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REVIEW

Conceptualizing product sustainability performance: a systematic literature review and proposed definition

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Abstract
Assessing product sustainability performance is essential for supporting sustainable product development since it enables comparison and progress monitoring and informs decision-making. However, approaches for integrating sustainability considerations into product development are not merely technical choices; they reflect underlying assumptions about how sustainability performance is conceptualized and interpreted, which has significant implications for what the goal of sustainable product development is considered to be. Based on a systematic literature review, complemented by exploratory interviews with practitioners, this study examined how product sustainability performance is conceptualized in relation to what is assessed (scope), at what level impacts are considered (scale of impact), and in relation to what results are interpreted (point of reference). Three conceptualizations emerged from the clustering of the findings, showing different combinations of the spectrum of scope, scale of impact and point of reference. In addition, it was found that the choice of performance lens, i.e., efficiency or effectiveness, can be linked to the adopted point of reference. Both lenses are necessary in the product development process, and the paper therefore proposes a definition of product sustainability performance that combines both. The discussion presents theoretical implications of the proposed definition to the product development process. The paper concludes that advancing sustainable product development may depend less on creating new assessment tools and more on strategically applying existing ones within a shared conceptual understanding of product sustainability performance.

Keywords Sustainable product development · Sustainability assessment · Ecodesign · Effectiveness · Systems innovation · Sustainable design

1 Introduction

Product development and manufacturing companies play an essential role in supporting society's transition towards sustainability (Bengtsson et al., 2018; Ceschin & Gaziulusoy, 2016), since this is where "the new elements of the new socio-technical systems and cultural meanings associated with these will be ideated and realized through design and innovation efforts" (Gaziulusoy & Brezet, 2015). However, sustainability is a systems property that emerges from the interactions between products and the larger socio-technical systems they operate within. Therefore, products cannot be sustainable or unsustainable in isolation; instead, they either contribute to or counteract the broader systems' movement towards sustainability (Boks & McAloone, 2009; Ceschin & Gaziulusoy, 2016).

This movement of the systems towards sustainability is characterized by uncertainty and entails a plethora of business risks and opportunities to product development and manufacturing companies, such as reputational issues, legislative change, and shifting customer preferences and stakeholder expectations (Gomez-Valencia et al., 2021). The challenge is to find the optimal pace for sustainability ambitions that is neither too passive (with risks related to reputational damage, liability claims, etc.) nor too proactive (with risks related to immature supply chains, insufficient return on investment, etc.) (Schulte & Knuts, 2022; Villamil et al., 2022). This presupposes company practices for sustainable product development (SPD), which means that "a strategic

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sustainability perspective is integrated and implemented into the early phases of the product innovation process, including life-cycle thinking" (Hallstedt & Isaksson, 2017). The *early phases*, such as idea generation, conceptual design, and requirement definition, are critical because they offer freedom to explore alternatives, and the decisions made during these phases are critical in determining the product's sustainability impacts throughout its life-cycle (Albers et al., 2019; McAloone & Tan, 2005). A *strategic sustainability perspective* is necessary for enabling backcasting, i.e. planning and prioritizing product development pathways based on a long-term vision of sustainability rather than extrapolating from current conditions with the risk of developing solutions that are not scalable towards full sustainability (Kishita et al., 2024; Vergragt & Quist, 2011).

Company capabilities to evaluate and assess product concepts' contribution towards sustainability objectives play a key role in this context to support and guide prioritization in e.g. portfolio management, product planning and requirements management (Kravchenko et al., 2019; Parolin et al., 2024; Villamil et al., 2023). Also, conducting assessments is fundamental to be able to communicate the value of a new or improved product for internal and external stakeholders. Sustainability assessments thus are the backbone of comparison, selection, decision-making and monitoring of progress (Kalish et al., 2018; López-Mesa & Bylund, 2011; Mallalieu et al., 2024).

However, assessing product sustainability is a complex and challenging task. Beyond operational challenges, e.g. data availability and management, limited sustainability expertise, uncertainty and the need for collaboration across departments and stakeholders (Schöggl et al., 2024; Vilochani et al., 2025), there is also a fundamental challenge in determining what exactly constitutes product sustainability performance—which is essential to guide the selection of assessment methods, criteria and indicators (Gaziulusoy, 2015; Sala et al., 2015). This selection is not merely a technical choice with technical implications, as each assessment approach is grounded in underlying conceptualizations of what constitutes a product's sustainability performance, carrying assumptions about what sustainability means and what role products should play in the transition towards a sustainable future (Sala et al., 2015). Although there are numerous approaches to assess sustainability on the product-level (Issa et al., 2015), such as life-cycle assessment (LCA), Ecodesign guidelines, Circular Economy (CE) methods and tools and Product Environmental Footprint (PEF), there is a lack of agreed definitions of what constitutes product sustainability performance within the field of SPD (Lövdahl et al., 2024). Without a clear understanding of what product sustainability performance is, and how it needs to be assessed, practice becomes fragmented (Faludi et al., 2020; Nappi et al., 2024), hindering the potential to contribute to the transition towards sustainability (Gaziulusoy, 2015; Kravchenko et al., 2019; Sala et al., 2015).

The aim of this paper is twofold. First, it is to map and systematize how product sustainability performance is conceptualized in existing approaches for integrating sustainability considerations in product development. Second, by analyzing these conceptualizations' characteristics and implications to support sustainable product development and the broader transition towards sustainability, this paper also aims to propose a new definition for product sustainability performance. The main research question is:

> How can product sustainability performance be conceptualized and defined, and what are the theoretical implications in the product development process?

By addressing this question, this paper makes three main contributions: (i) it provides a structured synthesis of how current product development and sustainability assessment approaches conceptualize product sustainability performance; (ii) based on the findings, it proposes a definition of product sustainability performance; and (iii) it discusses theoretical implications of the proposed definition for the product development process and outlines directions for future research.

2 Background and conceptual framework

2.1 Product sustainability assessment and the concept of performance

In SPD, assessing product sustainability performance is essential to support strategic decision-making regarding design alternatives, since it enables comparison, selection and monitoring of progress towards sustainability vision and goals (Kalish et al., 2018; López-Mesa & Bylund, 2011; Mallalieu et al., 2024). In practice, decision-making in the early stages of product development typically progresses through two distinct yet interconnected domains. It begins in the problem domain, where requirements are defined based on stakeholder needs and contextual analysis. These requirements articulate what the product must achieve. The process then moves into the solution domain, where the initial needs-based requirements are translated into more concrete and technical specifications, such as functionality, durability, lifetime, and ease of use, that describe how the product should be designed to fulfill the needs identified in the problem domain. Finally, the product development process moves to the design requirements, characterized by detailed technical aspects of the design solution (Watz & Hallstedt, 2018). As decision-making evolves across these domains, the nature of what needs to be assessed also shifts from broader strategic and needs-based considerations toward increasingly technical and detailed ones (Duffy & O'Donnell, 1998; Johnsson et al., 2008).

The conceptualization of product sustainability performance informs how requirements are defined by clarifying what *sustainability performance* entails. However, requirements are also shaped by additional factors, such as corporate strategic goals and regulatory scenarios, which together determine how sustainability considerations are translated into concrete product requirements (Gaziulusoy, 2015; Petersen, 2021). Nevertheless, as highlighted by Lövdahl et al. (2024), product sustainability performance is often used without a clear conceptual foundation, creating ambiguity about what is being assessed and in relation to what objective and from which perspective. Therefore, there is a need to clarify what sustainability encompasses, what the objectives are, and how performance should be assessed in relation to them.

The concept of performance itself can be interpreted as an action (the process to achieve a particular result), as an outcome (what the action achieves), and ultimately as success (the degree to which outcomes meet stated goals) (Pintea & Achim, 2010). Performance assessment implies comparison in relation to a point of reference and is of essential value to inform strategic decision-making and to support coherence between goals and actions (Duffy & O'Donnell, 1998; Neely et al., 1995).

