
**CIRCULAR PRODUCT DEVELOPMENT IN SUPPLY CHAINS:
A STRUCTURED REVIEW OF CONTRIBUTIONS,
LIMITATIONS AND CONSEQUENT GAPS**

**DESENVOLVIMENTO DE PRODUTOS CIRCULARES EM
CADEIAS DE ABASTECIMENTO: UMA REVISÃO
ESTRUTURADA DAS CONTRIBUIÇÕES, LIMITAÇÕES E
CONSEQUENTES LACUNAS**

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Abstract - The transition from a linear production model towards a circular economy (CE) requires systemic changes in the way products, processes and supply chains are designed and managed. Rather than merely promoting the recovery of products and materials at the end of their useful life, circularity should be embedded from the early stages of product development, with the aim of preserving value, reducing resource consumption, and enabling cycles of use, reuse, repair, remanufacturing and recycling. In this context, this paper presents a structured analysis of the literature on the integration of CE principles into product development and supply chain management, seeking to identify existing advances, approaches and research gaps. A literature review was conducted using the IEEE Xplore, Scopus and Web of Science databases, combining concepts related to the circular economy, product development and supply chains. The results demonstrate significant advances in circular design, CE-oriented frameworks and approaches for supply chain integration. However, the literature remains fragmented. Product development is frequently restricted to design or redesign, while circularity indicators tend to prioritise resource-use efficiency, material recovery and waste reduction, at the expense of preserving and maximising product value throughout its life cycle. Furthermore, the identified frameworks and tools are often context-specific and are rarely empirically validated as broadly applicable classification methods. Accordingly, a significant research gap is identified: the absence of an integrated, clear, and product-oriented classification logic capable of relating circularity strategies, product development stages and implications across the supply chain. This gap reinforces the need for a systematic,

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consistent and comparable approach to guide the development of circular products across different contexts.

Keywords: *Circular economy. Circular product development. Supply chain management. Classification framework.*

Resumo – *A transição de um modelo de produção linear para uma economia circular (EC) exige mudanças sistêmicas na forma como produtos, processos e cadeias de suprimentos são projetados e gerenciados. Mais do que promover a recuperação de produtos e materiais ao final de sua vida útil, a circularidade deve ser incorporada desde as etapas iniciais do desenvolvimento de produtos, visando preservar valor, reduzir o consumo de recursos e viabilizar ciclos de uso, reutilização, reparo, remanufatura e reciclagem. Nesse contexto, este artigo apresenta uma análise estruturada da literatura sobre a integração dos princípios da EC ao desenvolvimento de produtos e à gestão da cadeia de suprimentos, buscando identificar avanços, abordagens e lacunas existentes. Foi realizada uma revisão da literatura nas bases IEEE Xplore, Scopus e Web of Science, relacionando economia circular, desenvolvimento de produtos e cadeia de suprimentos. Os resultados evidenciaram avanços em design circular, frameworks orientados à EC e abordagens de integração da cadeia de suprimentos. Entretanto, a literatura permanece fragmentada. O desenvolvimento de produtos é frequentemente limitado ao design ou redesign, enquanto os indicadores de circularidade priorizam eficiência no uso de recursos, recuperação de materiais e redução de resíduos, em detrimento da preservação e maximização do valor do produto ao longo de seu ciclo de vida. Além disso, frameworks e ferramentas são frequentemente específicos a determinados contextos e raramente validados empiricamente como métodos de classificação amplamente aplicáveis. Assim, identifica-se uma lacuna relevante: a ausência de uma lógica de classificação integrada, clara e orientada ao produto, capaz de relacionar estratégias de circularidade, etapas do desenvolvimento de produtos e implicações na cadeia de suprimentos. Essa lacuna reforça a necessidade de uma abordagem sistemática, consistente e comparável para orientar o desenvolvimento de produtos circulares em diferentes contextos.*

Palavras-chave: *Economia circular. Desenvolvimento de produtos circulares. Gestão da cadeia de suprimentos. Framework de classificação.*

I. INTRODUCTION

The prevailing economy model based on linear production (characterized by rapid resource throughput) is a rock in the way of becoming sustainable societies, and it has shown to be a difficult theme to be addressed (KIRCHHERR et al., 2018). The motives being that linear models are the dominant industry system since the beginning of how it is known today (ELLEN MACARTHUR FOUNDATION, 2015): companies take natural resources, transform into consumable products, sell to consumers, who will use and discard to buy a new one, rewinding the process. This take-make-dispose logic creates inefficient resource use, minimal recycling and material recovery, and environmental constraints (GOVINDAN; HASANAGIC, 2018); its persistence creates tension between economic activity and the preservation of material value. The challenge, however, is not limited to waste treatment: closing material loops becomes more difficult as product complexity and supply chain length increase (WORLD ECONOMIC FORUM; ELLEN MACARTHUR FOUNDATION; MCKINSEY & COMPANY, 2014). Consequently, circular economy (CE) is herein understood as a regenerative economic logic that seeks to eliminate waste and pollution, keep products and materials in use and regenerate natural systems (ELLEN MACARTHUR FOUNDATION, 2024; ELLEN MACARTHUR FOUNDATION; UNITED NATIONS, 2021).

