



## Review Article

# Beyond the life cycle: assessing business models for the circular economy through life-cycle-based methodologies<sup>☆</sup>

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## ABSTRACT

Although Life Cycle Assessment (LCA) is widely used in the literature to quantify the impact of products designed according to circularity principles, the analysis of circular business models (CBMs) remains a niche topic. In recent years, some empirical studies have highlighted the urgency of addressing this issue; however, the literature remains fragmented, and a more structured approach is needed for further progress.

This paper aims to fill this gap through a systematic literature review of 60 studies that combine LCA and life-cycle-based (LC-based) methodologies with other methods to assess the environmental sustainability of CBMs. The findings reveal that most studies rely on conventional LCA, which is frequently combined with Life Cycle Costing (LCC) and other qualitative or quantitative methods. There is also growing interest in hybrid and emerging approaches such as Business Model LCA (BM-LCA). LC-based methodologies are often used to compare the environmental impacts of linear business models (BM) and CBMs or to guide the transition from linear BMs toward the design of new CBMs. Particular emphasis is also placed on adopting CBMs such as product service systems, CBMs that extend product lifespan or industrial symbiosis, rather than CBMs focused on using circular materials. A comprehensive coverage across a wide range of sectors emerges.

The study's implications are significant for both researchers and managers. For researchers, the review highlights the need for standardisation efforts to refine tools for assessing CBMs. For managers, the review offers an 8-step operational framework to conduct LC-based analyses for CBM implementation.

## 1. Introduction

Given the strong connection between economic activity and environmental impact (Böckin et al., 2022), companies are facing mounting pressure to transform their business models (BMs) into more circular and sustainable ones (Caferra et al., 2023; Goffetti et al., 2022). This shift usually involves a profound transformation in the way companies operate (Bocken et al., 2016). Circular business models (CBMs) offer a viable alternative to linear production systems, serving as a key strategy for advancing the circular economy at the micro level (e.g., Bjørnbet and Vildåsen, 2021; Bocken et al., 2016; Longo et al., 2024). By adopting CBMs, companies can maintain profitability while minimising environmental impacts, both in terms of resource inputs and waste generation,

through strategies such as cycling, extending, intensifying, and dematerialising resource use (Geissdoerfer et al., 2020).

However, while CBMs are designed to promote circularity, they are not inherently more environmentally sustainable unless carefully designed and well implemented (Blum et al., 2020; De Pádua Pieroni et al., 2018). While CBMs can encourage sustainable consumption, they may also lead to unintended rebound or backfire effects (Bączyk et al., 2024; Das et al., 2023). This highlights the critical need to evaluate and monitor the environmental impacts of CBMs (Böckin et al., 2022; Das et al., 2022; Ghisellini et al., 2024)—a need reflected in the growing body of research on this topic (e.g., Gonzalez-Salazar et al., 2023; Kambanou et al., 2024; Otterbach and Fröhling, 2024). Life Cycle Assessment (LCA)—a methodology originally developed to evaluate the

*Abbreviations:* BM, business model; BM-LCA, business model life cycle assessment; CBM, circular business model; CE, circular economy; LC-based, life-cycle-based; LCA, life cycle assessment; LCC, life cycle costing; LCSA, life cycle sustainability assessment; PSS, product-service systems; S-LCA, social LCA.

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environmental impact of products, covering all stages from raw material extraction to final disposal and considering a range of impact categories (ISO, 2006a, 2006b)—has become the most widely used tool for assessing CBMs (De Carvalho Araújo et al., 2022; Sassanelli et al., 2019). LCA provides companies with valuable insights into the environmental performance of their products, identifies critical stages within the life cycle, and highlights areas for potential improvement (Liu and Cui, 2024; Solimene et al., 2023). It also supports eco-design and innovation by informing decisions related to material selection, recyclability, and product development needs (Liu and Cui, 2024). Importantly, LCA helps to prevent burden shifting, ensuring that environmental impacts are not transferred from one life cycle stage to another, from one impact category to another, or from one geographical location to another (Bjørnset and Vildåsen, 2021; Manda et al., 2016).