There are two main elements within performance: efficiency and effectiveness. Efficiency is related to the relationship between inputs and outputs, i.e. how well resources are transformed into results. In product development, it can, for example, be related to the process and the resources used to manufacture a product, often being described in terms of time, man hours, materials, etc. Effectiveness refers to the result of the process in relation to the planned outcome, i.e. how well the final result fulfills the intended purpose (Duffy & O'Donnell, 1998; Pintea & Achim, 2010). In that sense, effectiveness should be assessed according to a specific context, meaning that it can change according to the company's and/or project's objectives. In product development, effectiveness can be related to how well the final product characteristics fulfill the requirements and customer needs (Duffy & O'Donnell, 1998). Effectiveness is inherently difficult to operationalize; while efficiency can be expressed through measurable ratios of inputs and outputs, assessing effectiveness requires that goals be explicitly stated and that outputs be evaluated against them (Duffy & O'Donnell, 1998). This challenge intensifies when sustainability is integrated into performance assessment, as it introduces additional system levels with complex interactions. While efficiency and effectiveness can coexist, an action or a result may also be efficient without being effective or vice-versa. Both lenses are needed in performance assessment as an imbalance between them can lead to resource misuse or strategic misalignment (Neely et al., 1995).

2.2 Conceptual framework

To uncover how existing assessment approaches define sustainability and assess product performance in relation to it, three elements have been pointed out as essential in the literature: what is being assessed (*scope*), at what level (*scale of impact*) and in relation to what (*point of reference*). These three aspects, summarized in Table 1, represent distinct and complementary elements that are necessary for conceptualizing product sustainability performance. Since sustainability operates as a systems property and product development has a role in supporting strategic transitions in socio-technical systems, assessments must be capable of addressing multiple interconnected dimensions of sustainability (*scope*), of capturing system-level impacts rather than remaining confined to product-level boundaries (*scale of impact*), and of evaluating performance against defined sustainability goals rather than merely relative to alternatives (*point of reference*). While these three aspects do not cover all possible aspects related to product sustainability performance assessment—such as implementations or potential to drive innovation—they provide the conceptual foundation necessary to understand how an assessment approach constructs its understanding of product sustainability performance and positions products within the broader sustainability transition.

Scope refers to the range of sustainability dimensions that are included in an assessment. As sustainability is multidimensional and spans ecological, social, and economic considerations, the scope establishes what dimensions are considered (Broman & Robèrt, 2017; Sala et al., 2015; Vermeulen, 2018). In this paper, scope is categorized into narrow and wide, based on whether only one sustainability dimension, e.g. environmental impacts, or multiple interconnected dimensions, e.g. social and environmental impacts, are considered (Gaziulusoy, 2015; Sala et al., 2015).

Given that sustainability is a systems property (Broman & Robèrt, 2017; Gaziulusoy & Brezet, 2015), it is relevant to consider the *scale of impact* adopted in sustainability assessments. Scale of impact refers to the level at which sustainability impacts are included and assessed. In this paper, scale of impact is categorized into insular and systemic. An insular scale of impact treats sustainability impacts as limited to the immediate product system, without considering interactions with the larger social or ecological systems (Gaziulusoy, 2015; Sala et al., 2015; Zimek & Baumgartner, 2024). A systemic scale of impact expands the assessment to consider how products interact with and impact the larger systems' dynamics and boundaries (Gaziulusoy, 2015; Sala et al., 2015; Zimek & Baumgartner, 2024). Hence, a systemic

Table 1 Conceptual framework aspects and spectrum (based on Gaziulusoy, 2015; Gebler et al., 2022; Sala et al., 2015)

Scope		Scale of impact		Point of reference	
Narrow	Wide	Insular	Systemic	Relative	Absolute
Focus on one dimension of sustainability	Integration of multiple dimensions of sustainability	Impact is evaluated in the immediate product system	Impact is evaluated with consideration of the larger system in which the product is embedded	Impact is evaluated in relation to a baseline or benchmark	Impact is evaluated in relation to defined boundaries

scale considers how changes at the micro level (e.g. product design) can affect larger systemic transformations (Gaziulusoy, 2015; Hauschild et al., 2020).

Finally, sustainability assessments require a *point of reference*, representing a basis for interpreting results (Nappi et al., 2024; Sala et al., 2015). In this paper, point of reference is categorized into relative and absolute. With a relative point of reference, performance is evaluated against other alternatives, benchmarks, or previous results (Bjørn & Hauschild, 2013; Gebler et al., 2022). The result is interpreted as better or worse than the chosen point of reference. An absolute point of reference supports the evaluation of performance against defined boundaries, usually based on boundary conditions necessary to maintain system functioning and integrity (Bjørn & Hauschild, 2013; Broman & Robèrt, 2017; Gebler et al., 2022). Absolute boundaries enable the identification if the result is good enough in relation to the overall goal, providing information to strategic and long-term thinking (Bjørn & Hauschild, 2013; Broman & Robèrt, 2017).

Together, these elements enable a systematic examination of the assumptions shaping how assessments conceptualize product sustainability performance. This integrated perspective supports the identification of patterns across approaches and analyzing how these assumptions influence the perceived role of products in the sustainability transition and how they are assessed.

3 Methods

A systematic literature review based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) framework (Page et al., 2021), shown in Fig. 1, was conducted with the aim to explore conceptualizations of product sustainability performance proposed by different approaches to support sustainable product development. The review was complemented with exploratory interviews with experts in industry to gain insights into practitioners' perspectives on product sustainability performance and to contrast literature findings with existing practices.

3.1 Search strategy

The search was conducted in Scopus and Web of Science databases. Considering that the research question focused on the conceptualization of product sustainability performance and its implications for SPD, the review focused on three main areas: sustainability, product development, and performance. Related terms and concepts were identified for each area both deductively and inductively through an iterative process of testing search strings, evaluating the comprehensiveness and precision of search results, and further