Such transition, from a predominantly bigger-better-faster-safer economy pattern (STAHEL, 2016), affects the entire product system. A product is not isolated from the supply chain that sources its materials, manufactures its components, distributes it, supports its use and manages its post-use flows (GEISSDOERFER et al., 2017; HANDFIELD; NICHOLS JR, 1999). Truthfully, product development is similarly broader than the drawing of a product: it is a collaborative and interdisciplinary process through which products are conceived and launched to meet user and organisational needs (JONKER; GOMSTYN, 2023). Circularity depends on the interaction among product decisions, process decisions and supply chain decisions rather than on a single design intervention. Thus, CE emerges as an alternative to promote sustainable production, as well as a response to unsustainable chains, endorsing a take-make-use plan (ELISHA, 2020).

Furthermore, the need for this integration is reinforced by the barriers identified in the literature. CE implementation is constrained by legislative, market, financial, technological, organisational, informational, cultural and coordination barriers (TRIGUERO; MORENO-MONDEJAR; SÁEZ-MARTÍNEZ, 2023). Also, organisations face a practical problem before implementation begins: the meaning of CE (KIRCHHERR et al., 2023), the point at which its principles should enter product development, and the evidence needed to demonstrate progress are not sufficiently clear (GEISSDOERFER et al., 2017; PARCHOMENKO et al., 2019; VAN LOON; DIENER; HARRIS, 2021). A company may recognize the need for circularity while lacking a common language for classifying products, comparing alternatives or communicating the consequences of its decisions.

In this idealisation, the CE supports advancement in at least 12 Sustainable Development Goals (SDGs), however only 20% of companies have actually built circular supply chains, which are claimed to be the “key unit of action” (ELLEN MACARTHUR FOUNDATION, 2021c). Business still see CE only as a sustainability issue (WORLD ECONOMIC FORUM; BAIN & COMPANY; UNIVERSITY OF CAMBRIDGE, 2025b), not a ripple effect one, which has potential to be beneficial for other contexts beyond the environment. Contextually, the issue is especially relevant to progress towards SDGs 9 and 12. While SDG 9 emphasizes sustainable industrialisation, technological capability and innovation, SDG 12 focuses on responsible production, waste prevention, reuse, reporting and technological capacity (ELLEN MACARTHUR FOUNDATION, 2021c).

Against the aforementioned background, this research aims at making known the current state of relevant literature in the field and answer the following research question: ***What contributions, limitations and unresolved methodological needs emerge from the literature connecting circular economy, product development and supply chains?*** Its purpose is to identify the main works, with their respective bibliometric data and content analysis, then, afterword, discuss its contributions and limitations, for, at last, corroborate in a research gap for future study.

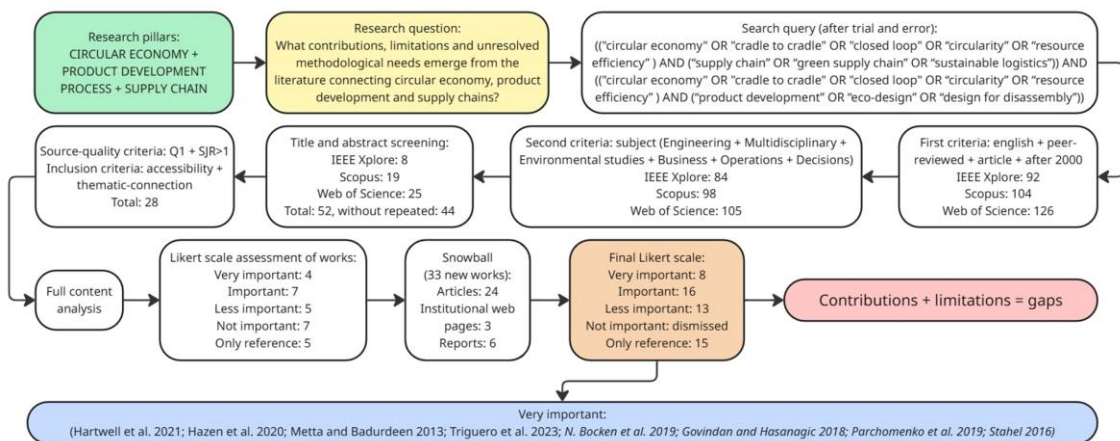
The remainder of this article is organized as follows: Section II describes the adopted methodology for the research, with the procedure, systematic literature review and content analysis; Section III displays the contributions followed by Section IV with the limitations; Section V discusses and synthesises the findings; and Section VI concludes the study with final considerations and future exploration directions.

II. METHODOLOGY

2.1 – Review procedure

The review adopted an exploratory, structured literature approach with qualitative content analysis. Its organising pillars were *circular economy* (CE), *product development* and *supply chain*. These pillars were expanded through related terms, including circularity, resource efficiency, cradle-to-cradle, closed loop, sustainable logistics, eco-design, design for disassembly, among others (shown in Figure 1). The procedure follows a general integrative orientation: rather than treating CE and the pillars as separate subjects, it organises the literature around their points of connection, which includes their focus, problems, solutions, tools and settings, for example. Figure 1 represents in a flowchart the main steps of the review procedure, which will be explained as follows.

Figure 1 – Flowchart of the review procedure steps.



Source: Authors, 2026.

