices amongst many customers and collaboration partners. The sustainability association of the brand is considered by customers in their purchasing decisions.	The company has a significant advantage by being well-prepared in the face of legislative change in relation to its competitors for some time.	The company significantly increases its competitiveness in a business area of medium importance for up to a year. There is a significant increase in customer demand for some time.
	Minor	2	4 3	The brand receives a slight positive connotation amongst a limited group of collaboration partners and customers.	The company has a minor benefit from being slightly better positioned in the face of legislative change than its competitors for a short period of time.	The company slightly increases its competitiveness in a business are of minor importance for a few months. There is a minor increase in customer demand for a short period of time.
	Marginal	1	2 1	No or marginal discernible effect.	No or marginal discernible effect.	No or marginal discernible effect.
	Guidance			**Consider**: Scope: is the issue connected to the behavior of an individual or to company structure or culture? Public outrage: for example, high for issues like child labor, racism, discrimination, etc. and lower for e.g. quality problems, inefficiency, etc. Spread: Is the issue picked in a single local new paper article or in global media? Intention: was the issue an honest mistake or a conscious action?	**Consider:** Scope: Are core- or only minor operations affected? Cost: How costly will it be to reach compliance? Non-compliance: Is there a risk that the company will not be able to ensure compliance? Predictability: How predictable are the regulatory changes and how high is the company's capability to adapt in time? Competition: Are competitors relatively more or less affected by legislative change?	**Consider:** Scope: Are core- or minor business areas affected? Duration: For how long time will the company suffer from decreased competitiveness? How easy will it be to achieve competitiveness again? Extend: How far behind competitors will the company be? How much decrease in customer demand can be expected for the company's products?

(continued on next page)

Table 4 (*continued*)

	Ranking			Reputational Risk	Regulatory Risk	Competitive Risk
THREATS	Marginal	1	1, 2	No or marginal discernible effect.	No or marginal discernible effect.	No or marginal discernible effect.
THREATS	Minor	2	3, 4	One or few scattered reports. The issue is not picked up by general media and does not reach the general public or a significant share of the customer base. The issue is minor and public outrage in relation to the issue is low.	Regulation that will require some effort to reach compliance with or that will lead to minor effects on operations, cost, or competitiveness. No risk of non-compliance.	The company loses some competitiveness in a minor business area or market. However, the company will be able to easily regain competitiveness in a matter of a few months. Customer demand is slightly affected for a short period of time.
THREATS	Significant	3	5, 6	Some coverage in media or attention among parts of the customer base. The issue is serious, but forgivable. Company brand and reputation are significantly damaged for 1-5 years.	Regulation that affects core parts of the company in a significant way or that affects minor parts of the business in a major way. Reaching compliance requires significant changes or costs but can be achieved in time.	The company loses some competitiveness in a business area or market of medium importance. Some effort will be required, and it will take up to a year to regain competitiveness. There is a notable decrease in customer demand.
THREATS	Major	4	7, 8	Some coverage in general media and wide-spread attention among the customer base. The issue is in direct conflict with company values and is considered important by customers. Company brand and reputation are severely damaged for 5-10 years.	Regulation that requires major changes in core company operations with major effects on costs or competitiveness. Reaching compliance may take time.	The company falls behind its competitors in an important business area or market. It will be challenging and take 1-2 years to regain competitiveness. There is a major decrease in customer demand.
THREATS	Catastrophic	5	9, 10	Extensive media coverage, reaching millions of people in multiple countries. The issue is in direct conflict with company values and has a high societal interest. Company brand and reputation are destroyed for decades and could take the company out of business.	Regulation that is directly and long-lastingly affecting core company operations and where the company would have severe problems to comply or the cost to reach compliance would be extreme. Catastrophic effects on e.g. competitiveness that could take the company out of business.	The company falls far behind its competitors in its major business are and/or market. It will be very difficult and take more than 2 years to become competitive again. The majority of customer's prefers competitors' products and there is a huge drop in demand that could take the company out of business.
Examples	Based on Anderson (2005) and Willard (2012)			In the 1990s, media reporting about Nike's use of sweatshops to produce their sportswear made stock prices and revenues drop. Since then, Nike has undertaken significant efforts to manage this issue and improve working environment and disclose information about supply-chains. In the early 2000, Starbucks became a focus of a boycott by the Organic Consumers Association (OCA), because of its use of genetically modified ingredients and non-organic and non-fair trade ingredients. H&M got negative publicity when it was discovered that they burn tons of new clothes each year, because they exceed legal limits for chemicals or were damaged during transport. On the other end, companies like Patagonia, Unilever, 3M, IKEA, and The Body Shop have benefitted from building strong sustainability brands.	Ban of materials, substances, or manufacturing methods, e.g. lead, perfluorinated compounds (PFC), glyphosate, etc. Taxes on emissions or materials, e.g. carbon taxes. Extended producer responsibility. Increasing reporting requirements in relation to chemical use, product content, etc., e.g. REACH and RoHS. In 2003, Maine became the first US state to pass a law demanding specific reductions of greenhouse gas emissions across the economy. There have been several cases, e.g. in the automobile industry, of companies asking legislators to step up and to put tougher environmental and social regulation in place, because these companies were at the forefront and would have gained a competitive advantage.	Companies like 3M, IBM, and Electrolux, exploited sustainability related opportunities and anticipated market changes, resulting in substantial competitive advantage and financial gains. Toyota was able to significantly reduce its costs by decreasing the average energy consumption per vehicle produced by 17% between 2000 and 2004.