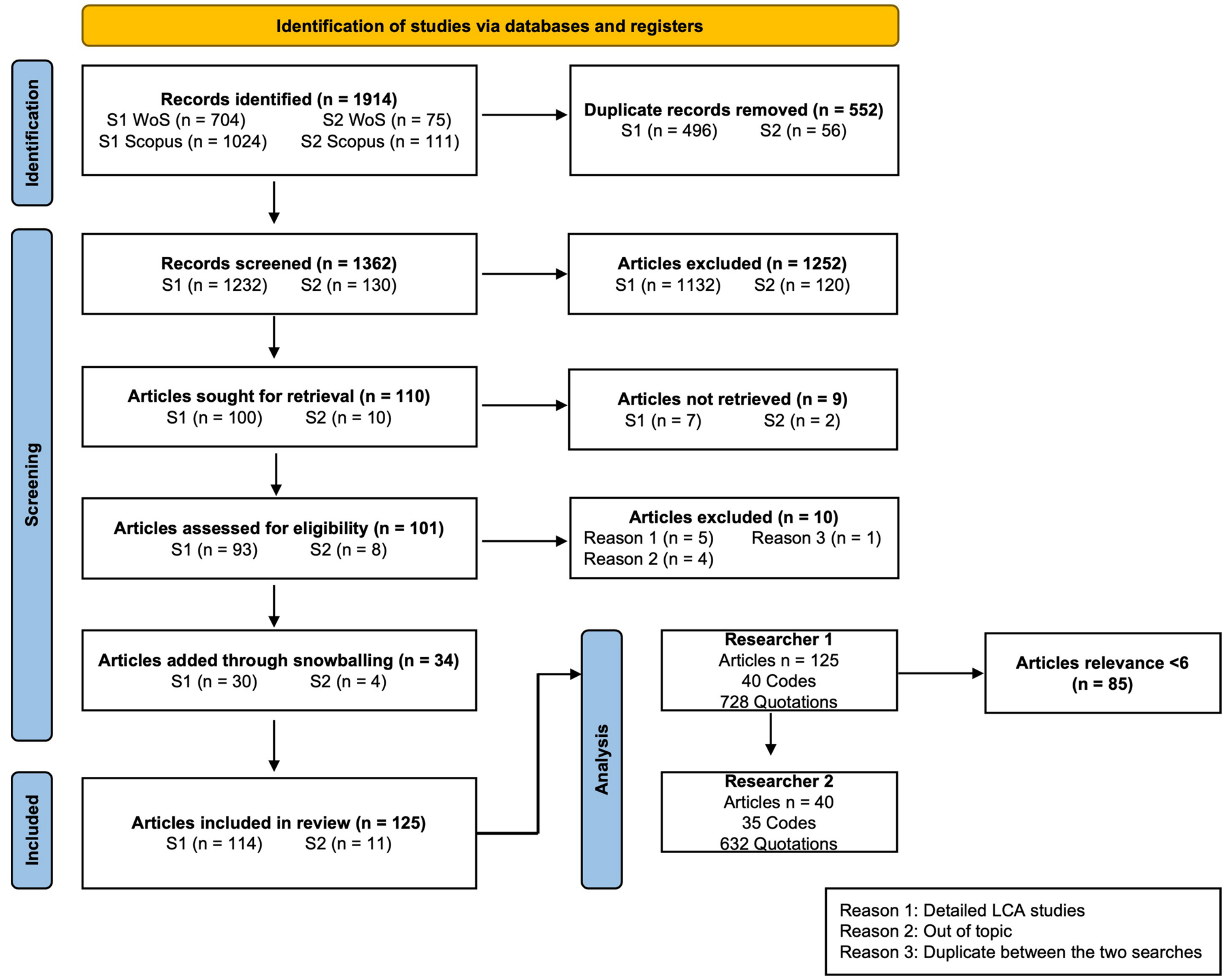

Fig. 1 Flow diagram of the literature review based on PRISMA 2020 (Page et al., 2021)

refinement. Economic terms were omitted to avoid retrieving results addressing performance purely from a financial perspective, and systems design terms were excluded to maintain focus on product-level performance. The search was restricted to the title field to delimit the corpus to studies in which sustainability performance in a product context is a central and explicit focus rather than a peripheral theme. Truncation was applied selectively to terms where variation in word endings was anticipated and where its omission would risk excluding relevant results. The following search string (S1) was used:

TI = ((sustainab OR environment* OR ESG OR ecolog* OR social) AND ((product OR service OR concept OR initiative*) AND (develop* OR innovat* OR design* OR screening)) AND (perform* OR footprint* OR handprint* OR indicator* OR impact OR assess*)).*

An initial analysis of the search results revealed that the majority of papers are not explicit as to how they define product sustainability performance or impact. For that reason, a second search (S2) was conducted to focus on reviews of approaches for including sustainability aspects in product development. Review papers that synthesize multiple approaches tend to have a higher level of abstraction and were therefore considered more likely to reveal underlying conceptualizations that were not articulated in the result of S1. S2 was:

TI = (Review AND ("sustainable design" OR "sustainable innovation" OR "sustainable product development" OR "design for sustainability" OR "DfS" OR "eco-design" OR "eco design" OR "green design" OR "design for environment" OR "design for the environment" OR "DfE" OR "design for social sustainability")).

3.2 Screening

A stepwise screening process was applied (Karlsson, 2010), first on the title-and-abstract level, then followed by a full-text assessment of all potentially relevant articles. Both stages applied the inclusion and exclusion criteria shown in Table 2.

After the screening, 110 articles were sought for retrieval of which 9 could not be retrieved. Then, articles were assessed for eligibility, 10 articles were excluded and a set of 91 remained. These articles were reviewed in full by Researcher 1 (R1) and documented and categorized in an Excel spreadsheet, including key attributes and short summaries of each paper. Due to the breadth of research in sustainable product development and adjacent fields, as well as the multitude of terms and concepts that are used, backward snowballing (Wohlin, 2014) was used to identify additional articles that were not captured by the initial search strings. Both researchers independently identified references cited in support of key arguments that appeared potentially relevant to the research question. These references were screened against the same inclusion and exclusion criteria applied to the original search results. This process added 34 articles, resulting in a final set of 125 articles, as shown in Supplementary Information SI1.

3.3 Data analysis

Qualitative content analysis aided by Atlas.ti software was applied using a combination of deductive and inductive coding (Mayring, 2000). Deductive codes were derived from the research question and established concepts related to the product development process (e.g. different development stages). Inductive codes supported the identification of emerging patterns as of the difference of assessments' goals and scope, connections to different dimensions of sustainability and other business aspects. As inductive codes started to increase the level of detail in the analysis, deductive and inductive codes were clustered in code groups that represent a higher level of abstraction of the main themes.

Alongside the coding, R1 assessed the relevance of each article in relation to the research question on a 1–10 scale. All articles with a rated relevance > 5 (n = 40) were then also reviewed by Researcher 2 (R2), using the same deductive codes but independently creating inductive codes. This approach was used to reduce researcher bias and allow for a more nuanced analysis, while maintaining efficiency by making R2 focus on the most relevant subset of articles. Each researcher coded independently and started to analyze the findings using software-aided data restructuring and following a three-step iterative coding process (Corbin & Strauss, 2008): (1) open coding—reading data repeatedly and assigning it to codes; (2) axial coding—making connections between the codes and placing them into categories; (3) selective coding—identifying core themes and relating other codes to them. Multiple strategies, such as theme generation, and constant comparison were applied to generate meaning and identify clusters from the data (Miles et al., 2014). When conflicting evidence was identified, it was flagged by each researcher. These instances were then discussed in research team meetings and were considered in the final analysis where they were used to capture nuances or different perspectives represented in the literature. The emerging themes were constantly discussed by the researchers to reach greater depth. Finally, the identified themes were assessed in light of the conceptual framework to support the clustering of the assessment approaches and the abstraction of the conceptualizations of product sustainability performance.

3.4 Exploratory interviews

In parallel to the literature review, six exploratory interviews were conducted at three product development and manufacturing companies in Sweden, shown in Table 3. The main goal of the interviews was to capture practitioners' understanding of product sustainability performance and their current practices. Specifically, the interviews aimed to explore

Table 2 Inclusion and exclusion criteria used for the screening of search results

Criterion	Inclusion	Exclusion
Publication type	Peer-reviewed journal article or conference paper	Not peer-reviewed
Language	Published in English	Non-English language
Topical relevance	Focus on sustainability integration in product development, product-related sustainability assessment, or conceptual discussions relevant to product sustainability performance	Empirical focus limited exclusively to LCA case studies without broader implications for conceptualizing product sustainability performance
Conceptual contribution	Contains either an explicit discussion of sustainability performance at the product level or an implicit conceptualization that could be interpreted through analysis	Peripheral relevance where sustainability or products are mentioned without addressing their relationship in a way relevant to the research question

Table 3 Overview of the companies and interview participants

Companies	Interviewees
A: Manufacturer of jet engine components, ca. 2000 employees, Sweden	P1: Sustainability specialist, 17 years of experience P2: Sustainability engineer, 5 years of experience
B: Manufacturer of compaction machines, ca. 300 employees, Sweden	P3: Division and Sustainability manager, 10 years of experience P4: Design and development manager, 18 years of experience
C: Manufacturer of ice-cream, ca. 170 employees, Sweden	P5: Head of sustainability, 17 years of experience P6: Product developer, 10 years of experience

challenges in operationalizing sustainability assessments and potential gaps between theoretical understanding of sustainability performance and its practical integration in company processes.

Purposeful sampling was applied both for the companies and interviewees, similar to the studies by Dangelico and Pujari (2010) and Høgevold et al. (2014). The selected companies actively work with sustainability beyond mere compliance while not being companies that purely define themselves in sustainability terms. This profile was considered appropriate for this study, as it reflects companies that have sustainability as a strategic concern or value, but not as their core characteristic or driver, providing insights related to how to define sustainability for their business and also what is needed to support a systematic and strategic integration. Interviewees were identified in dialogue with a principal informant at each company, targeting people with high levels of expertise and roles related to SPD. Interviewees' main responsibilities were related to developing and implementing corporate sustainability strategy and reporting; supporting the coherence between the sustainability strategy and product development; and integration and assessment of sustainability issues in product development decisions spanning from design to production.

Each interview lasted one hour, and two researchers were present during all interviews. In addition to notetaking during and immediately after the interview, interviews were recorded and transcribed. Transcripts were sent back for validation to the interviewees, allowing respondents to correct mistakes or provide clarifications.