2.2 – Systematic literature review

Three scientific data bases were used for literature research: IEEE Xplore, Scopus and Web of Science, mainly because the problem addressed is engineering-oriented with multidisciplinary implications and the aforementioned bases are key enablers. The initial criteria required English language, peer-reviewed articles published after 2000. The final Boolean search query combined pillar-related terms and it returned 92 records in IEEE Xplore, 104 in Scopus and 126 in Web of Science. After subject-area filters, the totals were 84, 98 and 105, respectively. Title and abstract screening retained 52 relevant records, which became 44 after removing duplicates.

Then, the review applied source-quality (Q1 and SJR>1), accessibility and thematic-connection criteria. Finally, 28 articles were retained for full-text content analysis. The studies were classified by relevance in a Likert scale: *very important*, *important*, *less important*, *not important* and *only reference*, which has its criteria described in Table 1.

Forward citation snowballing added 24 articles, three institutional webpages and six reports (texts in *italic* at Table 2), resulting in 33 additional works. After the same relevance assessment, the final base contained 52 works in the previous categories: eight *very important*, 16 *important*, 13 *less important* and 15 *only reference*. Table 2 displays the works in each assessment category. The *not important* category was dismissed from here forward.

Table 1 – Rating Likert scale and respective description.

Assessment scale	Description
Very important	Central and systematic integration of the pillars throughout the whole work.
Important	Clear and consistent integration of the pillars into the work, although not central to the study.
Less important	Partial development of the pillars, with some conceptual or empirical integration, but not a primary focus.
Not important	Superficial mention, with no meaningful development or connection to the pillars.
Only reference	Brief discussion, with limited depth and relevance to the analysis.

By conducting the literature review in this form, first with databases search and secondly with the snowballing process, it ensures both theoretical/academic and practical/institutional views, guaranteeing broader information capture (HAZEN et al., 2020). Moreover, it helps with understanding scholars' and organizations' needs, challenges, and stimulates proposing far-reaching ideas.

Table 2 – Likert scale of the filtered articles.

Classification	No. papers	Author
Very important	8	(BOCKEN et al., 2019; GOVINDAN; HASANAGIC, 2018; HARTWELL; MACMILLAN; OVEREND, 2021; HAZEN et al., 2020; METTA; BADURDEEN, 2013; PARCHOMENKO et al., 2019; STAHEL, 2016; TRIGUERO; MORENO-MONDÉJAR; SÁEZ-MARTÍNEZ, 2023)
Important	16	(BOCKEN et al., 2016; BURKE; ZHANG; WANG, 2023; CAZERI et al., 2024; CIRCLE ECONOMY, 2021; DE JESUS et al., 2018; ELLEN MACARTHUR FOUNDATION, 2021c; JENSEN; LAURSEN; HAASE, 2021; JUGEND et al., 2024; KHARAYAT; GUPTA, 2025; MENDOZA et al., 2017; MOSTAFAYI DARMIAN et al., 2025, 2026; PINHEIRO et al., 2018; SASSANELLI et al., 2020; URAIN; EGUREN; JUSTEL, 2022; WORLD ECONOMIC FORUM; ELLEN MACARTHUR FOUNDATION; MCKINSEY & COMPANY, 2014)
Less important	13	(AGUIAR; JUGEND, 2022; DEN HOLLANDER; BAKKER; HULTINK, 2017; DIAZ; REYES; BAUMGARTNER, 2022; ELLEN MACARTHUR FOUNDATION, 2025; FRANZÒ et al., 2021; HROUGA; MICHEL, 2023; ISSA et al., 2015; KARAGIANNOPOULOS; MANOUSAKIS; PSOMOPOULOS, 2024; KAZANCOGLU et al., 2020; KIRCHHERR et al., 2023; LIEDER; RASHID, 2016; LIU et al., 2019; QURESHI et al., 2025)
Not important	9	(ABDULRAHMAN; SUBRAMANIAN, 2024; COTTAFAVA; RITZEN, 2021; CRADLE TO CRADLE INSTITUTE, 2026a, 2026b; DALHAMMAR, 2016; DWIVEDI; PAUL, 2022; ELLEN MACARTHUR FOUNDATION, 2021a, 2021b; GEISSDOERFER et al., 2017; KHAN; MUBARIK; PAUL, 2022; MORENO et al., 2016; VAN LOON; DIENER; HARRIS, 2021; VELLESLU et al., 2023; WORLD ECONOMIC FORUM; BAIN & COMPANY;

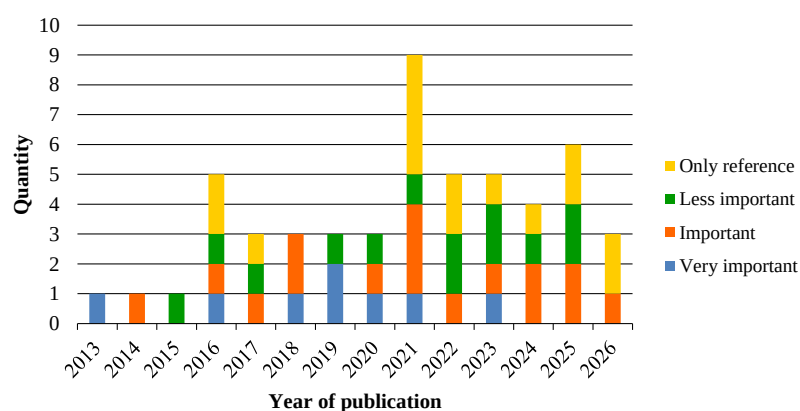
2.3 – Content analysis

Figure 2 shows the year of publication of the works with the Likert scale colour coding as well. It is important to notice that institutional web pages and reports were added to the counting, even though the inclusion and exclusion criteria for them were not defined. They are, however, validated sources with verified organizations behind it, which justifies the integration.