Despite the growing recognition of LCA as a crucial tool for assessing the environmental impacts of CBMs, knowledge about how LCA can be applied most effectively in this evaluation remains fragmented, and a comprehensive understanding on the subject is still lacking. Numerous studies have indeed employed a variety of life-cycle-based (LC-based) methodologies to evaluate different types of CBMs for diverse purposes (e.g., Capucha et al., 2023; Goffetti et al., 2022; Mura et al., 2024), revealing significant heterogeneity in methodological approaches, purposes of analysis, and the CBM types considered. In parallel, literature reviews, meta-analyses, and qualitative investigations have explored specific challenges related to using LCA to assess different types of CBMs across different sectors (e.g., Kjaer et al., 2016; Koide et al., 2022; Longo et al., 2024). However, while this body of literature is substantial and has grown markedly since 2015, it remains both formative and dispersed. Collectively, the insights revealed point to a complex and multi-faceted research landscape that underscores the need for a structured and comprehensive synthesis—one that is capable of informing and guiding future methodological developments and practical applications in the field. Johnson and Mont (2025) and Bjørnset and Skaar (2024) are reviews that consider how LCA has been used in the context of CBMs. The review by Johnson and Mont (2025) examines CBMs, product service systems (PSS), and sharing BMs from three perspectives: normative (i.e., intentions and goals), strategic (i.e., structures and conditions enabling the pursuit of those goals), and operational (i.e., processes supporting goal achievement). While the review offers a discussion of the environmental impacts of CBMs and identifies the factors influencing these impacts, it does not provide an in-depth analysis of how LC-based methodologies have been used to assess CBMs, nor what specific purposes they serve or which types of CBMs are considered (Johnson and Mont, 2025). Conversely, the review by Bjørnset and Skaar (2024) focuses on how LCA has been used to implement CBM. It identifies the different types of CBM innovations to which LCA was applied, analyses how LCA was implemented (i.e., type of LCA), and evaluates how LCA was used to support decision-making during the implementation process (Bjørnset and Skaar, 2024). However, although the review provides an in-depth analysis of how LCA can be used to evaluate CBMs, the focus remains exclusively on LCA, without considering how it has been used in conjunction with other LC-based, qualitative and quantitative methods. Moreover, the emphasis is on CBM innovation, while already-implemented or established CBMs are not considered. In addition, the narrow analytical scope and the small temporal window (2012–2022) mean many relevant studies are excluded. These limitations hinder a more comprehensive understanding of the expanding body of literature on LCA and CBMs, particularly considering the growing academic interest and the increasing number of publications in recent years. This evidence confirms the existence of a research gap.

This study aims to address this critical gap in the literature by investigating how LCA and more generally LC-based methodologies (i.e., Life Cycle Sustainability Assessment—LCSA; Life Cycle Costing—LCC; social LCA—S-LCA; Business Model Life Cycle Assessment—BM-LCA) have been used to assess the environmental impacts of

CBMs. More specifically, this study focuses on identifying the LC-based methodologies employed, the purposes of these assessments, the specific types of CBMs evaluated, and the sectors analysed. Additionally, this review highlights gaps in existing research, providing a foundation for advancing knowledge in this field. Therefore, the study seeks to answer the following primary research question (RQ):

RQ: How can the evaluation of a CBM be conducted using LC-based methodologies?

To further explore the answer, the main research question is divided into the following sub-questions:

RQ1: Which LC-based methodologies have been used to quantify the environmental impact of BMs in a circular economy context?

RQ2: Which purpose are LC-based methodologies used for?

RQ3: Which types of CBMs are assessed with LC-based methodologies?

RQ4: What gaps exist in the current research on this topic?

To answer these research questions, we conducted a systematic literature review on 60 studies that applied LC-based methodologies to assess CBMs.

## 2. Conceptual background

This section provides the operational grounding that underpins this review, focusing on the following concepts: defining and classifying CBMs (Section 2.1) and assessing the environmental impacts of CBMs (Section 2.2).

### 2.1. Definition and classification of circular business models

Numerous definitions and classifications of CBMs have been proposed in the academic literature and among practitioners.

CBMs have been defined as “business models that are cycling, extending, intensifying, and/or dematerialising material and energy loops to reduce the resource inputs into and the waste and emission leakage out of an organisational system. This comprises recycling measures (cycling), use phase extensions (extending), a more intense use phase (intensifying), and the substitution of products by service and software solutions (dematerialising)” (Geissdoerfer et al., 2020, p. 7). Bocken et al. (2016) outline three key strategies associated with resource cycling: slowing resource loops, i.e., slow the flow of resources by extending and/or intensifying product use through strategies such as product-life extension and design of long-lasting goods; closing resource loops, i.e., close the loop between post-use and production and establish a circular flow or resources through designing products whose materials can be continuously recycled into new materials or products, designing products with biodegradable materials, and designing products and parts that can be disassembled and reassembled easily; resource efficiency or narrowing resource flow, i.e., reduce resource consumption in the production process and in the final product.