severity of opportunities or threats related to, for example, reputation or the ability to attract top talent.

Initially, this step was designed in a similar way to FMEA and the SIEA user was supposed to enter recommended and implemented actions, to assess the effects on likelihoods and severities, and then to calculate a new TRPN. However, in workshops at Company A, the importance of including an opportunity perspective more explicitly was highlighted and the step was re-designed. The user is still asked to enter recommended and implemented actions, but focus is then shifted towards explaining what opportunities these actions would present for the company. Thereby, the double nature of risks and the fact that threats can be turned into opportunities is emphasized.

The team at Company A identified treatment options such as (i) separating scrap metal at different parts of the product during production to avoid mixing different waste materials; (ii) creating a more holistic view of the implications of using AM in terms of total material and substance use; and (iii) ensuring continuous manage-

4. Sustainability Risk Treatment and Communication		
Recommended Actions	Related Opportunities	Implemented Actions
Investigate how cost would be affected by using recycled instead of virgin raw material. Adjust requirements based on the outcome of the investigation.	More resilient supply-chain. Enhanced reputation. Increased customer demand (in the long term)	Person X responsible for initiating an investigation.

Fig. 8. Excerpt of the sustainability risk treatment and communication step with an example from Company A.

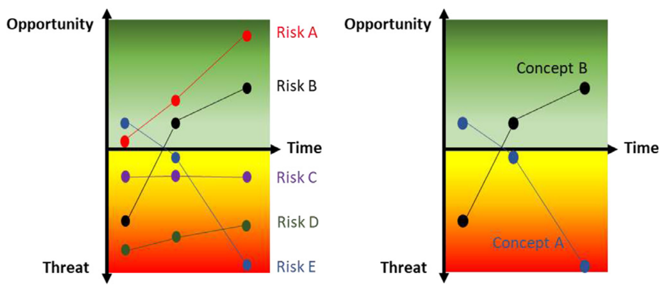

Fig. 9. Visualization of SIEA results for different risks of one solution (left side) and for different concepts or solutions within a company's portfolio (right side).

ment support and resource allocation to exploit competitive opportunities related to capabilities for AM. Company B decided among other things to further investigate the legislative implications of changing to the low-lead material.