It can be noted in Figure 2 that since year 2016 the topics CE, product development and supply chain gained attention across academia and research institutions, with the last six years accounting for more publications than the former. Also, even though the categories were strictly based on empiric choices, it is to notice that the most part of *very important* works are in the prior years, meaning, perhaps, that this works are already accepted by the scientific community and, consequently, used more as a reference, which led to their position.

Regarding the works' source, Table 3 discloses each one, with 24 in total. Journal of Cleaner Production was prevalent among works in this review, responsible for 12 out of 52 works. Published by Elsevier, “is an international, transdisciplinary journal focusing on Cleaner Production, Environmental, and Sustainability research and practice” (JOURNAL OF CLEANER PRODUCTION), clarifying its relation to CE, product development and supply chain (the pillars of the present study).

Figure 2 – Distribution of works by year of publication and Likert scale.



Source: Authors, 2026.

Table 3 – Distribution of works by source and Likert scale.

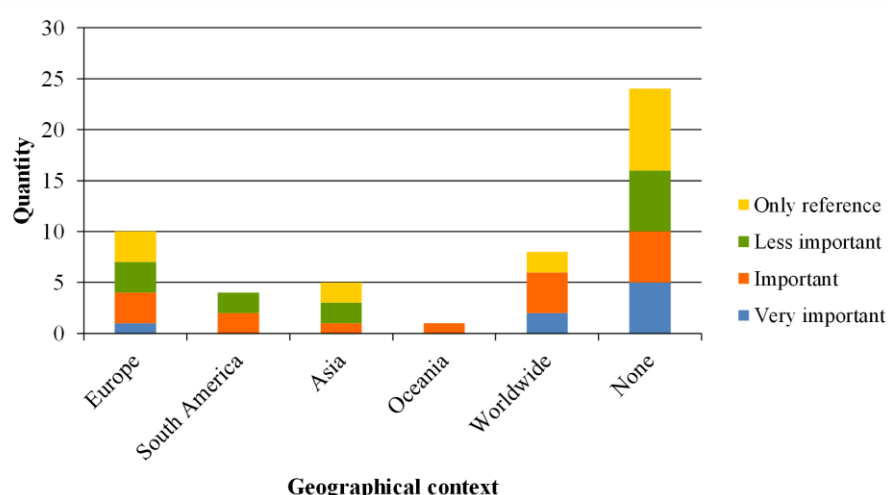
	Very important	Important	Less important	Only reference	Total
Benchmarking: An International Journal				1	1
Business Process Management Journal			1		1
Business Strategy and the Environment		2	2	1	5
Circle Economy		1			1
Computers in Industry		1			1

	Very important	Important	Less important	Only reference	Total
<i>Cradle to Cradle Institute</i>				2	2
<i>Ellen MacArthur Foundation</i>		1	1	2	4
IEEE Transactions on Consumer Electronics			1		1
IEEE Transactions on Engineering Management	1				1
International Journal of Logistics Management	1				1
International Journal of Production Research	1	1			2
International Journal of Sustainable Development and World Ecology		1			1
Journal of Cleaner Production	1	3	3	5	12
Journal of Industrial and Production Engineering		1			1
Journal of Industrial Ecology		1	1		2
Management Decision		1			1
Nature	1				1
Omega (UK)		1			1
Production Planning & Control		1			1
Resources, Conservation and Recycling	1		2	1	4
Sustainability MDPI	1			1	2
Sustainable Development	1		1		2
Transportation Research Part E: Logistics and Transportation Review			1		1
<i>World Economic Forum</i>		1		2	3
TOTAL	8	16	13	15	52

*Names in italic are sources from web pages, reports and white papers.

Furthermore, Figure 3 specifies the geographical context each work's methodology was developed. Four areas were cited: Europe, South America, Asia and Oceania; worldwide encompass works that cited more than one region (or white papers and reports); none refers to papers that did not cite a specific country (this category cover institutional web pages, systematic reviews and conceptual developments without applied research).

Figure 3 – Distribution of works by geographical context and Likert scale.



Source: Authors, 2026.

Content analysis of the screened papers was dissected using Govindan and Hasanagic (2018), and Pinheiro et al. (2018) presentation, which recorded focus, methodology and industry setting; but, with category changes (Table 4). In these authors' publications only one box could be ticked per work; herein, however, given the multidimensional characteristics of the works analysed, one or more boxes per work were marked. The colours represent the Likert scale; works' names in *italic* are web pages, reports or white papers; last column accounts for the amount of boxes marked for each category.

