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Incorporating sustainability into product lifecycle management: a systematic literature review

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Abstract

Amidst environmental, regulatory, and societal pressures, integrating sustainability into Product Lifecycle Management (PLM) is key, evolving into Sustainable PLM (sPLM). This paper uses a systematic literature review and text-mining (C-value method) to categorise sPLM research into clusters, assess their integration at organisational levels, and evaluate the level's maturity. Findings highlight a gap in operational sPLM research. Future studies should bridge the gap between theory and industrial application, enhance sPLM operationalisation, and explore emerging technologies' impact on sPLM.

Keywords: product lifecycle management (PLM), sustainability, emerging IT, sustainability incorporation, research clusters

1. Introduction

The integration of sustainability into corporate practices, driven by environmental challenges, regulatory demands, and societal expectations, significantly impacts Product Lifecycle Management (PLM). While traditionally defined as managing products throughout their lifecycle, within this paper, emphasis is placed on a more systemic definition of PLM. Therefore, PLM is considered a technological solution encompassing various tools to facilitate collaboration among stakeholders, ensuring effective management of product lifecycles (De Oliveira et al., 2021). In the industry's effort to manage environmental impacts across product lifecycles, expanding PLM to include sustainability marks a pivotal change. Sustainable Product Lifecycle Management (sPLM) broadens PLM's focus to additionally manage sustainability-related data, information, and knowledge within the industrial value chain (Vila et al., 2015). This extension facilitates an integrated approach to sPLM processes and implies the sustainable configuration and operation of the PLM systems themselves, thereby necessitating a more holistic understanding of PLM frameworks, processes, and tools. When examining current industrial sustainability initiatives, it becomes evident that sustainability is becoming an integral part of corporate practices at different levels. Based on Herrmann (2010) and Lindow (2017), these levels can be visualised as interconnected tiers of a sustainability pyramid (see Figure 1).

Figure 1. Sustainability levels within the sustainability pyramid based on Lindow (2017, p. 39)

At the apex of this pyramid is the normative level (N) where the integration of sustainability principles into the foundational values of the organisation takes place. Progressing to the intermediate tier, the strategic level (S) becomes evident as a critical link. It entails the translation of normative sustainability principles into practical measures. The base of the pyramid represents the operational level (O), where sustainability is operationalised in value-creation activities across the entire lifecycle. Illustrating the multi-tiered integration of sustainability in corporate practices, the sustainability pyramid sets the context for a deeper exploration of the field of sPLM. To analyse the state of the art of research on PLM in the context of sustainability and to frame directions for future research, a systematic literature review (SLR) was conducted to address the following research questions (RQs): (RQ1) What are the emerging research clusters (RCs) in the context of sPLM? (RQ2) Which sustainability levels (SLs) do these RCs predominantly occupy and what is the technology readiness level (TRL) within these SLs? To answer RQ1 and RQ2, this paper is organised as follows: Section 2 introduces the SLR methodology. Section 3 outlines the literature findings related to the RCs in the context of sPLM. This includes an analysis of their placement in the sustainability pyramid and the evaluation of the SL's technological maturity. Section 4 presents the main conclusions and future research directions. Acknowledging Industry 4.0's role in enhancing economic sustainability within sPLM, and recognising the current complexities in directly associating social impact categories with product data, this paper will focus on environmental sustainability, with all references to sustainability herein confined to the environmental dimension.

2. Methodology

For the identification of relevant papers, the literature search was carried out on Scopus and Web of Science. The query, exemplified by the Scopus search string "AUTHKEY(("sustainab*") AND ("PLM" OR "product lifecycle management")) AND PUBYEAR > 2009 AND (LIMIT-TO (DOCTYPE, "cp") OR LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English") OR LIMIT-TO (LANGUAGE, "German")) emphasised author's keywords to exclude papers that only incidentally reference the specified terms. The scope encompassed conference proceedings, articles, and reviews from 2010 onwards. The query retrieved 60 records on Scopus and 35 on Web of Science (Last extraction of the databases: October 2023). After the elimination of 31 duplicates, the dataset contained 64 records. In the first step, the abstracts of these publications were examined to assess their relevance to the subject matter. Papers that did not exhibit a clear and explicit focus on environmental sustainability or a systemic approach to PLM were excluded from further analysis. This resulted in 55 papers that met the selection criteria for full-text screening. After the full-text screening process, another 12 publications without specific reference to environmental sustainability and/or PLM at the system level were excluded. While some papers contained mentions of PLM in their keywords or abstracts, it was observed that these references often pertained to the broader context of the product lifecycle as a whole, rather than specifically addressing the integration of sustainability at a PLM system level. The final stage within this review represented the analysis and classification of the remaining 33 papers that passed through the previously defined filters. The corresponding literature findings are presented in the following chapter.