For the purpose of this review, the following three classifications are particularly relevant (see Table S1 in Supplementary material). Bocken et al. (2016) identify six types of CBM, four of which aim to slow resource loops (i.e., access and performance model, extending product value, classic long-life model, and encourage sufficiency) and two focus on closing resource loops (i.e., extending resource value and industrial symbiosis). Accenture (2014) offers an alternative, practitioner-oriented classification of CBMs (Lüdeke-Freund et al., 2019) that partially aligns with Bocken et al. (2016) and distinguishes five CBMs: sharing platforms, product as a service, product life extension, resource recovery, and circular supplies. The access and performance model identified by Bocken et al. (2016) and the product as a service identified by Accenture (2014), are further classified by Tukker (2004) into three types of PSS:

product-oriented PSS, use-oriented PSS, and result-oriented PSS.

## 2.2. The assessment of the environmental impacts of circular business models

As discussed in Section 2.1, CBMs aim to preserve the value of resources and products while minimising resource consumption and waste (Geissdoerfer et al., 2020). Nevertheless, defining a BM as “circular” does not imply that the BM is more sustainable unless it is specifically designed with this purpose (Blum et al., 2020; De Pádua Pieroni et al., 2018). CBMs can indeed support conservation and foster sustainable consumption through resource-saving behaviours, lower demand for new products, substituting linear products and services with circular alternatives, and adopting practices that extend product lifespans (e.g., repair and maintenance) (Bączyk et al., 2024). However, CBMs may have rebound effects, where the environmental benefits achieved are lower than anticipated due to shifts in consumption behaviours (Bączyk et al., 2024; Das et al., 2023; Kjaer et al., 2019). In the worst cases, backfire effects may arise, negating the environmental advantages that were expected (Bączyk et al., 2024).

Given the potential for both conservation mechanisms and rebound/backfire effects, it is crucial to monitor the environmental impacts of CBMs using scientific methods (Böckin et al., 2022; Das et al., 2022; Ghisellini et al., 2024). Such evaluations enable companies to maximise the positive outcomes of CBMs (Bech et al., 2019).

Various methods have been proposed to assess the environmental

impacts of CBMs (Das et al., 2022). Some focus on ex-post evaluations, which analyse the final outcomes of certain activities using lagging indicators, reactive indicators, or assessment tools like LCA (De Pádua Pieroni et al., 2018; Kravchenko et al., 2019). Conversely, other approaches allow an ex-ante assessment, i.e., forecast impacts before the events occur through leading or proactive indicators (De Pádua Pieroni et al., 2018; Kravchenko et al., 2019). Among the existing assessment methods, LCA is the most widely used technique (De Carvalho Araújo et al., 2022; Sassanelli et al., 2019).

## 3. Methods

To investigate the use of LC-based methodologies to assess CBMs, we conducted a systematic literature review following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method (Page et al., 2021a, 2021b), which consists of four phases: identification, screening, eligibility, and inclusion (see Fig. 1).

In the first phase (identification), we used the Web of Science and Scopus databases to identify relevant publications. These databases are well-established and widely used for scientific research (Paul and Criado, 2020; Zhu and Liu, 2020). They offer significant advantages, including frequent updates, reliable and relevant results, and the inclusion of high-impact studies (Falagas et al., 2008). Furthermore, using both databases combined provides results that are more comprehensive and reliable due to their complementary features (Echchakoui, 2020).