Furthermore, Table 5 scrutinise the *very important* works category. It accounts for identifying columns, such as title, year and author from the publications, with content analysis as well: problem, proposed solution, tool indicated for achieving the solution and research gap. In this, the most important column is the research gap one, because it makes explicit the room for improvements, and, consequently, the importance of this study. Also, it is relevant to address that the research gap was either identified by the authors of the works themselves or by this paper's authors. This structure distinguishes what each paper contributes from what it leaves unresolved.

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	Very important
	Important
	Less important
	Only reference
Abc	Articles
Abc	Web pages, reports and white papers

Table 5 – Analysis of the category of highly important works.

Title	Author	Year	Problem	Solution	Tool(s) indicated for achieving the solution	Research gap
A Review and Evaluation of Circular Business Model Innovation Tools	Bocken et al.	2019	Operationalize the CE concept focusing on the business level: which are the circular business models tools?	Quality criteria for examination and selection of circular business models innovation (CBMI) tools; checklist for CBMI tool development.	Screening and selecting of tools: purpose and type, characteristic and form, use and validation.	Majority of tools are (semi-) qualitative in nature and focus on the ideation and design phase; they also lack comprehensive use descriptions.
A systematic review on drivers, barriers, and practices towards circular economy: a supply chain perspective	Govindan and Hasanagic	2018	Which drivers, barriers and practices influence the CE implementation in the SC context, from the stakeholder point of view? How are they related?	13 drivers, 34 practices and 39 barriers were identified, both internal and external, with subject clusters within them.	Government need to make laws, indicators and policies for organisations to follow; stakeholders need to design with CE point of view from the beginning and use environmentally friendly technologies; society need awareness of consumers.	One of the barriers was <i>CE framework issues</i> : lack of successful CE in SC implementation, SC needs are not included in the frameworks and other solutions may be more favourable than CE in SC. However, their own framework was not tested, nor investigated, which adds to the perceived barrier.
Circular economy of façades: Real-world challenges and opportunities	Hartwell et al.	2021	How the stakeholders perceive recovery of façade products?	Advancement on circular design depends on: awareness, environmental value, take-back infrastructure, technological separation methods, communication, design trade-offs and holistic legislation.	Reuse, design for disassembly, recovery, reconditioning, standard design, R&D and recycling.	Designing for reuse would need to be quantified to justify it; recycling and reuse obligations should be product-specific; stakeholders are more preoccupied with the perception of <i>old materials</i> by clients.
Supply chain management for circular economy: conceptual framework and research agenda	Hazen et al.	2020	How SC processes can support the successful implementation of CE?	Change customers' perceptions and behaviours, product longevity, co-opetition, servitization, digitalization and dematerialization.	Understand the eight core processes of SC from the five CE principles point of view.	Addresses the <i>product development</i> process of SC and how it needs multidisciplinary collaboration, but mentions mostly the (re)design process.
Integrating Sustainable Product and Supply Chain Design: Modeling Issues and Challenges	Metta and Badurdeen	2013	How to improve SCs performance by effectively reducing environmental and societal impacts of SCs while maintaining profitability?	Coordination of product, process and SC design for sustainable SCs.	Supply chain design model.	Discloses about the importance of process for sustainable SCs, but only talks about the design process stage of a product; makes the new product development be a single phase: design.
Measuring the circular economy - A Multiple Correspondence Analysis of 63 metrics	Parchomenko et al.	2019	No generally accepted CE monitoring framework; Which are the current CE metrics?	Three main clusters of metrics: resource-efficiency, materials stocks and flows, and product-centric cluster.	Visualisation framework of CE elements provides guidance for development of CE metrics.	A large number of metrics focuses on value recovery and efficiency instead of value maintenance; more metrics on <i>materials</i> than on <i>products</i> ; need for specialized metrics; no standards within CE.
The circular economy	Stahel	2016	Replace production with sufficiency: how to overtake the fear of the unknown?	Social, technological and commercial research and innovation.	Excellence in metallurgical and chemical sciences for deeper research, academic knowledge, governments policies levers, stewardship over ownership, communication and information.	How to marry the three types of economy: linear, circular and performance? Is there a way to do it?
Circular economy and firm performance: The influence of product life cycle analysis, upcycling, and redesign	Triguero et al.	2023	What are the consequences of CE product design related practices on firm performance?	Superior economic performance: LCA, eco-innovation, eco-design (DfD, DfRecycling). Superior environmental performance: LCA.	Life cycle assessment (LCA), eco-design, DfD, reuse, recycling, LCA and product upgradability.	Do not consider research-intensive industries that work with raw materials; focus only on the product design stage of production, but not discloses which stages are there.

2.4 – Discussion of content analysis

Different insights can be taken from the geographical context of the works (Figure 3). First is that Europe is the focus of researchers (ten works), maybe because of quantity of industries open to be studied, more incentives for a CE or the urgent need for change (Europe is the fastest-warming continent, see (CHEN, 2026)). Second, North America, as the second global industry leader (UNIDO, 2025), does not have a presence in research about the topics (even in the worldwide bit), which is a concerning reality for planet's human and environmental health. Third, the works with no local specified is a twofold: scholars are not going beyond literature review (GOVINDAN; HASANAGIC, 2018) or there is still a pressing need to make clear concepts and achieve a consensus about CE, product development and supply chains. Forth, and last, South America only had case studies in Brazil, a promising reality for the nation, but a worrying one for the remaining countries. The previous conclusions were drawn by a tiny, even miniscule, sample of works about CE available in the academic world; so, it is advised to take them with cautiousness.