A descriptive thematic summary approach based on Braun and Clarke (2006) and Sandelowski (2000) was applied to identify and summarize the most prominent patterns. Structured summaries were produced for the interviews at each company. The summaries were then compared to identify recurring ideas and patterns, reflecting their frequency or emphasis within the data. This process was iterative: the researchers revisited original transcripts to check that identified patterns accurately reflected interviewees' perspectives and to ensure that less frequent but also relevant ideas were not overlooked.

Having a complementary role to the literature review findings, the exploratory interviews provided a practitioners' lens through which the conceptual framework and the conceptualizations identified in the literature could be examined and contextualized. The interviews were used to identify how practitioners understand and work with the different dimensions of sustainability, i.e. what *scope* they apply, how they relate to the *scale of impact* when assessing product sustainability performance, and what *points of reference* they use or would prefer when making product sustainability performance assessments. These practitioner perspectives were used in the discussion section to examine the extent to which the identified conceptualizations and assessment approaches converge or diverge from practice and potential implications for the product development process.

4 Findings

The concept of product sustainability performance is rarely used explicitly in the reviewed literature but can be decoded from the underlying assumptions of approaches for integrating sustainability considerations in product development. The approaches were analyzed qualitatively in relation to the spectrum of each aspect of the conceptual framework, focusing on their foundational assumptions and theoretical principles rather than on how they are operationalized in practice. Approaches that gravitated around similar assumptions, despite differing in how these assumptions were operationalized, formed a cluster as they tended to align in terms of scope, scale of impact, and point of reference. From the assumptions and characteristics of each cluster, it was possible to interpret and identify a distinct conceptualization of product sustainability performance. Table 4 summarizes these conceptualizations, indicating their positioning along the spectrum of each aspect of the conceptual framework and providing examples of assessment approaches that represent them. In this context, the term "representation" refers to assessment approaches that reflect or embody a particular conceptualization, i.e. approaches whose underlying

Table 4 Summary of identified conceptualizations of product sustainability performance

Cluster	Conceptualization of product sustainability performance	Scope	Scale of impact	Point of reference	Examples of representations	Examples of references
Cluster 1	Product sustainability performance is based on an efficiency lens, in which the aim is to design a product that has a better ratio between a desirable outcome (e.g. cost, quality, value) and a negative impact on a defined safeguard object (e.g. ecosystem or human health) in comparison to another product or benchmark	*Narrow*—exclusive focus on environmental or social impacts	*Insular*—impact assessment is limited to the product's direct subsystem	*Relative*—performance is assessed in comparison to previous results or benchmarks	Eco-efficiency Ecodesign LCA Social-LCA	Ahmad et al. (2018), Bjørn et al. (2020), Bjørn and Hauschild, (2013), Chen et al. (2012), Daneshjo et al. (2023), Fiksel et al. (1998), Issa et al. (2015), and Rodrigues et al. (2016)
Cluster 2	Product sustainability performance is based on an effectiveness lens, in which the aim is to design a product whose impacts remain within the ecological system limits. The focus is on ensuring that material and energy flows do not exceed biophysical boundaries, contributing to a neutral or regenerative influence on ecological systems	*Narrow*—exclusive focus on environmental impacts	*Systemic*—impacts are assessed in consideration of the ecological system	*Absolute*—performance is assessed in relation to the boundaries of the ecological system	Cradle to cradle Circular economy Environmental footprint Absolute Environmental Sustainability	Andersen et al. (2024), Bjørn et al. (2020), Bjørn and Hauschild (2013), Ferng (2014), Gebler et al. (2022), Gupta et al. (2024), Hauschild et al. (2020), Kravchenko et al. (2019)
Cluster 3	Product sustainability performance is based on an effectiveness lens, in which the aim is to design a product that contributes to moving the socio-technical system toward a sustainable state, defined by absolute socio-ecological boundaries	*Wide*—includes both social and environmental impacts	*Systemic*—impacts are assessed in consideration of the socio-ecological system	*Absolute*—performance is assessed in relation to social and ecological boundaries	PROSA FSSD. Checklist for Sustainable Product Development Sustainability fingerprint	Broman and Robèrt (2017), Hallstedt et al. (2023), Hallstedt and Isaksson (2017), Möller and Grießhammer (2024), Schöggl et al. (2017), Zimek and Baumgartner (2024)

assumptions make a specific conceptualization of product sustainability performance visible through analysis.

4.1 Cluster 1: narrow, insular, relative

The conceptualization of product sustainability performance in the approaches in cluster 1 is characterized by a narrow scope, insular scale of impact and relative point of reference. The *narrow scope* is characterized by a focus on a single dimension of sustainability, that unfold in action towards environmental or social impact management in product development (Dyllick & Rost, 2017; Simons et al., 2001). The *scale of impact is insular* since the identified approaches in this cluster focus on impact analysis that is limited to the product's direct subsystem, i.e. the processes and flows directly involved in its life-cycle. Impacts and interactions beyond this subsystem, for example, rebound effects in other sectors are not assessed. The product is thus seen in isolation from broader ecological system's dynamics. This is based on the assumption that there is a linear causality between design decisions and the final impact of a product on the environment. The assessment of performance in this context is based on a *relative point of reference* in which the result is compared with previous ones or with internal or external benchmarks. In summary, impact is seen as a technical issue, that is measurable, and the ultimate goal is to increase eco-efficiency (Bjørn & Hauschild, 2013; Chen et al., 2012; Daneshjo et al., 2023; Fiksel et al., 1998; He et al., 2020); generally defined as "adding maximum value with minimum resource use and minimum pollution"(Welford, 1997).

This narrow, insular and relative conceptualization can be recognized in concepts of Ecodesign and design for the environment that propose a systematic incorporation of environmental impact considerations in the product development process, including a focus on the whole life-cycle, and seeking to produce products with better environmental performance (Ahmad et al., 2018; Ceschin & Gaziulusoy, 2016; Fiksel et al., 1998; Issa et al., 2015; Rodrigues et al., 2016; Schöggl et al., 2017). This conceptualization is also manifested in LCA and Social-LCA (S-LCA), that support a comprehensive, detailed and quantitative assessment of environmental and social impacts, respectively, across the product life-cycle (Ahmad et al., 2018; Bjørn et al., 2020; Eberle et al., 2022; Herrera Almanza & Corona, 2020). Apart from their different sustainability dimension focus, both LCA types support an efficiency perspective on product sustainability performance assessment (Daneshjo et al., 2023) by enabling the quantification of impacts per functional unit and facilitating comparisons between design alternatives to identify the one with the lowest impact relative to its function (Bjørn et al., 2020). The main focus is an isolated subsystem, such as a company or a specific product, without consideration of the broader system in which they are embedded (Ceschin & Gaziulusoy, 2016; Dangelico & Pontrandolfo, 2010). For example, LCA supports an analysis of the full life-cycle, together with upstream and downstream flows of materials and energy associated with its value chains. However, it does not include the ecosystem in the system boundary (Bjørn & Hauschild, 2013; Fiksel et al., 1998). As a result, impacts on the ecological system dynamics are not assessed, which can lead to overlooking links between product impacts and potential future impacts on raw material availability, that could hinder a systemic state of sustainability.

4.2 Cluster 2: narrow, systemic, absolute

The conceptualization of product sustainability performance present in the approaches found in cluster 2 is characterized by a narrow scope, systemic scale of impact and absolute point of reference. The *narrow scope* is characterized by a focus on environmental issues. The *scale of impact is systemic*, since the approaches explicitly place the product as part of—and in interaction with—the broader ecological system. The ecological system is understood as dynamic and bounded by finite biophysical limits that must not be transgressed to maintain its functioning and regenerative capacity. Products depend on and influence these dynamics through material and energy flows, which must remain within ecological limits to reduce the risk of irreversible and major changes on the functioning of the system. The assessment of performance in this context has an *absolute point of reference* that is based on the biophysical limits of the ecological system.