To support decision-making and communication of results, multiple visualization options can be applied. The left part of Fig. 9 shows how the magnitude of risks connected to a solution can be plotted along a time axis, based on the risks RPNs. This provides an overview of the risks and how they are assessed to change over time. Such a figure can be created before and after risk treatment actions are taken, thereby also showing the intended effect of such actions at different time horizons. Another possibility is to use the results of multiple SIEA applications to compare different solutions (right part of Fig. 9). Thereby, the sustainability risks of different parts of the company portfolio can be assessed and visualized. This could provide support in balancing the portfolio and timing the introduction of new solutions, e.g. by having solutions that are profitable today but have high sustainability-related threats in the longer term, and solutions that may be unprofitable today, but that offer large sustainability-related opportunities in the future.

4.1. Evaluation

In addition to the feedback and the resulting changes of the tool described in the previous sections, SIEA was evaluated in relation to its usefulness, usability, and effect potential through the continuous interaction with Company A, as well as explicit feedback sessions and a questionnaire at Companies A and B. Based on the experience gathered with the companies and the identified success factors for the application of the SIEA tool, a checklist with 16 items was created to provide support for the SIEA user. The checklist is available in the full version of the SIEA tool in the supplementary material.

4.1.1. Challenges

Both companies highlighted the importance of carefully defining the purpose and scope before moving on with the analysis. SIEA was designed for two main application purposes: (i) to identify, assess and manage the sustainability risks with a specific product to improve it so it would avoid threats and exploit opportunities; and (ii) to compare different alternatives from a strategic sustainability risk perspective in order to make a selection. It is crucial to make the purpose clear for the whole team before moving on with the work. Companies A and B chose to focus on the new solution that they considered introducing. As noted by a practitioner at Company A, by asking "What would happen if we do not do this and are passive?" the risks with the new solution are still seen in the light of the existing solution. It is not only purpose and scope that the group needs to agree upon. It is also about how to apply the assessment scales, for example "*seemingly negative events that affect the whole industry can be an opportunity for us if we are affected less than our competitors*", and how to handle the three different time perspectives, for example in relation to what kind of assumptions that should or should not be made about the future. Reaching a shared understanding of these issues and to apply that consistently throughout the analysis was the largest challenge encountered by both companies. Such challenges in creating a shared understanding are common for risk management exercises in general and were not surprising, given that SIEA also includes new and unfamiliar concepts like sustainability and different time perspectives. On the other hand, the discussions that naturally evolved around these issues were appreciated, because they forced the teams to engage in a dialog around the product, its role at the company and how that would evolve over time, and how the future in the industry sector could look like. Another challenge was related to the diverse nature of sustainability risks, sometimes making it unclear for the participants how they should take some risks further and who should be responsible. For example, aspects in relation to the company's ability to attract talented employees are not usually considered or managed in development projects.

4.1.2. Success factors

Existing research has identified success factors both for risk management practices (Oehmen et al., 2014) and for the application and implementation of tools and methods for sustainable product design (Faludi et al., 2020; Peace et al., 2018). The success factors identified by the company SIEA teams are in line with these findings but provide more detailed insights. Besides creating consistency in the analysis, the practitioners identified the following success factors for making effective and efficient use of SIEA: (i) like with many other risk management or sustainable product development tools, SIEA must be applied by a "*multifunctional group of people with good knowledge about the external world and internal company processes*"; (ii) as sustainability risk management is new and unfamiliar to most people and there is some complexity in the SIEA tool, either an external facilitator is required or at least one person in the group should have gone through training in the tool; (iii) to achieve a real and long-lasting effect on decision-making, SIEA must be integrated into the existing work-flow and processes; (iv) writing down the thoughts behind the analysis in the tool, because it is in the underlying discussion that the main value is created; (v) keeping the purpose in mind to direct attention and allocate time on the most important things; and (vi) consciously and explicitly applying opportunity thinking, which is necessary to create the interest and commitment needed to trigger action.