Just as (GOVINDAN; HASANAGIC, 2018) found, most studies around CE are literature reviews, followed by case studies and conceptual works, as represented by Table 4. For the pillars of this research, the main methodology was literature review, meaning that researchers are still developing and looking for patterns within the topics. Not only, it can also mean that case studies are: getting difficult to produce (because of resources, regulations, participation or information sharing, for example), industries do not see necessity for the studies or even the lack of general applicability for CE literature (KIRCHHERR et al., 2023).

For industry setting, the scope of the works presented more unspecified cases, justified by the bigger number of literature reviews and theoretical/conceptual works. Not far behind was the category *diversified*, which accounts for two or multiple cited industries. Manufacturing was the most mentioned setting, responsible for transforming raw materials into finished products; the automotive, home appliance and textile sectors are within the manufacturing industry but were separated because works explicitly talked about them. Although the automotive industry has little mentions, only two, it is a fast developing sector that has gained attention with the electric vehicles and their impact on the environment; this segment responds for about 10% of the global CO₂ emissions (MCKNIGHT; FAHRNI, 2024). Construction industry is also an important category to be present, since it is one of the focus for sustainability aspects and is responsible for around 30% of greenhouse gas emissions (UNITED NATIONS ENVIRONMENT PROGRAMME; GLOBAL ALLIANCE FOR BUILDINGS AND CONSTRUCTION, 2025).

As exhibited by Table 4, the works have miscellaneous focuses, with *framework proposal* leading the count (16), followed by *circular design* (13), right before *product development* and *SC (management)* (11). A framework “can guide researchers in designing new empirical research by indicating which core concepts and relationships are of interest to be measured and compared” (PARTELOW, 2023). The difference from this category to *CE tool, method proposal/application* and *guideline proposal/application* relies on the definition from the authors themselves, which this study attempted to maintain trustworthy. *Circular design* counting reveals the authors' focus preference for this terminology (e.g. when compared to eco-design), as well as the inclination for studying specifically this stage of product development.

Closed-loop production was more focused by institutional web pages, reports and white papers, meaning that research institutions address the bigger picture, understandably, since their target audience is, primarily, the general public with broader

knowledge. CE focused categories (*concept, practices, principles, tools, challenges/barriers* and *opportunities/drivers*) had least occurrences than the others, between two and seven. Maybe, authors do not want to focus on *CE concept, practices, principles and/or tools* because it is, supposedly, already validated scopes, with the concept existing and developing since around middle 20th century. Perhaps, *challenges/barriers* and *opportunities/drivers* are still being studied regarding new technologies and realities, or such topics were embedded within the researches, not focused on. *Digitalization, eco-innovation* and *product-service system* are terms relatively new, with still questionable definitions around CE, which explains, perchance, their minimal occurrences (one or two).

10 R's/6 R's/3 R's refers to key CE practices, known as imperatives, adopted by the literature, which started with three (i.e., reduce, reuse and recycle), grew for six (i.e., reduce, recycle, reuse, recover, remanufacture and redesign) and is at ten (i.e., refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover). Even if not the focus, several, if not all works, explored at least one of these R-imperatives, varying from author, time and research. Reuse and recycle were the prevalent ones, accordingly with the circular aspect of this research. It can be noticed, though, that the R's diverge for each author, causing, potentially, conceptual deadlock (KIRCHHERR et al., 2023).

Regarding Table 5, a pattern was noticed: five out of eight works had a design-related gap (BOCKEN et al., 2019; HARTWELL; MACMILLAN; OVEREND, 2021; HAZEN et al., 2020; METTA; BADURDEEN, 2013; TRIGUERO; MORENO-MONDÉJAR; SÁEZ-MARTÍNEZ, 2023); when writing about product development, they only mention the design stage or design process. Moreover, it was perceived a difficulty among authors to disclose phases of product development further from design. Noticeably, though, they make known how product development for CE in supply chains should be quantifiable (HARTWELL; MACMILLAN; OVEREND, 2021), standardized (PARCHOMENKO et al., 2019), multidisciplinary (HAZEN et al., 2020) and comprehensive (BOCKEN et al., 2019) (lengthy words for lengthier modifications; they address the problem but do not give solutions to it). Framework issues are pointed at (GOVINDAN; HASANAGIC, 2018), as well as disseminated metrics, lost focus of CE principles (value maintenance) (PARCHOMENKO et al., 2019) and even the need to overcome the fear of the unknown CE (STAHEL, 2016).

III. CONTRIBUTIONS

The transition towards a CE normally requires a systemic understanding of how production and consumption systems can be transformed to reduce resource depletion, minimise waste, and create long-term environmental, economic and social value; rather than focusing solely on end-of-life waste management. Also, it provides a broader rationale for rethinking how products, processes, business models, and supply chains are designed and managed throughout their lifecycles. In this context, organisations need to understand the factors that enable or constrain circular transformation, as well as the practices and mechanisms through which circularity can be implemented and evaluated. Accordingly, in the following subsections the authors will discuss complementary dimensions of the CE explored in this research in terms of its contributions. First, CE provides a system-level rationale for redesigning production, establishing the conceptual foundation for systemic transformation. Second, drivers, barriers and practices are discussed to identify the main factors influencing the adoption and implementation of circular strategies. Third, the state of the art about frameworks

and tools is pointed out. Finally, CE indicators are presented as mechanisms for assessing, monitoring and comparing progress towards circularity.