3. Literature findings

To derive RCs in the context of sPLM (RQ1), NaCTeM's TerMine service (http://www.nactem.ac.uk/) was utilised, applying the C-value method for automatic recognition of multi-word terms (Frantzi et al., 2000). This method quantifies term importance beyond the scope of author-generated keywords, mitigating author bias and harnessing statistical relevance to detect emerging trends. The approach facilitates a more comprehensive understanding of the domain's research landscape, ensuring an objective and thorough analysis. Building on the initial extraction for each paper of the literature body, terms with a C-value of zero were discarded to ensure domain specificity and maintain data quality. The average C-value across each document determined the inclusion threshold, with only above-average terms considered for further analysis. The synonym consolidation merged terms, facilitating the co-occurrence analysis that led to identifying RCs based on thematic proximity. Figure 2 illustrates the resulting co-occurrence network, where each node represents selected terms, with their size reflecting the frequency of mentions after text mining and synonym consolidation in the sPLM literature. Nodes are colour-coded to represent the following RCs: sustainable business model management (sBMM), sustainable product development (sPD), sustainable materials management (sMM), sustainable production (sP), sustainable supply chain management (sSCM), sustainable knowledge management (sKM), circular economy (CE), and compliance and reporting (CR). The inclusion of the CE and CR enriches the sPLM scope by integrating key sustainability aspects alongside the primary engineering-focused themes. Central to the network, in orange, are terms that broadly pertain to sustainability and PLM, including cross-cluster methods and technologies such as life cycle assessment (LCA), ontology, and blockchain, underscoring their foundational role in the domain. Connections between nodes indicate thematic linkages, offering a visual exploration of the field’s interconnectedness.