We first identified the search terms based on studies using LC-based

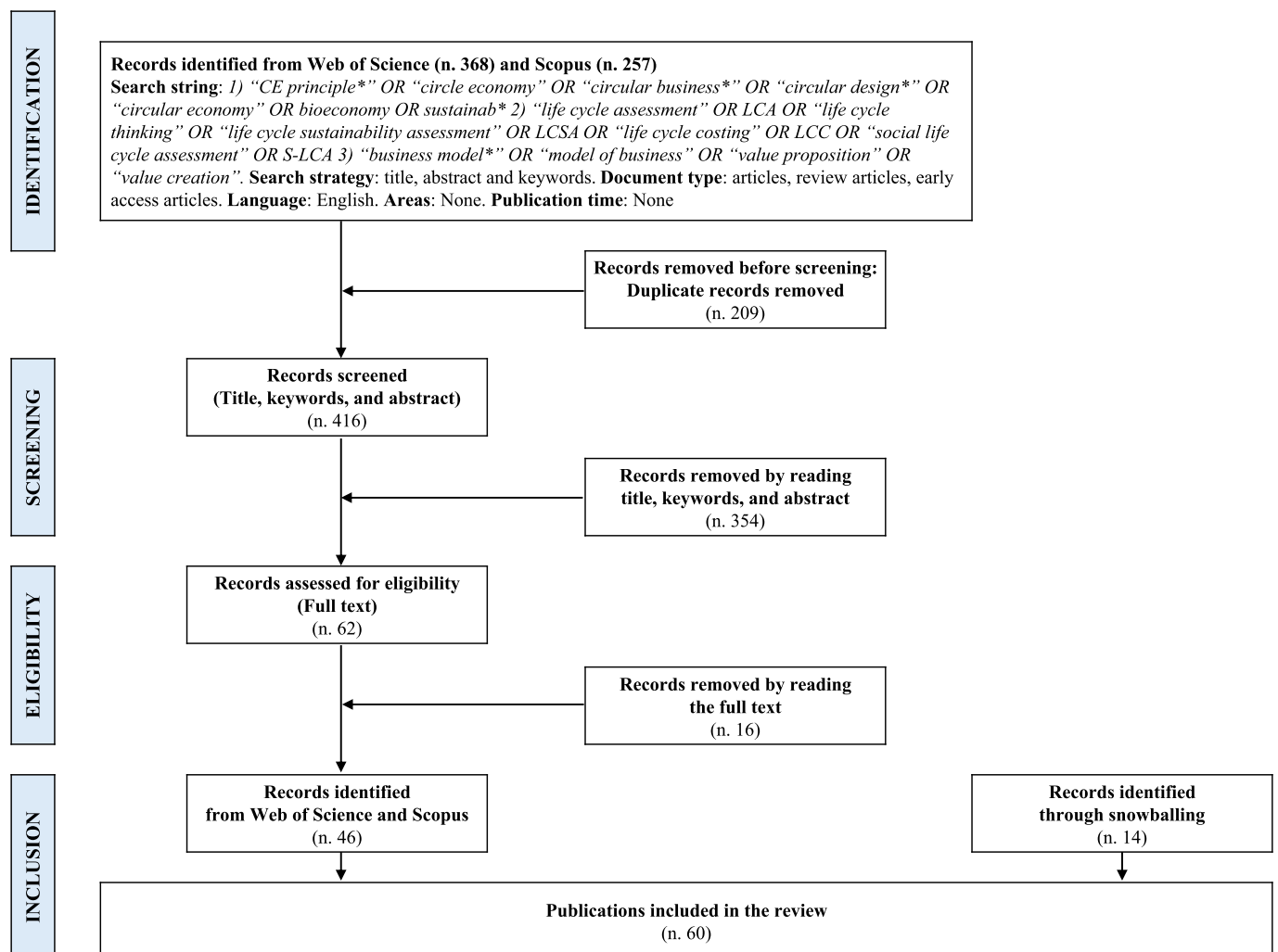


Fig. 1. Review process following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method.

methodologies to assess the environmental impacts of CBMs. Hence, we discussed which terms should be included in the final search string, which consists of three parts. The first one focuses on circular economy (CE) and included these terms: “*CE principle\**” OR “*circle economy*” OR “*circular business\**” OR “*circular design\**” OR “*circular economy*” OR “*bioeconomy*” OR “*sustainab\**” (De Carvalho Araújo et al., 2022; Longo et al., 2024). The second part captures LC-based methodologies as follows: “*life cycle assessment*” OR “*LCA*” OR “*life cycle thinking*” OR “*life cycle sustainability assessment*” OR “*LCSA*” OR “*life cycle costing*” OR “*LCC*” OR “*social life cycle assessment*” OR “*S-LCA*” (De Carvalho Araújo et al., 2022; Koide et al., 2022; Longo et al., 2024). The third part relates to BMs and consists of the following terms: “*business model\**” OR “*model of business*” OR “*value proposition*” OR “*value creation*” (Bhatnagar et al., 2022). We used broad terms with the aim of conducting a comprehensive and open-ended search. We required the final search string to appear in the title, abstract, or keywords (Paul and Criado, 2020). We also applied some additional criteria. First, we restricted the search of relevant publication to articles, review articles, and early access articles with the goal of considering only high-quality and peer-reviewed studies. Second, we only included documents written in English. Instead, we applied no selection criteria to the research field classification since the assessment of environmental impacts of CBM encompasses, among others, economic, engineering, and environmental aspects. We also applied no publication time criteria. We extracted publications in early July 2025, retrieving 368 publications from Web of Science and 257 from Scopus. We then combined the publications into a single unified database. This process led to the removal of 209 duplicates, resulting in an initial database of 416 unique publications.