3.1 – CE provides a system-level rationale for redesigning production

Reviewed literature establishes CE as more than a waste management program. Its central concern is the preservation and regeneration of value through strategies that close, slow, intensify, narrow and/or dematerialize resource flows (HAZEN et al., 2020). This creates an underlying principle for bringing circularity upstream into product development and for treating supply chains as the operational setting in which circular flows must be coordinated.

Such point of view is important because product development decisions influence later options for repair, reuse, disassembly, remanufacture, recycling, recovery and product-service substitution. Conversely, supply chain conditions influence whether a circular design can actually be sourced, produced, distributed, supported and recovered. Therefore, the literature supports integration rather than isolated optimisation: product, process and supply chain decisions should be considered together.

3.2 – Drivers, barriers and practices

Govindan and Hasanagic (2018) supply chain perspective identifies 13 drivers, 34 practices and 39 barriers, including internal and external dimensions. This contribution is valuable because it shows that CE adoption cannot be reduced to a technical design problem. Regulation, infrastructure, stakeholder awareness, economics, information and organisational capabilities all shape implementation.

Also, literature identifies practices associated with circular product development: eco-design, eco-innovation, recycling, reuse, remanufacture, reverse logistics, servitization, dematerialisation, among others (see Table 4 for specified references). Such practices connect the product to the wider system, but they are not yet assembled consistently into one product-oriented development logic (BOCKEN et al., 2019; PARCHOMENKO et al., 2019). However, identifying them is one step closer to achieving the CE principles.

3.3 – Frameworks and tools

Frameworks and tools proposals are prominent in the screened literature, indicating growing emphasis on a field designed to translate CE principles into actionable decision support. Such finding is relevant for circular product development, where strategies require the systematic comparison, classification, evaluation, monitoring and implementation of ideas across the stages and supply chain activities. Therefore, the literature provides various perspectives on how circularity can be translated into operational decisions and suit as guidance.

3.4 – CE indicators

Parchomenko et al., (2019) identifies three broad clusters of CE metrics (resource efficiency, material stocks and flows, and product-centric metrics) but many of them favour value recovery and efficiency over value maintenance, contain more material-level than product-level measures, and lack standardisation. Thus, the implication is not that existing indicators are unhelpful; rather, the evidence suggests that they answer different questions at different system levels. Regardless of, they cannot automatically be treated as a coherent product classification method.

For product development, such distinction is substantial. A post-use recovery rate can describe a system outcome, but it does not, by itself, explain whether a product was designed for longevity, repair, disassembly, upgradeability or material preservation. A material-efficiency metric can show reduced input intensity, but it may not capture whether the product maintains value through multiple cycles. Therefore, the literature supports the need for product-oriented and interpretable assessment but still strives for delivering a generally accepted way to combine these dimensions. Again, nonetheless, developing indicators can help researchers and practitioners reach a consensus on truthfully meaningful metrics for measuring CE progress.

IV. LIMITATIONS

Despite the contributions identified in the literature, several limitations constrain the consolidation and practical application of CE principles in product development and supply chains. The reviewed studies reveal conceptual, methodological, technological and contextual challenges that prevent a consistent and broadly applicable approach to circular product development. In particular, the literature frequently narrows product development to design or redesign, leaving other development stages insufficiently addressed. Additionally, although numerous frameworks and tools have been proposed, their empirical validation and applicability across different organisational and industrial contexts remain limited. The heterogeneity of existing tools also makes comparison, integration and interpretation difficult, as they differ in scope, level of analysis, outputs and application requirements. Furthermore, many assessments adopt a post-production perspective, emphasising materials, waste, resource efficiency and recovery rather than supporting circular decisions during the product development process. Finally, the transferability of proposed approaches remains uncertain because contextual characteristics, evaluation criteria and professional roles are not consistently defined. The following subsections discuss these five limitations in detail.

4.1 – Product development is often reduced to design

Alongside the contributions, limitations revealed practical challenges and chasms that restrict large scale adoption of circular actions. The most consistent pattern in the literature review is the concentration of product development research on design or redesign. Metta and Badurdeen (2013) work, for example, recognize the coordination of product, process and supply chain design but treats new product development essentially as a design phase. Hazen et al. (2020) similarly emphasize multidisciplinary supply chain processes while giving product development substantial attention through redesign and design-related activities.

This reduction narrows the meaning of circular product development. Literature records materially different descriptions of product development stages, ranging from conception, production and post-production (PINHEIRO et al., 2018) to ideation, conceptual design, detailed design, testing, execution and review (CIRCIT NORDEN, [s.d.]). Without a shared process boundary, it is difficult to determine when a circular criterion should be applied, what evidence should be collected or how products should be compared. Thus, definition of product development stages (further from design) is a conceptual breach in this review.