This narrow, systemic and absolute conceptualization is represented in approaches such as Circular Economy (CE), that aims at designing products that contribute to a restorative or regenerative industrial system where materials circulate rather than become waste (Ceschin & Gaziulusoy, 2016; Sassanelli et al., 2019). Similarly, cradle-to-cradle (C2C) proposes that waste equals food, reinforcing the premise that outputs can serve as inputs elsewhere. Their systemic perspective on scale of impact assumes that the ecological system functions as a closed loop, and that industrial systems must operate within ecological regenerative capacity limits. Consequently, products are viewed as system components whose role is to sustain the loop by enabling resource circulation and regeneration (Bjørn & Hauschild, 2013; Dangelico & Pontrandolfo, 2010), for example through strategies in the 10-R hierarchy such as reuse, repair, remanufacturing and recycling (Bjørn & Hauschild, 2013). This leads to an absolute point of reference—maintaining closed-loop balance within industrial and ecological systems. When combined with this absolute reference, an effectiveness lens assesses how well products preserve or enhance the system's regenerative potential, while efficiency thinking is embedded in the premise that, in order to contribute to this regenerative potential, it is important to optimize resource flows.

Although in its foundations, CE highlights the need for effectiveness and efficiency guided by an absolute point of reference and systemic scale of impact, in practice, circularity assessments are often conducted using LCA, resulting in a predominantly relative perspective (Sassanelli et al., 2019). For instance, Hapuwatte et al. (2017) highlights how the 6R strategy (Reduce, Reuse and Recycle, Recover, Redesign and Remanufacture) can enhance the Product Sustainability Index (ProdSI), which includes metrics on investment, cost, energy and material efficiency, durability and technical performance. Yet, although grounded in loop-closing intentions, the assessment remains tied to an efficiency perspective and relative comparisons. The practical application of CE and C2C with an efficiency performance induces rebound effects, such as increased consumption or intensified energy use driven by recycling requirements (Bjørn & Hauschild, 2013; Hauschild et al., 2020; Kravchenko et al., 2019). Some scholars also argue that circularity approaches lack clarity in linking the micro and macro levels, largely because the socio-economic system itself requires redesigning to support a circular economy (Broman & Robèrt, 2025).

Another example is the Ecological Footprint approach. It calculates the biologically productive area necessary to provide the resources consumed by a defined human society and to absorb the waste it generates (Ferng, 2014; Monfreda et al., 2004). It has been used to demonstrate that, at the global scale, society has already overshot Earth's biocapacity (Monfreda et al., 2004). Ferng (2014) highlighted the importance of the concept of open nested systems when conducting environmental footprint assessments to be able to map the interconnections between resource flows in different levels, for example, countries, and their impacts in the overall ecological system. The European Union (EU) uses a combination of LCA and Ecological Footprint in the Product Environmental Footprint method, which enables product-based comparative environmental performance assessment in relation to scientifically grounded ecological limits, e.g. the Planetary Boundaries (European Commission, n.d.; Sala et al., 2020).

Furthermore, there is an emerging approach called Absolute Environmental Sustainability Assessments (AESA) (Bjørn & Hauschild, 2013; Bjørn et al., 2020). In contrast to the absolute perspective based on a closed-loop system, AESA adopts the Earth's carrying capacity as an absolute point of reference and is as such grounded in Earth system science. The Earth's carrying capacity is allocated across different levels (e.g. countries, sectors, companies and products) and the AESA supports the assessment of impacts in relation to the allocated share (Bjørn et al., 2020). In practice, AESA uses results from LCA impact assessment to assess performance of products in relation to their allocated share of the Earth's carrying capacity (Bjørn et al., 2020). The aim is to support the design of products that are good enough for a thriving planet, by not only minimizing environmental impact, but actually assessing if the impact is coherent with the allocated share of the Earth's carrying capacity across the life-cycle and time, also focusing on identifying potential burden shifts (Andersen et al., 2024; Bjørn & Hauschild, 2013; Hauschild et al., 2020). Other authors (Gebler et al., 2022; Gupta et al., 2024) have been discussing how to complement this approach with issues such as social justice, well-being considerations and the need to aim for positive impact that counteracts on exceeded boundaries.

4.3 Cluster 3: wide, systemic and absolute

The third conceptualization emerging from the literature is characterized by a wide scope, systemic scale of impact and absolute point of reference. The *wide scope* is represented by the inclusion of environmental and social dimensions. The *scale of impact is systemic*, since most of the approaches identified in this cluster assume that products and the economic system are nested within the social and ecological systems, respectively. Due to the interdependence of the nested systems, this part of the literature argues that it is not possible to analyze sustainability dimensions separately from each other, i.e. with a narrow scope. The assessment of performance has an *absolute point of reference* that is based on the assumption that the socio-ecological system has boundary conditions that must be respected to achieve and maintain a sustainable state.

In this context, product sustainability performance is seen through an effectiveness lens, where the best alternative is the one that contributes to moving the socio-technical system toward a sustainable state, defined by socio-ecological boundaries. Correspondingly, evaluating performance involves reflecting on and redefining the product's role within the system, shifting from a perspective in which sustainability is solely a technical problem to one in which the product's influence on patterns of production, consumption and social behavior are considered.

This conceptualization requires that the social dimension is explicitly integrated rather than overlooked or treated as secondary. However, defining and measuring social impacts remains challenging, as often-used indicators risk neglecting intangible and systemic effects such as equity, empowerment, and wellbeing (Corsini & Moultrie, 2021; Cunha & Benneworth, 2020). Multiple lines of research seek to clarify how products can contribute to social-system transitions (Corsini & Moultrie, 2021; Cunha & Benneworth, 2020; Ottosson et al., 2017).

This wide, systemic and absolute conceptualization of product sustainability performance is represented in PROSA

(Product Sustainability Assessment) (Möller & Grießhammer, 2024; Möller et al., 2021). PROSA supports the assessment of product improvements and innovation, while applying a life-cycle perspective and assessing environmental, economic and social opportunities and risks. The assessment is based on LCA methodology and in its latest version included the Sustainable Development Goals (SDGs) as a basis for defining the assessment point of reference. The SDGs are a normative framework that defines politically negotiated targets for achieving social and environmental benefits and multiple approaches in the literature (e.g. Agusdinata et al., 2023; Eberle et al., 2022; Herrera Almanza & Corona, 2020; Kühnen et al., 2019) use it as a reference point for sustainability assessments. PROSA therefore assesses product sustainability performance through the product's contribution to societal benefit and systemic value creation rather than only its reduction of negative impacts, linking product design to broader transitions toward sustainability (Möller & Grießhammer, 2024; Möller et al., 2021).

Similar to PROSA, the Handprint approach proposed by Kühnen et al. (2019) also uses LCA methodology as a basis to assess a product's or company's contribution to the SDGs. The Handprint approach mirrors the Ecological Footprint, but evaluates restorative and contributive actions, that, e.g., remediate existing damage or advancement towards sustainability goals. Eberle et al. (2022) similarly propose a method to measure a product's contribution to SDG targets. Their approach selects indicators from the Global Indicator Framework (GIF-SDG) and applies them in a social life-cycle impact assessment, producing results that show whether a product supports or hinders achievement of specific SDG targets. Herrera Almanza and Corona (2020) adopt an even more systemic perspective, exploring how textile product life-cycle impacts can influence the SDGs by linking social-LCA and SDG indicators.

This cluster also includes approaches based on the Framework for Strategic Sustainable Development (FSSD), which intends to provide support for organizations in moving strategically towards sustainability, i.e. in a stepwise way that both contributes to the societal transition and benefits the own organization. Also grounded in a nested-systems view, the FSSD derives an absolute point of reference in the form of first-order sustainability principles (SPs), i.e. eight fundamental constraints that must not be violated to ensure sustainability of the socio-ecological system (Broman & Robèrt, 2017). The SPs are derived from the root causes of unsustainability, upstream in cause-and-effect chains, differing from absolute boundaries based on ecological carrying capacities. This principled definition allows "open-ended and non-prescriptive co-creation toward sustainability" (Hallstedt, 2017) and has served as a foundation for design supports, such as the Sustainability Design Space, which provides product-specific, long-term strategic sustainability criteria derived from the SPs (Hallstedt, 2017). From the definition of the criteria, a subset of leading sustainability criteria is selected to focus design attention on the most influential lifecycle aspects early in the product development process (Watz & Hallstedt, 2024). To assess progress toward these criteria, the Sustainability Compliance Index enables a structured, qualitative evaluation of both minimum and desired performance levels (Hallstedt & Isaksson, 2017; Hallstedt et al., 2013, 2023). Finally, product alternatives can be assessed in relation to these criteria and the results are visualized in the Sustainability Fingerprint, which summarizes performance in each criterion and supports comparison of alternatives (Hallstedt et al., 2023).