In the second phase (screening), we carefully examined the content of each extracted publication to ensure that only relevant studies were included in the review. Specifically, we assessed publications based on their title, keywords, and abstracts (Moher et al., 2009), verifying that they assessed the environmental impacts of CBMs using LC-based methodologies. At least two authors independently conducted this evaluation, and the results were then discussed collectively. From this process, 354 publications were excluded because they focused on assessing products, materials or value chains or discussing subjects such as consumer acceptance of circular economy strategies and corporate sustainability practices.

In the third phase (eligibility), we evaluated the publications based on their full text (Moher et al., 2009). Sixteen additional publications were excluded as a result of this process. Although these publications used LC-based methodologies, they did not focus on CBMs. Rather, their primary concern was to evaluate industrial and economic systems (e.g., industrial districts, economic sectors, and circular recovery processes), service sectors (e.g., cross-border e-commerce, food delivery, and water tourism), and agri-food and manufacturing processes (e.g., food waste management, fruit and vegetable cultivation, and fabric dyeing).

At the same time, we performed an upward snowballing process (Bączyk et al., 2024; De Carvalho Araújo et al., 2022), reviewing the reference list of publications retrieved from Web of Science and Scopus. Additionally, a downstream snowballing approach (Wohlin, 2014) was performed, reviewing publications that cited these initial publications. These approaches aimed to identify any additional relevant publications that were not uncovered through the initial database searches, thereby enhancing the comprehensiveness of the literature search.

As a result, we included 60 publications in the review, of which 46 were identified through Web of Science and Scopus and 14 through snowballing.

In the fourth and last phase (inclusion), relevant publications were examined to extract and synthesise relevant information and research findings. Specifically, the following information was codified:

- Bibliometric characteristics, i.e., year and journal;
- Type of analysis conducted, i.e., quantitative analysis, qualitative analysis, literature review, and meta-analysis;

- LC-based methodologies employed in the analysis, i.e., LCA (including sensitivity analysis and/or scenario analysis), LCC, other qualitative methods, other quantitative methods, and BM-LCA (including sensitivity analysis);
- Types of data employed in the analysis, i.e., primary data and secondary data (including estimated data and assumed data);
- Relationships among the methods used in the analysis, i.e., simultaneous and independent application, simultaneous and interactive application, sequential application, and integration;
- Purpose of analysis, i.e., evaluate the environmental impacts of singular CBMs, compare the environmental impacts of BMs and/or CBMs, evaluate the transition from a BM to a CBM, and design and implement CBMs;
- Types of CBMs analysed, i.e., product-oriented PSS, use-oriented PSS, result-oriented PSS, extending product life, encourage sufficiency, extending resource value, industrial symbiosis, and circular supplies;
- Sectors analysed, i.e., batteries, chemical & pharmaceutical, child-care products, cleaning services, clothing, construction, electrical & electronic equipment, energy production, food & food packaging, machinery & machinery components, vehicles, waste management;
- Additional qualitative insights regarding the assessment of CBMs using LC-based methodologies.

#### 4. Results and discussion

The following subsections present and discuss the results derived from this review: type of analysis (Section 4.1), RQ-1: LC-based methodologies employed (Section 4.2), relationships among methodologies (Section 4.3), evolution of methodologies over time (Section 4.4), RQ2: purpose of analysis (Section 4.5), RQ3: types of CBMs (Section 4.6), sectors (Section 4.7), relationships among the key dimensions of analysis (Section 4.8), RQ4: research gaps and future research avenues (Section 4.9), and managerial suggestions (Section 4.10).