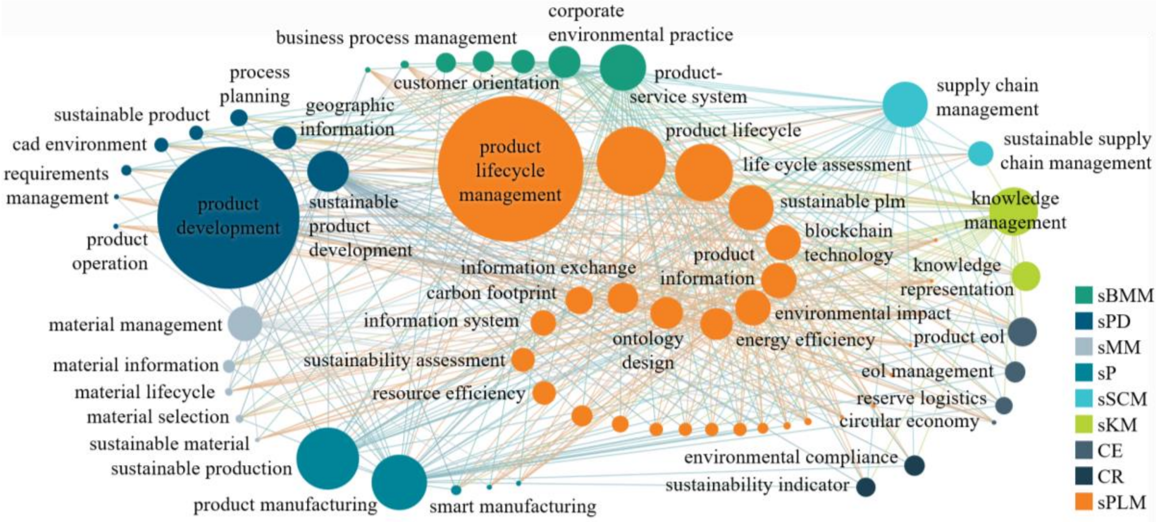

Figure 2. Research clusters based on co-occurrence of selected C-value terms

Table 1 categorises references into RCs, SLs, and TRLs, with TRL definitions provided in the table legend (Horizon 2020). The subsequent sections detail the literature findings within each RC identified in the SLR. When categorising the references, the primary consideration was the paper's central theme to assign it to the appropriate RCs, with the acknowledgement that some works intersect multiple RCs. The allocation to distinct SLs (Normative (N), Strategic (S), Operational (O)) was not always clear-cut, leading to the recognition of the intermediary levels N - S and S - O to accommodate the nuanced positioning of certain studies. Each reference was independently categorised by the authors, and results were compared to ensure consistency and enhance classification credibility.

Table 1. Results of literature body analysis

ID	Reference	RC	SL	TRL*
1	Armijo et al., 2015	sBMM	N	5
2	Belkadi et al., 2015	sP, sKM	S	2
3	Borsato, 2014	sKM	S	3
4	Buchert and Stark, 2018	sPD	O	4
5	Ch. et al., 2010	sPD, sKM	S - O	4
6	Eigner et al., 2013	sPD	S - O	2
7	Eigner et al., 2011	sPD	S	2
8	Helman et al., 2023	CR	N	3
9	Hribernik et al., 2011	CE	N	3
10	Leng et al., 2020	sP	S	1
11	Li et al., 2016	sBMM	N	3
18	Rosich et al., 2013	sSCM	N - S	2
19	Rubio et al., 2023	sP	S	2
20	Salonitis and Stavropoulos, 2013	sPD	S	3
21	Trotta, 2010	sPD	S	1
22	Vadoudi et al., 2014a	sPD	S	2
23	Vadoudi et al., 2017	sPD	S	3
24	Vadoudi et al., 2014b	sPD	S	2
25	Vadoudi and Troussier, 2015	sPD	S	3
26	Vieira et al., 2016	sPD, sP, sSCM	N	1
27	Vila et al., 2015	sPD, sP	S	2

ID	Reference	RC	SL	TRL*
12	Lin et al., 2018	sMM, CR	N - S	3
13	Marconi and Germani, 2017	sPD, CE	O	2
14	Marcos De Oliveira et al., 2021	sP	N	1
15	Nahkala, 2013	sPD	S	1
16	Papinniemi et al., 2014	sBMM	N	1
17	Quesada Díaz and Syberfeldt, 2022	CE	O	5
28	Villamil Velasquez et al., 2020	sBMM, CE	N	1
29	Witherell et al., 2013	sMM	S	2
30	Zhang et al., 2014	sPD, CR	N - S	5
31	Zhang et al., 2022	sSCM, sKM	S	3
32	Zhao et al., 2015	sP, CR	N - S	4
33	Zhao et al., 2012	sP, CR	N - S	4

* TRL 1: Basic principles observed (e.g. SLR, survey), TRL 2: Technology concept formulated (e.g. conceptual framework), TRL 3: Experimental proof of concept (e.g. validated conceptual framework), TRL 4: Technology validated in academic environment, TRL 5: Technology demonstrated in relevant environment

3.1. Sustainable business model management (sBMM)

sBMM is a strategic approach to reconfiguring and aligning business models with sustainability goals. It involves shifting from traditional, ownership-based models to service-oriented paradigms that prioritise sustainability, resource efficiency, and environmental responsibility. sBMM seeks to create long-term value by integrating sustainability principles at the normative level into every aspect of business operations. In the examined literature, four papers pertain to the RC of sBMM, with one of them encompassing aspects of CE. The TRL of these sBMM-focused papers spans from 1 to 5, with two at the level of observed basic principles (SLR, survey). Li et al. (2016) reached TRL 3 with an experimental proof of concept, while Armijo et al. (2015) validated their concept in an industrial setting, attaining TRL 5. Armijo et al. (2015) present the results of the project EPES (Eco Process Engineering System), which provides information and communication technology (ICT) solutions to generate services aimed at improving the performance of highly customised industrial processes, products and services during their lifecycle. The EPES platform integrates modelling and simulation services into business processes, facilitating sustainable business operations, communication, knowledge management, and multi-objective decision-making within an extended enterprise. Li et al. (2016) propose a concept of product service lifecycle management within the context of sustainable development and analyse the benefits of the combination of PSS and PLM. By further elaborating on the topic of customer-centric businesses, Papinniemi et al. (2014) elicit requirements for PSS in customer-centric industries that can be utilised in companies planning and developing their product-service offering on a business strategy level. They introduce PSS as a means to enhance sustainability and traceability, emphasising the shift toward customer orientation and the imperative for changes in information management practices driven by environmental sustainability and legislative changes. Villamil Velasquez et al. (2020) review the current literature on the role of ICT in enabling CE-focused business models and emphasise ICT's potential to facilitate collaboration in a circular economy.