Similarly, Schöggl et al. (2017) developed the Checklist for Sustainable Product Development which supports the assessment of environmental, economic and social aspects during the early phases of product development based on 49 yes or no questions derived from the SPs. Zimek and Baumgartner (2024) explored how a systemic sustainability assessment built on the SPs can include a spatial and a time perspective. Despite the adoption of this systemic and long-term perspective that fulfills a normative function to provide a clear picture of a desired future state, approaches based on the SPs have been criticized for lacking elements and guidance that can support systemic and radical innovation, by, for example, not challenging business responsibilities and the focus on financial results (Gaziulusoy, 2015).

4.4 Findings from exploratory interviews

Exploratory interviews at product development companies were conducted to investigate how practitioners conceptualize and operationalize product sustainability performance. Interviewees demonstrated distinct internal and external motivations for assessing product sustainability performance. Despite some differences, all interviewees associated SPD initiatives with regulatory compliance and increased competitiveness, demonstrating the potential influence of product sustainability performance conceptualizations adopted by external actors and regulations.

Assessment practices varied across companies. Interviewees in Company A reported using a qualitative environmental sustainability impact assessment tool across development stages, complemented by a designated individual responsible for conducting LCAs on specific components. Interviewees from Company B noted the absence of a systematic approach, although the company has experimented with assessment tools in research projects. At Company C, interviewees reported conducting qualitative sustainability risk assessments of raw materials involving a diverse employee group, relying on discussion and documentation of the rationale for results. They are also exploring carbon footprint assessments to inform product development. Interviewees in Companies A and B have previously used the Sustainability Fingerprint.

The diversity of practices resulted in variations of the overall conceptualizations of product sustainability performance in relation to scope, scale, and point of reference. Regarding *scope,* all interviewees stressed the need for a comprehensive approach encompassing social and environmental dimensions across the life-cycle. However, in practice, assessments remained narrower in scope, focusing on environmental impacts and a few social aspects, mostly related to health and safety concerns in supply chains and product use phases. In terms of *scale*, all interviewees referred primarily to the product subsystem, emphasizing the upstream value chain. One interviewee from Company A acknowledged the relevance of a systemic perspective for sector-wide sustainability transitions but also noted their organization's limited influence and dependence on customer requirements and willingness to change. Regarding the *point of reference*, most interviewees associated sustainability improvement with reducing negative environmental and social impacts while maintaining economic viability. An interviewee from Company B described a sustainable product as one that performs efficiently with minimal waste and environmental consequences, aligning with an efficiency-oriented performance lens. Efficiency was also considered a valuable marketing attribute. Interviewees from Companies A and C were familiar with the SPs of the FSSD, and those from Company A also mentioned research on absolute environmental sustainability. In both cases, they highlighted the difficulty of connecting macro-level sustainability goals to product-level assessments.

Interviewees identified several challenges in implementing sustainability assessments within product development and decision-making. Data availability and reliability emerged as key challenges, along with the time and resource intensity required for comprehensive assessments. Interviewees also emphasized the need for efficient, iterative tools suited to early development stages. Quantitative results were strongly preferred, as they are perceived as more reliable, easier to communicate, and more persuasive for internal decision-making and customer engagement. The demand for quick, quantitative and easy to communicate results, motivated by time constraints and data availability, privileges measurable environmental indicators and relative comparisons. These preferences create a tension with the characteristics of wide, systemic and absolute assessments, which tend to be more qualitative, abstract and time demanding.

5 Discussion

5.1 Conceptualizing product sustainability performance

Considering the literature findings, distinct patterns emerge regarding how different ends of the spectrum of each aspect of the conceptual framework (scope, scale and point of reference) tend to combine and shape different conceptualizations of product sustainability performance, as shown in the dotted lines in Fig. 2.

In relation to *scope*, two of the three identified conceptualizations are characterized by a narrow focus, as seen in Clusters 1 and 2, with most of their representations addressing primarily the ecological dimension. A narrow focus on a specific dimension of sustainability can make the complex sustainability challenge more manageable and easier to communicate; for instance, focusing on a single issue, such as climate change, makes it easier to assess and communicate results (Hallstedt, 2017; Peace et al., 2018), which was considered important by the interviewees. These approaches, e.g. Ecodesign, Eco-efficiency, LCA, are widespread in both research (Ahmad et al., 2018; Ceschin & Gaziulusoy, 2016; Chen et al., 2012; Daneshjo et al., 2023; Dangelico & Pontrandolfo, 2010) and in practice (e.g. EU Product Environmental Footprint, Ecodesign for Sustainable Products Regulation, ISO 14040), reflecting their practical implementation. However, a narrow scope misses connections between sustainability dimensions, increasing the risk of unintended consequences in other dimensions that can undermine the long-term sustainability transition (Gaziulusoy, 2015; Hauschild et al., 2020). A wide scope, by contrast, recognizes that

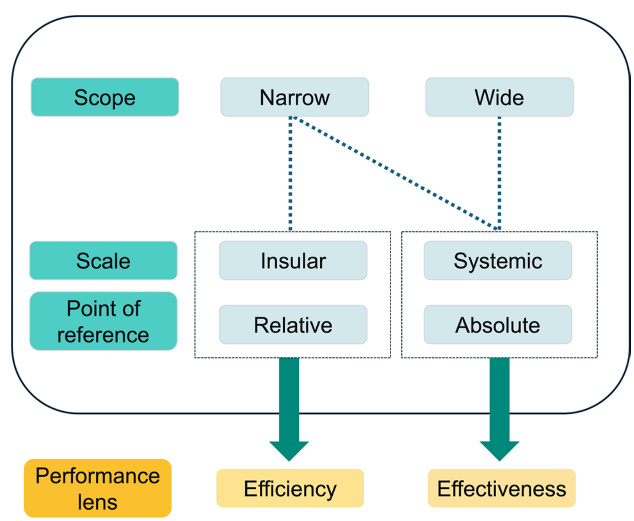

Fig. 2 Identified combinations between different spectrums of the conceptual framework

the social and ecological dimensions are needed to tackle the full complexity of the sustainability transition (Broman & Robèrt, 2017; Ceschin & Gaziulusoy, 2016; Gaziulusoy, 2015; Sala et al., 2015), addressing the interconnections between them. However, it should be noted that, in practice, the extent to which each dimension is addressed in an assessment approach may vary. Therefore, even approaches with a wide scope may be reductionist if sustainability dimensions are represented by one or a few aspects.

In relation to *scale of impact*, is was found that approaches in Cluster 1 tend to assess impacts from an insular perspective, looking at products' impacts across their value chain and life-cycle, as usually done in LCA (Herrera Almanza & Corona, 2020). By contrast, approaches in Cluster 2, e.g. Circular Economy and AESA, go beyond the insular scale of impact by viewing the product within the ecological system and recognizing that maintaining the ecological system's stability requires staying within biophysical limits that serve as an absolute point of reference. However, Cluster 2 approaches remain primarily concerned with whether products operate within ecological limits, without considering the social system and its boundaries. This is a critical limitation: recognizing that the social system is nested within the ecological system, and that a sustainable state must be defined in relation to both social and ecological conditions, is a major difference between Cluster 2 and Cluster 3. Approaches such as the FSSD-based Sustainability Fingerprint expand the scale of impact exploring how products contribute to systemic change toward a sustainable state that encompasses both ecological and social dimensions. This requires understanding system dynamics and the ability to trace cause-effect relations across product and organizational limits, as well as analyzing trends, risks and uncertainties across contexts and time horizons (Sala et al., 2015; Zimek & Baumgartner, 2024). As highlighted in the interviews, practitioners recognized the importance of systemic assessments but mentioned challenges in understanding their position within the broader socio-technical system and in assessing how their product development decisions can contribute to influencing it. Although approaches such as the Sustainability Compliance Index and the Sustainability Fingerprint are based on a systemic scale of impact and an absolute point of reference, their application generally lacks mapping interrelations between system levels and sustainability criteria (Hunger et al., 2025).