4.2 – Frameworks are proposed more often than they are validated

Screened literature repeatedly calls for frameworks that include supply chain needs, but proposals are not necessarily tested in real organisational settings. Govindan

and Hasanagic (2018) identify framework deficiencies as a CE barrier while their own framework is not tested nor investigated. Scenarios like this create a circular difficulty: organisations lack usable frameworks, while proposed frameworks lack sufficient empirical and specialised validation to establish usability across contexts. As a result, the problem is not simply the absence of another conceptual model; it is the absence of a transparent relationship among criteria, product development stages, supply chain implications, evidence requirements and interpretable outputs.

4.3 – Heterogeneity of the tools

The tool landscape is fragmented across ideation, design, lifecycle analysis, business model innovation, material assessment, certification and post-use recovery. Their levels of analysis and outputs differ, ranging from semi-qualitative tools concentrated in ideation and design, to metric clusters focused on resources, material stocks and product characteristics (BOCKEN et al., 2019; PARCHOMENKO et al., 2019). Such heterogeneity is useful for specialised decisions but problematic for general product development practice. Recurring practical concerns are complexity, time, cost, specialised labour, context-specific application and difficulty on the outputs interpretation.

4.4 – Post-production perspective

Often CE assessments concentrated on materials, waste and resource efficiency rather than the preservation of value. Product-level choices mediate the possibility of retaining value in components, functions and materials. So, if an assessment begins only after production or disposal, it may identify the consequences of a product architecture without helping developers change that architecture. Consequently, the unresolved issue is temporal as well as conceptual: circularity should inform decisions before the product is finalised, not only evaluate performance after the first version has been produced.

4.5 – Uncertain applicability

The reviewed sample contains literature reviews, conceptual works, case studies and surveys, with manufacturing and diversified settings occurring frequently; however many works do not state a particular industry context. While this perspective helps establish general principles, it also limits available evidence regarding their transferability. The limited specification of contextual characteristics, evaluation criteria and professional roles in some of the proposed models creates uncertainty regarding how these approaches can be applied, adapted and operationalised, which leaves an unfamiliar and unrivalled pathway for different industries. Hence, the identified gap concerns contextual applicability and transferability, instead of proof that a universal model is impossible.

V. DISCUSSION AND SYNTHESIS

A clear progression was recognised with the review: CE principles define the intended direction, supply chain research identifies implementation conditions, product development research foregrounds design decisions, and measurement research organises indicators into resource-, material- and product-oriented clusters. However, these contributions do not yet form a sufficiently integrated classification logic. The unanswered gap has five connected dimensions:

1. Process gap: product development is inconsistently delimited and is often reduced to design;

2. Integration gap: product, process and supply chain decisions are recognised as interdependent, but are not consistently operationalised together;
3. Measurement gap: indicators are dispersed across material, process, product and system levels, with stronger emphasis on efficiency and recovery than on maintaining product value;
4. Applicability gap: tools and certifications are frequently specialised, complex, qualitative or insufficiently described for routine use across diversified contexts;
5. Validation gap: frameworks are proposed, but their testing and practical use are not sufficiently demonstrated.

Taken together, literature does not merely lack another list of circular strategies; it lacks a clear way to organise existing knowledge into a product-oriented classification that is understandable, applicable during the whole process of product development and connected to supply chain decisions. The research question was, then, answered. However, a resulting research problem can be stated as follows: ***How can CE principles be systematically integrated into product development and supply chains through a classification framework that supports sustainability-oriented decision-making?***

VI. CONCLUSION

This research investigated the current state of knowledge connecting circular economy (CE), product development and supply chain management through a structured literature review combining bibliometric and qualitative content analysis. The review of studies identified in IEEE Xplore, Scopus and Web of Science, complemented by citation snowballing, demonstrates that the literature has substantially advanced the understanding of CE principles, circular design, implementation drivers and barriers, supply chain practices, frameworks, tools and circularity indicators. However, the findings also demonstrate that this knowledge remains fragmented and is not yet sufficiently integrated into a coherent product-oriented development approach.

Five interconnected research gaps were identified. First, product development is frequently reduced to design or redesign, leaving other stages insufficiently addressed. Second, frameworks are proposed more frequently than they are empirically validated, limiting evidence of their effectiveness and transferability. Third, the heterogeneity of existing tools results in differences in scope, analytical level, outputs, complexity and interpretation. Fourth, many circularity assessments adopt a post-production perspective, emphasising resource efficiency, material recovery and waste rather than supporting circular decisions during product development. Finally, the applicability and transferability of existing approaches remain uncertain because contextual characteristics, evaluation criteria and professional responsibilities are not consistently specified.

The study therefore concludes that the main research challenge is not the absence of circular strategies, tools or indicators, but the lack of an integrated classification logic capable of connecting CE strategies with the different stages of product development and their implications for supply chain decisions. Such an approach should be product-oriented, understandable, applicable throughout the development process and sufficiently flexible to accommodate different industrial contexts.

Consequently, future research should focus on developing and empirically validating an integrated classification framework that links circularity principles, product development stages, supply chain requirements, decision criteria and measurable outcomes. Such a framework could contribute to transforming the extensive, but fragmented, body of CE knowledge into practical decision support for organisations

seeking to develop products that preserve value, enable circular flows and support more sustainable supply chains.

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