3.2. Sustainable product development (sPD)

sPD within sPLM encompasses the holistic incorporation of sustainability principles from the onset of design, ensuring that sustainability impacts are considered throughout a product's lifecycle. Within the corpus of sPLM research, 15 out of 33 papers specifically address sPD, predominantly focusing on strategic sustainability by converting normative principles into actionable, operational measures. The studies are distributed across a TRL spectrum from 1 to 5, with the majority positioned at the stage where technology concepts have either been formulated or subjected to experimental validation. Within the research landscape, 5 of the sPD-centric papers concurrently contribute to other RCs, including sKM, sP, sSCM, CE, and CR. Zhang et al. (2014) evaluate PLM maturity models and functionalities, integrating a sustainability dimension that encompasses PLM components such as 'New product development & skills' advocating for a comprehensive and integrated approach to sustainability within PLM systems. Vieira et al. (2016) examine the dynamics of managerial aspects of sPLM, underscoring how decisions in sPD are pivotal in shaping production systems and supply chains. Eigner et al. (2011) present a sustainability monitoring framework that utilises the integrated sustainability triangle to systematically address the complex aspects of sustainability management. Salonitis and Stavropoulos (2013) introduce a methodology that integrates CAD/CAPP/CAM with PLM to assess the sustainability of different process plans. Vila et al. (2015) reinforce the managerial perspective by proposing a Green PLM framework that highlights the essential role of sPD in minimising lifecycle impacts and emphasise the necessity for research that connects design with end-of-life (EoL) strategies. Building on this integrative approach, Marconi and Germani (2017) propose an EoL-oriented framework featuring a conceptual Design for Disassembly tool to facilitate informed decision-making that addresses potential EoL issues proactively. Following the theme of informed decision-making in PLM, Buchert and Stark (2018) introduce an Engineering Decision Support System (EDSS), an operational tool that aids in the assessment and comparison of product concepts in early design. Ch. et al. (2010) leverage sKM in PLM underlining the implementation of feedback cycles that channel information from product use back into development processes, thereby identifying opportunities for improvement and optimisation in subsequent product generations. Nahkala (2013) emphasises the strategic application of Design for Environment (DfE) to synergise the phases of the product lifecycle, aiming to improve overall sustainability outcomes. Expanding on the DfE focus, Trotta (2010) analyses the incorporation of tools like DfE and LCA into sPLM to facilitate sPD. Eigner et al. (2013) propose an eco-efficiency assessment within PLM that refines product and process models to evaluate energy and resource efficiency. Building on the refined product model concept, Vadoudi et al. (2014a; 2014b; 2015; 2017) support the incorporation of geographical and environmental data into PLM, facilitating the assessment of sustainability impacts at the territorial level and contextualising product sustainability on a global scale.

3.3. Sustainable materials management (sMM)

In the context of sPLM, sMM is essential for ensuring materials are selected and managed throughout their lifecycle. Of the 33 papers reviewed, only two directly address this cluster. Lin et al. (2018) emphasise the importance of integrating LCA into PLM for environmentally informed material selection. They introduce the concept of a Bill of Regulation (BOR) in PLM systems for real-time regulatory updates, which also intersects with the RC of CR. In a parallel discourse, Witherell et al. (2013) discuss synthesising material information across lifecycle stages, reviewing the existing standards and suggesting a more comprehensive sustainability-focused integration infrastructure. Both papers primarily focus on the strategic SL and offer conceptual frameworks at TRL 2-3.