In relation to the *point of reference*, across clusters, it emerged as a key factor for how product sustainability performance is interpreted: either through an efficiency or an effectiveness lens. An efficiency lens is usually connected to a relative point of reference, represented by goals to reduce negative impacts in relation to a baseline or benchmark, while maintaining or increasing technical performance and functionality (Ahmad et al., 2018; Bjørn et al., 2020; Daneshjo et al., 2023). A relative point of reference and efficiency lens are primarily expressed in quantitative assessments. Practitioners perceive this type of assessments as objective, precise, and easier to communicate, which helps explain the dominance of relative, efficiency-oriented approaches in both research and practice (Ahmad et al., 2018). An absolute point of reference, by contrast, supports an effectiveness lens by providing a vision of a sustainable state at the system level against which product performance can be evaluated (Gaziulusoy & Brezet, 2015; Sala et al., 2015).

How absolute boundaries are defined and operationalized varies considerably across approaches, with implications for how product-level performance can be assessed in relation to systemic sustainability goals. Within Cluster 2, CE translates absolute limits into the goal of closing the loop and creating regenerative systems (Bjørn & Hauschild, 2013). In parallel, AESA defines science-based ecological boundaries grounded in Earth's carrying capacity and provides methods to downscale these boundaries to the product level, resulting in the allowed impact for a product to be good enough in sustainability terms (Bjørn et al., 2020; Hauschild et al., 2020). However, challenges arise when allocating global limits to companies and products. Multiple allocation methods exist and reflect differing views on actors' economic contributions, historical responsibility, or needs (Bjørn et al., 2019; European Commission: Joint Research Centre et al., 2025). As in traditional LCA, the choice of allocation method strongly influences results and the perceived fairness of how burdens are distributed among actors (Andersen et al., 2024; Paulillo et al., 2026; Simons et al., 2001). In AESA, this influence is amplified because allocation affects how absolute thresholds are translated to the product level. The absence of standardized procedures for operationalizing absolute assessments increases the risk of subjective choices and interpretations of allocation methods (Paulillo et al., 2026).

Approaches in Cluster 3 have in common that they expand the point of reference to include both social and ecological boundaries. However, how these boundaries are defined and operationalized varies. PROSA (Möller & Grießhammer, 2024), for instance, define boundaries based on the SDGs. While the SDGs provide a globally recognized reference, they have limitations when used as an absolute point of reference in product sustainability assessments (Bengtsson et al., 2018). In contrast to the Planetary Boundaries or the SPs, which provide scientifically grounded boundaries, the SDGs are the outcome of political negotiation. Although they cover a wide range of themes related to the socio-ecological system, they were not designed to cover all necessary social and ecological conditions for maintaining a sustainable state. Their design for macro scales (nations, regions) means many targets and indicators are not directly transferable to micro-level assessment, requiring reinterpretation when applied to product systems (Backes & Traverso, 2022; Eberle et al., 2022). Additionally, in practice, the interdependencies of SGD targets and indicators are usually not assessed, limiting the potential for the assessment from a systemic scale of impact perspective (Cernev & Fenner, 2020). Also, as Bengtsson et al. (2018) highlighted, the targets and indicators of SDG 12, that aims at responsible consumption and production patterns, are still focused on efficiency rather than a systemic transition.

Science- and principle-based approaches, such as the SPs of the FSSD, instead provide necessary, sufficient, general, concrete and non-overlapping "boundary conditions within which society can continue to function and evolve" (Broman & Robèrt, 2017). Principle-based definitions provide a shared understanding of goals and guidance for actions and practices (Broman & Robèrt, 2017), and can be applied across levels (e.g., products, companies) without allocating shares (Holmberg & Robert, 2000). This allows for backcasting, rather than forecasting (which mostly supports incremental improvement), to guide strategic action, as the SPs help companies envision how their products could support a transition toward a sustainable future. This requires understanding system dynamics and the ability to trace cause-effect relations across product and organizational limits as well as analyzing trends, risks and uncertainties across contexts and time horizons (Sala et al., 2015; Zimek & Baumgartner, 2024).

The combinations of the different ends of the spectrum of *scope, scale of impact* and point of reference generate conceptualizations that stand in tension with each other and represent potential implications for the contribution to the transition towards sustainability. The conceptualization that emerged from Cluster 1 supports incremental improvements with a narrow scope, supporting an easier implementation and adoption in practice. These narrow and insular approaches with relative and efficiency-based assessments carry a higher risk of rebound effects and lack potential to drive systemic change (Entsalo et al., 2023; Gaziulusoy, 2015).

Another tension exists between conceptualizations that adopt an absolute point of reference but differ in scope. CE and AESA both adopt absolute ecological references, but their narrow scope means they do not account for the social system and its boundaries, creating a risk that closing material loops or staying within ecological carrying capacity could still be achieved in ways that undermine the stability of the social system. Approaches in Cluster 3 that adopt a wide scope and a socio-ecological absolute reference address the need for a wide scope with a systemic perspective, acknowledging that the product is embedded in the socio-ecological system and that its sustainability performance needs to be addressed in consideration of the interconnections between these systems.

For performance assessment in SPD, both efficiency and effectiveness are valuable and necessary lenses. Effectiveness clarifies how a product contributes to the transition toward a sustainable state, while an efficiency lens informs how well different options perform in relation to the defined constraints (Baumgartner & Rauter, 2017; Watz & Hallstedt, 2022). Adopting an efficiency lens without prior effectiveness orientation risks improving solutions that are ineffective or even hindering system change towards sustainability. On the other hand, an effectiveness lens without efficient implementation risks wasteful management of resources. This need for both lenses is not currently met by any single existing approach. Efficiency-based approaches found in Cluster 1 lack a definition of an absolute point of reference. Effectiveness approaches, found in Clusters 1 and 2, have a challenge in translating system-level boundaries into actionable product-level metrics that can subsequently support efficiency-focused assessments.

Therefore, it is necessary to establish a conceptualization of product sustainability performance that incorporates both lenses to guide product-level assessment and decision-making (Duffy & O'Donnell, 1998; Nappi et al., 2024). This is fundamental for defining what sustainability means in product development and for determining how it can be assessed at the product level (Gaziulusoy, 2015; Nappi et al., 2024; Watz & Hallstedt, 2024). In light of these findings, it is proposed that:

> Product sustainability performance can be defined as the degree to which a product effectively, through its life-cycle, contributes to moving socio-technical systems toward a state of sustainability defined by science-based systemic socio-ecological boundaries, while efficiently mitigating impacts within those boundaries.

This definition is grounded in and integrates insights from existing approaches across the three clusters, while making explicit what several of them leave implicit or incomplete: that sustainability requires addressing both ecological and social system boundaries, and that both effectiveness and efficiency are necessary but have distinct roles. Building on this definition, different types of performance assessment approaches can be applied across the product development process, provided that an effectiveness perspective is kept as a guiding principle, while an efficiency lens supports improvements that remain subordinate to the overarching aim of effectively contributing to the systemic transition towards a sustainable state (Baumgartner & Rauter, 2017; Duffy & O'Donnell, 1998).

5.2 Implications for sustainable product development

A comprehensive definition of product sustainability performance that includes efficiency and effectiveness can support the integration of both performance lenses throughout the product development process. Figure 3 illustrates how the performance lens applied to product sustainability evolves from effectiveness to efficiency in the product development process. We propose this as a gradual transition rather than a shift with a clear start and end point, one lens slowly fades as another becomes more prominent, reflecting the iterative nature of product development (Ulrich & Eppinger, 2012).