The practitioners were specifically asked about the time intensity of the SIEA tool. Even though the application of the full tool at Company A required significant amounts of time, this was not considered as a significant drawback, which was also confirmed by the anonymous questionnaire responses. A practitioner at Company A said: "*Maybe after some training it takes a full day to go through the whole thing. But that is not so much since it is about strategic questions, and the strategy exists for a long time*". Also, once the analysis is done for a product or product family, a lot can be re-used and updated, which will make it go faster. With that said, it was also mentioned that the analysis does require stamina like other risk analyses.

Aspects of SIEA that were particularly appreciated by the company participants include: (i) the tool having a similar format as existing tools like FMEA and since it is Microsoft Excel™ based, it is easy to get started and navigate in the tool; (ii) it is straight forward with a logical flow between the steps, "*hands-on and close to reality*"; it brings multiple functions and disciplines to the table and forces them to take a holistic view on sustainability and risks, instead of focusing on a few technical aspects, and it provides a structure for how to do that in a group; (iii) it provides traceability for decision-making and "*a structured way to analyze something, which is good because there otherwise is a lot of believing and opinions about things*"; (iv) the risk categories, which were "*of tremendous help for getting into the right mindset*"; (v) the different time perspectives, which, although complicating the assessment, were new and "*very interesting and inspiring and fun to also think about what will happen in the very long term*"; and (vi) the quick, but structured way to identify hot-spots of sustainability impact across the whole life-cycle.

4.1.3. Future development

Wishes for future development expressed by the company participants can be summarized in three main points: firstly, to create a "*fast track*" that enables a quick scanning of the portfolio or a specific product. This is especially important if SIEA shall be used in concept selection because support tools must be quick at this point of the development process. Secondly, the practitioners asked for functionality to summarize the results, e.g. in a dashboard format, to make it easier to communicate the results of the analysis, both internally and externally. More advanced and automatized visualization were also mentioned in this context. Thirdly, and most importantly, the need for investigating how SIEA can be naturally integrated into existing decision-making processes was highlighted as key for taking the step from developing and testing the tool as part of a research study to implementation and long-term use without the involvement of an academic researcher.

4.2. Meta reflection on the research process

In addition to interactively developing and testing SIEA, the researchers and practitioners reflected on the action research study as a whole. As regards to the process, the collaborative spirit between academic researchers and company practitioners was of key importance. Both because it provided rich insights on the many facets of real-world decision-making contexts, which are necessary to achieve quality in applied research, and because it contributes to creating the sense of ownership, commitment, and capabilities that are necessary to accomplish tool implementation in a value-adding way in the company. The practitioners were genuinely curious and motivated to take part in the work, which may partly be due to company culture and the fact that the work was based on a real need. As a result, all participants were active at meetings and workshops and spoke openly about their thoughts, about what they had knowledge about, but also what they lacked knowledge about, or what they did not understand. The foundation for this collaborative spirit was mutual trust, respect, and clear expectations, which were gradually built in the long history of joint research between the company and the academic research group.

In the beginning of the research study, the initial thought was that SIEA primarily should be used in concept selection. Over time, an understanding crystalized that it also could be applied on a higher level of decision-making, because it involves many strategic questions, and several practitioners expressed that it should be tested in portfolio planning. At this point, the room for making changes is larger and the results of the analysis could then be used in the development of requirements for product- or technology projects, which play a key role for integrating a sustainability perspective in product development (Watz and Hallstedt, 2020).