3.4. Sustainable production (sP)

In sPLM, sP refers to strategies that emphasise minimal environmental impacts and optimise resource efficiency during the production phase. Of the total literature body, 8 papers can be categorised under the sP cluster, with several exhibiting thematic overlaps with the sSCM, sPD, CR, and sKM clusters. Beginning with foundational research, Belkadi et al. (2015) propose a global approach for the definition of a knowledge-based PLM framework supporting resource optimisation in production systems through collaboration and knowledge-sharing. On a related note, Zhao et al. (2012) and Zhao et al. (2015) introduce a PLM information model and outline a framework for energy simulation to assess sustainability implications in manufacturing. With regard to Industry 4.0-associated technologies, Leng et al. (2020) investigated the application of blockchain within manufacturing information systems, emphasising its capability to streamline and unify product data sharing. Complementing this, Marcos De Oliveira et al. (2021) discussed the incorporation of Industry 4.0 technologies in PLM, underscoring the importance of real-time data processing for sustainability improvements. Rubio et al. (2023) introduce a framework leveraging a Digital Twin of an industrial facility to manage carbon emissions within the aerospace sector. Similarly centred on the aerospace sector, Vieira et al. (2016) examine the integration of managerial facets such as sPD, sP, and sSCM into sPLM, highlighting that sP's primary significance lies in fostering the advancement of eco-friendly processing technologies. On a parallel strategic front, Vila et al. (2015) propose a Green Product and Processes Lifecycle Management framework stressing the need for methods, tools, and knowledge required to mitigate impacts throughout the product lifecycle. Three-quarters of the references within the sP cluster possess a technological maturity rooted in the observation of basic principles or the formulation of technology concepts. Only two of these references have undergone validation in an academic setting. Notably, all these references align with the normative or strategic levels of the sustainability pyramid, signifying a gap in translating sustainability principles into actionable measures.

3.5. Sustainable supply chain management (sSCM)

Within the field of sPLM, sSCM is a critical component that seeks to incorporate sustainability throughout the product lifecycle enhancing cooperation among partnering companies to achieve sustainable performance and optimise material and information flows throughout the value chain. Among the 33 papers reviewed, three specifically focus on the sSCM cluster, with two of these also encompassing aspects of sKM, sPD, and sP. Rosich et al. (2013) present a methodology designed to help enterprises utilise PLM data to enhance the sustainability of their supply chain performance. This approach involves selecting sustainable indicators, identifying underlying causes, formulating corrective actions, and implementing these actions based on targeted data from PLM systems, ultimately improving the sustainability of supply chain operations. Zhang et al. (2022) emphasise that utilising an ontology-based knowledge representation can streamline the development of PLM software. This is achieved by enhancing multidisciplinary knowledge sharing and integration, particularly in collaborative tasks like the assessment of supply chain sustainability. Focusing on the aerospace industry, Vieira et al. (2016) discuss the dynamics of integrating managerial elements such as sPD, sP and sSCM into sPLM. They emphasise that a truly sustainable production system requires a sustainable supply chain and that the realisation of sustainable products is closely tied to the influence of suppliers on the design's sustainability. The reviewed studies span a range of technological maturity, from observed basic principles at TRL 1 to evaluated frameworks at TRL 3. They also encompass various SLs, from integrating foundational values (N) to translating principles into practical measures (S).

3.6. Sustainable knowledge management (sKM)

In the context of sPLM, sKM is the process of utilising knowledge to promote and achieve sustainability throughout the product lifecycle. Of the total literature body examined, four papers pertain to the RC of sKM, with two of these also intersecting with sPD, sP, and sSCM. Ch. et al. (2010) present an advanced knowledge management concept, emphasising its role in PLM, particularly in decision-making and quality management. Expanding on knowledge representation, Borsato (2014) proposes a reference ontology to overcome interoperability issues between engineering applications and facilitate the use of sustainability data throughout a product’s lifecycle. In a similar vein, Zhang et al. (2022) examine an ontology-based method for PLM software development focused on supply chain sustainability. Through their example application, they discuss how implementing ontologies to represent knowledge in PLM applications, especially for collaborative tasks like sustainability assessment, can support the efficiency of data sharing and integration. Offering a distinct perspective, Belkadi et al. (2015) propose a global approach for defining a knowledge-based PLM framework that combines knowledge systems with PLM to optimise resource consumption in production systems. This involves harnessing varied data sources, organising them efficiently, and enhancing information sharing using PLM approaches for the entire production process. Overall, the studies range from formulated technology concepts to those that have been validated experimentally or in an academic environment (TRL 2-4). The majority is situated on a strategic level, translating sustainability principles into practical measures.