##### 4.1. Type of analysis

Of the 60 publications reviewed, the majority (44 publications) are quantitative analyses that use various methods (i.e., LCA, LCC, other qualitative methods, other quantitative methods, and BM-LCA) to evaluate one or more types of CBMs (i.e., product-oriented PSS, use-oriented PSS, result-oriented PSS, extending product life, encourage sufficiency, extending resource value, industrial symbiosis, and circular supplies) with one or more purposes in mind (i.e., evaluate the environmental impacts of singular CBMs; compare the environmental impacts of BMs or CBMs; evaluate the transition from a BM to a CBM; design and implement CBMs), considering one or more sectors (e.g., electrical & electronic equipment, clothing, batteries, food & food packaging).

The remaining 16 publications are literature reviews (e.g., Aissani et al., 2019; Bhatnagar et al., 2022; Longo et al., 2024), meta-analyses (Koide et al., 2022; Suckling and Lee, 2015), and qualitative analyses (e.g., Das et al., 2022; Ghisellini et al., 2024; Solesvik et al., 2022). These publications have various objectives, including: analysing the extant sustainability assessment frameworks and tools for BM (Bhatnagar et al., 2022) and the adoption of environmental impact assessment methods (Ghisellini et al., 2024), understanding how companies measure and forecast the environmental impacts of their BMs (Das et al., 2022), discussing how companies benefit from using LCA to create value or implement a CBM (Bjørnset and Vildåsen, 2021; Manda et al., 2016; Tamym et al., 2023), showing the specific challenges when using LCA to evaluate the environmental performance of PSS (Kjaer et al., 2016) or when defining a reference scenario to consider when assessing industrial symbiosis (Aissani et al., 2019), and reviewing the use of life cycle thinking and LCA in specific sectors (De Carvalho Araújo et al., 2022; Longo et al., 2024).

#### 4.2. RQ1: LC-based methodologies employed

Relevant publications used the following combinations of LC-based methodologies (see Table 1):

- i) LCA (including sensitivity analysis and/or scenario analysis);
- ii) LCA (including sensitivity analysis and/or scenario analysis) combined with LCC;
- iii) LCA (including sensitivity analysis and/or scenario analysis) combined with LCC, other qualitative methods, and other quantitative methods;
- iv) LCA (including sensitivity analysis and/or scenario analysis) combined with other qualitative methods (e.g., business model canvas, user interviews, focus groups, user trials, user survey, provider interviews, and workshops);
- v) LCA (including sensitivity analysis and/or scenario analysis) combined with other quantitative methods (e.g., discrete event simulation, net present value analysis, battery fleet model, stock flow model, and energy flow model);
- vi) BM-LCA (including sensitivity analysis).

Publications generally rely on two types of data: (i) primary data, either provided by the analysed company or directly collected by the authors through various methods; and (ii) secondary data, gathered by the authors from various external sources and including estimated data (calculated by the authors based on other primary or secondary data) and assumed data (arbitrarily set by the authors).

##### 4.2.1. Life cycle assessment

LCA presents several advantages for assessing CBMs. First, it allows companies to compare different CE strategies, validate their effectiveness, prevent greenwashing, and reduce the risk of problem shifting (i.e., solving one environmental issue while creating another) by considering the entire product life cycle (Bjørnbet and Vildåsen, 2021; Solesvik et al., 2022). Conversely, the lack of application of adequate tools such as LCA, leading to uncertainty regarding the actual benefits of the funded CBMs, can result in public funding sometimes being allocated based on unsound environmental impact assessments (Løkke et al., 2020). LCA can be a useful tool also for evaluating the impacts of PSS, where the

**Table 1**  
Methodologies adopted to assess circular business models (CBMs).

Method	Number of publications	Percentage of publications
Life Cycle Assessment (including sensitivity analysis and/or scenario analysis)	24	55 %
Life Cycle Assessment (including sensitivity analysis and/or scenario analysis) combined with other quantitative methods	8	18 %
Life Cycle Assessment (including sensitivity analysis and/or scenario analysis) combined with other qualitative methods	6	14 %
Life Cycle Assessment (including sensitivity analysis and/or scenario analysis) combined with Life Cycle Costing	3	7 %
Business Model Life Cycle Assessment (including sensitivity analysis)	2	5 %
Life Cycle Assessment (including sensitivity analysis and/or scenario analysis) combined with Life Cycle Costing, other qualitative methods, and other quantitative methods	1	2 %
<b>Total</b>	<b>44</b>	<b>100 %</b>