In the step of developing a tool based on the SIEA method presented in Fig. 4, it could be observed that some steps of the tool were designed based on the theoretical understanding of the method, while the practitioners unconsciously applied the steps in a more intuitive way. This was particularly apparent in the risk identification step: it was designed to capture the instrumental stakeholder perspective that is central to the concept of sustainability risks. However, the practitioners did not consciously look at the sustainability hot-spots in relation to their stakeholders' needs. Instead of looking at their stakeholder map, they were able to identify risks directly by looking at the sustainability hot-spots identified in step 1 and the sustainability risk categories (Table 3). This point may deserve further attention and emphasizes the need to develop the tool in a way that is methodologically sound while being practically applicable, leveraging on practitioners' competence and intuition.

Looking at the potential of SIEA to provide decision-support and to facilitate change towards sustainable product development, participants expressed that it "*increase[s] awareness for sustainability risks*" and "*opens up new views and perspectives when working and discussing in the group, which is a big step*". This learning in a group, which was facilitated by the tool was considered as a main benefit in itself. SIEA was also found to be a good way to "*get these sometimes intangible issues black on white, which makes it easier to motivate a decision*". Also, the team "*actually discovered new issues that we did not think about before*". A further indication of the value of SIEA is the fact that there is ongoing work at Company A both to ensure that the identified risk responses are implemented and to further adapt SIEA to the company's specific needs, and to integrate it into existing decision-making processes.

5. Conclusions

By building on existing theory and findings from the area of sustainability risk management and action research with a product development and manufacturing company, this study presented the Sustainability Impact and Effects Analysis (SIEA). Its primary contribution to research is that the method shows how concepts from strategic sustainability thinking and a life-cycle perspective on the one hand, and instrumental stakeholder theory and the risk management process on the other hand, can be combined. Thereby, it fills an important gap related to how a solution's contribution or counteraction to strategic sustainable development can be connected to direct implications for the company's business and competitiveness, both in terms of opportunities and threats. Exploring this connection is necessary to understand the driving forces and highlight the motivation for considering sustainability aspects in decision-making. It can also help to find the smart zone in relation to sustainability in product development, i.e. the balance between being too passive, facing threats related to reputational damage, legislative change, inability to attract top talent, etc., and too proactive, facing threats related to increasing product cost, immature supply chains and markets, etc. (Robèrt and Broman, 2017; Villamil et al., 2021). While the importance of applying a strategic perspective in sustainable product development has been stressed in previous literature, the time dimension of sustainability, which is a prerequisite for strategic thinking, is often overlooked when integrating sustainability in industry decision-making (Faludi et al., 2020; Pigosso et al., 2015; Hallstedt et al., 2013). This study highlights both the importance as well as the difficulties of including a long-term strategic perspective in decision-support tools for sustainable product development.

This study's main contribution to practice is the development of the SIEA tool, which based on the structure of FMEA supports the systematic identification and analysis as well as strategic management of sustainability risks in early phases of the product innovation process. From a managerial perspective, the implications of these findings are (i) a risk perspective can support understanding and managing the dynamic interplay between sustainability aspects and economic implications, considering different time horizons; (ii) in contrast to Palousis et al. (2008, 2010), sustainability risks can be diverse and are not only related to direct costs; (iii) a long-term strategic perspective is essential for successfully foreseeing and responding to sustainability risks; (iv) while existing risk management practices primarily focus on threats, the opportunities that society's transition towards sustainability entails are at least as important to manage as the threats.

A case study with a company in another industry sector indicated that SIEA is applicable and adaptable in other contexts. However, given the limited number of cases, further research is needed to gain more insights about the generalizability of the findings, for example in relation to company size, companies that work with consumer products or services, or companies in other geographical locations. Other future research directions include (i) testing SIEA on different levels of decision-making, exploring if it is applicable and how it can be adapted to be used in strategic planning, portfolio management and for the development or weighting of requirements for development projects; (ii) combining SIEA with methods for quantitative risk modeling or scenario exploration; (iii) continuing the work with Company A to study how methods and tools can be adapted and integrated in existing company processes to achieve implementation beyond specific research studies; and (iv) further validating the impact of SIEA on decision-making. Thereby, a risk management perspective can be utilized to support product development companies in contributing to strategic sustainable development of society in a way that strengthens the own organization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The funding sources were not involved in the study design; in the collection, analysis and interpretation of data; in the writing of the report; and in the decision to submit the article for publication.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spc.2022.01.004.