3.7. Circular economy (CE)

In the context of sPLM, CE promotes a systematic approach to integrating sustainability and circularity, aiming to optimise resource utilisation and minimise environmental impact throughout a product's lifecycle. Of the 33 papers examined, four are categorised within the CE cluster, with two exhibiting intersections with sPD and sBMM. Hribernik et al. (2011) explore the potential of intelligent products in enhancing closed-loop reverse logistic processes. Their research indicates that intelligent products can support the integration of various actors across different lifecycle stages. In parallel, Marconi and Germani (2017) proposed an EoL-oriented framework integrating a Design for Disassembly tool, a disassembly knowledge database to support the redesign phase, and a collaborative EoL platform for the sharing of relevant data and materials. Their findings emphasise the potential advantages of adopting circular business models when there is effective inter-organisational collaboration and data sharing. From a technological perspective, Quesada Díaz and Syberfeldt (2022) assessed the role of Augmented Reality (AR) in the remanufacturing processes. Their work highlights the benefits of combining AR with PLM for remanufacturing within a CE context. Villamil Velasquez et al. (2020) analysed the influence of ICT in enabling the transition to CE based on PLM. Their study underlined the significance of ICT in redefining product lifecycles and promoting innovative business models. Across these studies, the TRL ranged from 1 to 5, encapsulating both early-stage reviews and concepts as well as more mature technological implementations Predominantly, the studies were centred on the normative level, highlighting a commitment to incorporating sustainability principles within organisational frameworks.

3.8. Compliance and reporting (CR)

CR in the context of sPLM emphasises the alignment of PLM practices with environmental regulatory standards. It reflects the integration of sustainability principles throughout the entire lifecycle, ensuring products meet both organisational goals and external regulatory requirements. Of the 33 papers analysed, five can be assigned to the CR cluster, with the majority exhibiting overlaps with other RCs. Helman et al. (2023) provide a systematic method to select and evaluate sustainability indicators specific to different phases of automotive lifecycle management, aiming to guide the industry towards sustainable development by identifying relevant indicators for each product lifecycle phase. Lin et al. (2018) present an approach that deals with material and substance compliance within PLM in a complex value chain. Zhang et al. (2014) identified 'Quality & compliance' as a crucial PLM component demanding improvement. Meanwhile, Zhao et al. (2012) and Zhao et al. (2015) investigate the integration of PLM within sP and introduce a PLM information model, designed to systematically evaluate environmental regulations and green indicators for sustainable products, utilising the Unified Modelling Language (UML) methodology. The TRL of the analysed papers ranged from 3-5, indicating the transition from experimental designs to real-world applications of CR in sPLM. Predominantly, these papers positioned themselves at the normative level, showcasing the evolving emphasis on embedding CR principles directly into organisational strategies and workflows.

3.9. Summary

Figure 3 visually quantifies and connects the derived RCs to their respective SLs, and in turn, maps these SLs to the corresponding TRLs. sBMM (n = 4) is solely aligned with the normative level, suggesting the integration of sBMM-related sustainability topics into core organisational values. sPD (n = 15) is predominantly located within the strategic level, but also touches on the normative and operational levels, indicating a comprehensive approach to sustainability integration. sMM (n = 2), sP (n = 8), and CR (n = 5) have a presence across the normative and strategic levels, respectively, reflecting a focus on strategy formulation and implementation based on sustainability principles.