The early stages of product development are centered on conceptual design, including innovation, idea generation and requirement definition, in which there is a movement from the problem to the solution domain (Dick et al., 2017). The problem domain can be seen as the stage where strategic sustainability decisions are made to balance market needs, stakeholders demands and corporate strategy (Watz & Hallstedt, 2018). Therefore, this is a stage in which the concept of product sustainability performance should fulfil a normative function in the identification of the role of the product within the societal transition towards sustainability from a wide scope, systemic scale of impact and absolute point of reference (Watz & Hallstedt, 2022). By providing this normative direction, the concept of product sustainability performance supports the adoption of an effectiveness lens in the problem domain, i.e. defining sustainability criteria that ensure the product is effective in supporting a systemic transition toward sustainability.

These criteria then serve as design constraints when moving to the solution domain (Ny et al., 2006; Watz & Hallstedt, 2022), when product requirements (e.g., functional, technical) are specified (Watz & Hallstedt, 2018). Placing the effectiveness lens to support requirement definition before moving to the solution domain has the potential to minimize the risk of trade-offs with traditional requirements, due to its anchoring in an absolute point of reference (Bengtsson et al., 2018; Kravchenko et al., 2019; Watz & Hallstedt, 2022). Later on, the efficiency lens informs, through the definition of sustainability KPIs, how well different options perform in relation to the established constraints (Baumgartner & Rauter, 2017; Watz & Hallstedt, 2022).

While this integration and interplay between effectiveness and efficiency provides useful insights for integrating sustainability in the product development process, it is important to acknowledge that achieving effectiveness at the product level is not sufficient both from a business and a transition to sustainability perspective. Since performance goals are interconnected across different business levels, from individual product activities to broader business strategic objectives and portfolio management, effectiveness at the product level must be aligned across decision-making levels (Duffy & O'Donnell, 1998). In the context of sustainability, this means that product-level effectiveness must be anchored in and aligned with a sustainability vision that extends beyond the product itself as well with sustainability considerations in business model design, supplier management, etc. (Ceschin & Gaziulusoy, 2016; Vilochani et al., 2025).

Furthermore, there are challenges related to assessing effectiveness as it requires understanding how product-level decisions relate to the stability of the broader socio-ecological system and its boundaries (Baumgartner & Rauter, 2017). Although several approaches establish science-based systemic boundaries to characterize a sustainable state (Bjørn & Hauschild, 2013; Broman & Robèrt, 2017; Hallstedt et al., 2023; Zimek & Baumgartner, 2024), translating these high-level boundary conditions into actionable, product-level performance metrics that can subsequently support efficiency-focused assessments remains a challenge. Furthermore, conducting a systemic product sustainability assessment requires companies to understand their role within the broader socio-technical system and how their products can contribute to shifting that system toward a more sustainable state (Ceschin & Gaziulusoy, 2016; Gaziulusoy & Brezet, 2015; Zimek & Baumgartner, 2024). In practice, this means companies must grapple with how a micro-level design

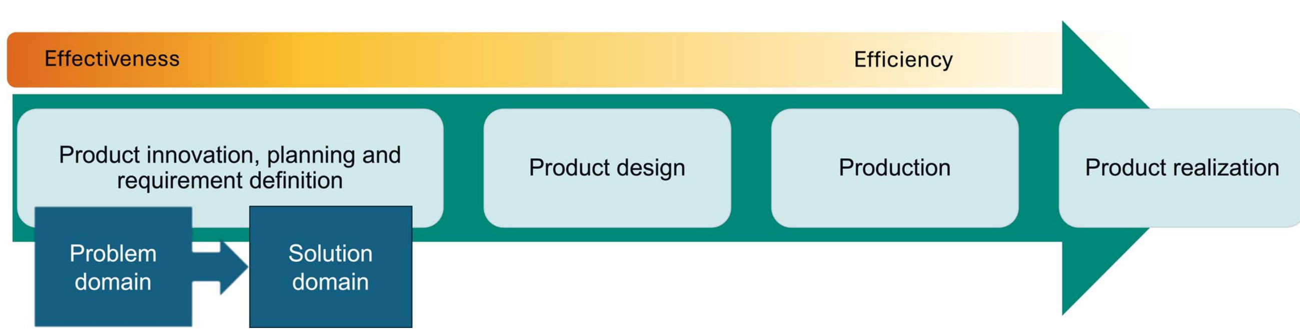

Fig. 3 Illustration of the evolution of the performance lens throughout the product development process

choice may influence macro-level socio-technical transition, an inherently complex and uncertain task. This challenge also emerged in the interview results and implies the need for capabilities to work with systemic complexity and deep uncertainty.

In practice, regulations play a key role in shaping and incentivizing industry perceptions and practices in relation to the concept of product sustainability performance (Gaziulusoy, 2015; Schöggl et al., 2017). However, most of the current regulations on product sustainability are based on a narrow scope, insular scale of impact, and relative point of reference when addressing product sustainability performance. This tends to perpetuate efficiency-based practices that have a higher risk of rebound effects and do not achieve the required pace of change required to address the sustainability challenge (Entsalo et al., 2023; Gaziulusoy, 2015). Policies that combine efficiency with effectiveness would better support companies in adopting a systemic approach to product sustainability (Bengtsson et al., 2018; Entsalo et al., 2023; Milios, 2018). The proposed definition of product sustainability performance could provide a normative basis for future regulations by linking product-level decisions to absolute sustainability thresholds, supporting a shift from efficiency-based compliance toward effectiveness-driven transformation.

6 Conclusions

To advance on SPD, companies need to assess product sustainability performance; however, what exactly constitutes product sustainability performance remains fragmented in the literature. Existing approaches are built on diverse and often implicit assumptions about sustainability, which have a fundamental influence on how sustainability is interpreted and included in product development. This study addressed this gap by examining how product sustainability performance is conceptualized in SPD literature and adjacent fields. By drawing on elements from the identified clusters in literature, a new definition was proposed.

From a systematic literature review, three distinct conceptualizations of product sustainability performance emerged, each differing in *scope, scale of impact*, and point of reference—differences that shape both the benefits and limitations of product sustainability assessments. These variations were found to not only influence what is assessed but also how performance is interpreted: typically, through an efficiency lens when using a relative point of reference, and through an effectiveness lens when using an absolute point of reference. Although the literature presents conceptualizations that combine different ends of the spectrum of *scope, scale of impact* and point of reference, interviews with industry representatives indicated that practice is dominated by a narrow, insular and relative focus—a conceptualization that is reinforced in current and emerging regulations.

Recognizing the importance of both efficiency and effectiveness for product development and for the transition towards sustainability, this paper proposed a definition of product sustainability performance that integrates both lenses. Effectiveness ensures that product development decisions move in the right direction, while efficiency ensures that these efforts are pursued with optimal use of resources and impact mitigation. Efficiency alone cannot drive sustainability; it must be combined with an effectiveness-oriented approach. The literature indicates that effectiveness is particularly important in early development phases, whereas the importance of efficiency increases as the product development process advances. Interviews confirmed this tendency but also revealed challenges to applying an effectiveness lens early on. Further research is therefore needed to explore how effectiveness-oriented assessments can be practically implemented in early product development phases.

This review has limitations that should be acknowledged. The conceptual framework used in this study focuses on three distinct aspects. While these together characterize fundamental assumptions of product sustainability performance conceptualizations, there are additional dimensions that are relevant for, e.g., the usefulness and implementation of assessment approaches, such as time perspectives, integration of risks and opportunities, and trade-off management. The literature review search was limited to the title field to ensure focus on the study topic amid an extensive research area but may have led to the exclusion of relevant studies. Furthermore, the limited number of exploratory interviews limits the generalizability of the empirical results.

Rather than signaling a need for entirely new assessment tools, this review points to the need for clearer guidance on how existing approaches can be strategically selected and combined at the right time and for the right purpose in line with the proposed definition of product sustainability performance. Future research could explore how such a coherent methodological support may be formed and operationalized. Additionally, empirical research is needed to support the operationalization of wide, systemic, and effectiveness-oriented assessments.

7 Summary

Supplementary Information SI1:

This supporting information provides the full list of the 125 papers included in the literature review, as reported in section 3.2.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s44498-026-00099-9.

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Data availability No datasets were generated or analysed during the current study.

Competing interest The authors declare no competing interests.

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