Appendix A. Questions used in the semi-structured feedback sessions

1. First thoughts: What parts or aspects of the tool did you like?
2. First thoughts: What do you think are the main challenges and drawbacks with the tool and/or for its implementation?
3. To what degree do you think the tool could increase the awareness of sustainability risks?
4. In what contexts do you think it could be useful?
5. Did you discover anything new or surprising?
6. In what way do you think the tool could be useful for portfolio evaluation (or other things)?
7. In what way would you like to see this tool developed?
8. What is your feedback specifically on...
   a. ...the risk categories? How can they help in understanding and identifying risks?
   b. ...the 1–10 scales with 5 levels that are described?
   c. ...the division into threats and opportunities?
   d. ...the descriptions of the severity levels for the different categories?
   e. ...the guidance?
   f. ...the helpfulness of examples?
9. What are your thoughts in relation to next steps...
   a. Do you find the subject matter relevant?
   b. Would it be interesting to further develop a method for sustainability risk management?
   c. What are your needs in relation to this?

Appendix B. Questionnaire questions

1. Which company are you working for?
2. Usefulness: To what degree can the tool support you to...
   a. ... increase awareness and provide a base for discussion around sustainability risks and why they are important?
   b. ... clarify the WHY for sustainability from a business perspective by linking sustainability impact to threats and opportunities for the business?
   c. ... identify, assess, and treat sustainability risks in a systematic way?
3. Usefulness: How VALUABLE did you find the following parts of the tool?
   a. Sustainability assessment to identify sustainability hot-spots in the life-cycle?
   b. Risk identification and connecting to stakeholders?
   c. Risk analysis and evaluation considering multiple time perspectives?
   d. Risk treatment and communication?
4. Usefulness: How DIFFICULT did you find the following steps of the tool?
   a. Sustainability assessment to identify sustainability hot-spots in the life-cycle?
   b. Risk identification and connecting to stakeholders?
   c. Risk analysis and evaluation considering multiple time perspectives?
   d. Risk treatment and communication?
5. Is there anything else you would like to comment on regarding the tool's USEFULNESS? (optional)
6. Usability: To what degree do you agree with the following statements?
   a. The excel tool had a clear structure and was easy to follow.
   b. The work-flow was intuitive and easy to understand.
   c. The risk categories (e.g. reputational, legislative, competitive, supply-chain, etc.) were helpful for risk identification.
   d. The tables explaining the scales for severity and likelihood were helpful for risk analysis and evaluation.
7. Usability: What do you consider as main challenges and drawbacks with the tool?
   a. Too time instensive.
   b. Too complicated.
   c. Requires too much up-start and training.
   d. Must be done in a group.
8. Is there anything else you would like to comment on regarding the tools USABILITY? (optional)
9. Effect potential: If further developed and implemented, to what degree could the SIEA tool affect...
   a. Including sustainability aspects more naturally alongside other factors in decision-making.

   b. Increased awareness about the potential consequences (positive and negative) of decisions.
   c. Improved decision-making that contributes to the company's success and competitiveness in the short- and long term.
   d. Balancing sustainability initiatives: neither being too slow and passive nor too fast and proactive in relation to sustainability.
10. Is there anything else you would like to comment on regarding the tools EFFECT POTENTIAL? (optional)
11. Next steps: To what degree to you think the following aspects would be interesting to further develop?
   a. A shorter, easier version that could be used for screening in concept selection.
   b. Visualization of results.
   c. Integration of this tool with existing tools/processes at the company.
   d. Refinement of the tool to increase usability, e.g. more user-friendly interface, instructions, examples, etc.
12. Is there anything else you would like to add? (optional).

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