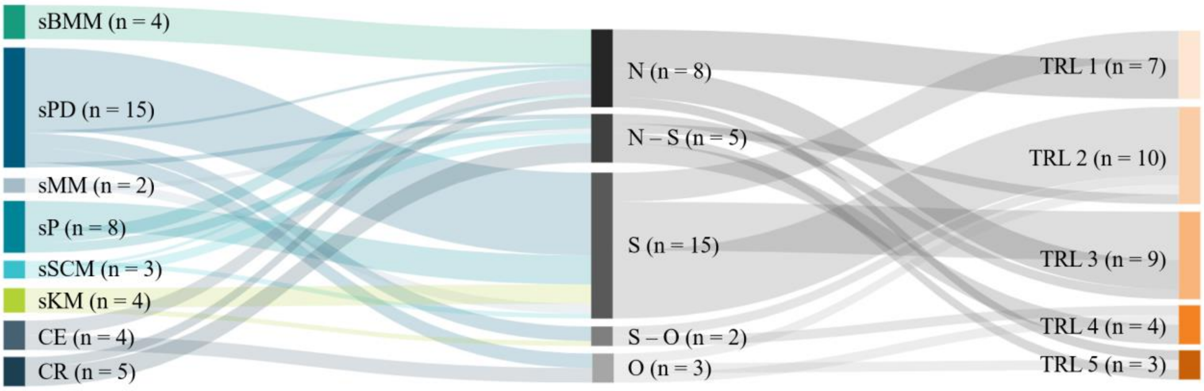

Figure 3. Distribution and relationships between RCs, SLs and TRLs

sSCM (n = 3) and sKM (n = 4) also concentrate on the strategic level, with some extension to the intermediary level between strategic and operational sustainability integration for sKM, pointing to an interest in applying strategic sustainability concepts. CE (n = 4) has studies allocated equally between the normative and operational levels, indicating a balanced approach, with efforts to both understand and embed CE principles at the level of core organisational values and operational processes. In terms of technological maturity, the strategic level spans TRLs 1 to 3, suggesting research is concentrated on early-stage technology development. The normative level, while less represented, extends up to TRL 5, indicating some normative concepts have reached advanced stages of demonstration. The presence of the operational level across TRLs 2 to 5, despite its limited representation, suggests that while the application of sustainability practices at this level is not as widespread, the existing studies indicate a progression from conceptual frameworks to testing and application in relevant operational settings.

4. Conclusion and future research directions

The literature findings indicate a concentration of sPLM research within the normative and strategic levels, pointing to a relative scarcity of studies with an operational focus. The literature predominantly resides at the initial stages of technological maturity (TRL 1-3), with a minority of studies reaching validation in academic or relevant environments. The lack of mature sPLM concepts in the literature might not accurately represent contemporary technological advancements in practice. Due to their proprietary nature and confidentiality, advanced sPLM applications are often not subject to scientific literature. This underscores the necessity for a broader methodology in assessing the current state of the art, incorporating elements such as technology assessments and industrial surveys, to achieve a more precise understanding of current sPLM applications. It is also important to acknowledge that the selection of databases, search strings, and the restriction to the author's keywords introduces limitations to the literature findings, potentially resulting in a partial or biased representation of research on the subject matter. The growing demand for product-related sustainability and circular economy capabilities necessitates companies to assume greater responsibility over their products' entire lifecycle, a transition that is effectively supported by the shift from traditional PLM to sPLM. In addressing RQ1 and RQ2, the SLR’s novelty lies in its methodical derivation of sPLM-centric RCs, the identification of their primary SLs, and the alignment of these SLs with their respective TRLs. This research offers valuable insights for both researchers and practitioners by elucidating which sustainability-related topics, represented as distinct RCs, necessitate attention at specific SLs, and might ultimately help to point towards future research directions. Recognising the SLR’s findings as a starting point, emphasises the need for future research focusing on the following pending questions: (1) How can the paper’s findings be further developed and incorporated into a theoretical framework for sPLM? (2) What are the current barriers to the practical application of sPLM concepts in various industrial contexts and how can they be mitigated? (3) How can sustainability practices be more effectively operationalised within each RC and how are emerging technologies influencing sPLM’s evolution? (4) How can SMEs be adequately supported in adopting sPLM practices, and what are their unique requirements regarding resources, technology adoption, and sustainability integration?

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