Note: The table reports quantitative analyses only, excluding literature reviews, meta-analyses, and qualitative analyses.

adoption of CE strategies can reduce greenhouse gas emissions, but may also create backfire effects that need to be considered in the evaluation (Koide et al., 2022). Second, LCA can be easily combined with other tools (e.g., big data analytics techniques and tools) to assess the environmental and social impacts of CBMs in a more efficient and comprehensive way (Tamym et al., 2023). Third, LCA fosters communication and collaboration with stakeholders, particularly regarding data collection, and raises awareness beyond mere resource efficiency (Bjørnbet and Vildåsen, 2021). Finally, applying LCA can also support business decision-making in four ways: (i) improving operational efficiency by reducing resource use and emissions; (ii) promoting product stewardship by taking responsibility for a product's entire life cycle and integrating stakeholder perspectives; (iii) transforming business processes, products, services, and BM to improve environmental performance and reduce costs across the value chain; and (iv) aligning a company's vision with societal needs (Manda et al., 2016). To facilitate value creation, a six-step procedure that relies on LCA can be followed (Manda et al., 2016). The steps are (Manda et al., 2016): (i) identifying the motivation and objectives of the LCA analysis and the opportunities for stakeholder value creation; (ii) involving relevant business functions in the LCA process; (iii) defining the goal, scope, and type of LCA to be conducted; (iv) engaging suppliers and customers by communicating the LCA's purpose and gathering their feedback; (v) conducting the LCA analysis and discussing the findings internally; and (vi) sharing results with suppliers and customers and collaborating with them to capture value.

However, LCA presents some limitations. First, it can complicate how CE strategies are assessed because, usually, multiple impact categories need to be evaluated and extensive data are required (Bjørnbet and Vildåsen, 2021; Das et al., 2022). Second, it demands consistency, which may introduce uncertainty during both the evaluation and experimentation phases, often necessitating many assumptions and generalisations (Bjørnbet and Vildåsen, 2021; Das et al., 2022). Knowledge for comprehensive evaluations may therefore lack (Das et al., 2022). Third, existing LCA tools are typically designed for large companies and require specialised expertise and supporting complex analyses, making them less suitable for small and medium firms (Eleftheriadis and Anagnostopoulou, 2024). Yet, assessing the environmental impact of CE strategies is nevertheless crucial for small and medium firms to determine whether a particular strategy aligns with firm's structure and processes, effectively evaluate suppliers and business partners for CE implementation, and address some internal barriers when adopting CE strategies (Eleftheriadis and Anagnostopoulou, 2024). Given these considerations, Eleftheriadis and Anagnostopoulou (2024) developed a tool specifically designed to address the unique characteristics and needs of small and medium firms, enabling them to map their business processes, evaluate and understand their environmental impacts, and identify the most environmentally impactful procedures. Forth, for some companies (e.g., circular start-ups), conducting an LCA analysis is costly and unjustified given the nature of their business activities (Ghisellini et al., 2024). Fifth, LCA cannot assess social and economic impacts, which need to be evaluated using other methods (Bjørnbet and Vildåsen, 2021). Finally, LCA poses some additional challenges when applied to PSS as existing LCA guidelines are typically designed for tangible products (Kjaer et al., 2016).

Yet, despite its disadvantages, LCA remains one of the most widely used tools for evaluating CBMs. LCA is also commonly used by circular start-ups to measure and certify their environmental and social impacts (Ghisellini et al., 2024). LCA is indeed used in 24 publications, i.e., more than half of the publications considered in this review (see Table 1). Most use LCA together with either a scenario analysis (e.g., Capucha et al., 2023; Johnson and Plepys, 2021), a sensitivity analysis (e.g., Chun and Lee, 2017; Hoffmann et al., 2020; Sivaraman et al., 2007), or both (e.g., Martin et al., 2021; Monticelli and Costamagna, 2023; Zamani et al., 2017). Scenario and sensitivity analyses are valuable tools for addressing uncertainty in LCA (Bisinella et al., 2021). Scenario analysis

focuses on epistemic uncertainty by exploring the impact of potential modelling choices and future developments (Bisinella et al., 2021). Sensitivity analysis, on the other hand, addresses uncertainties stemming from data used in the analysis (Bisinella et al., 2021). Notably, three publications (Barbieri and Santos, 2020; Wang et al., 2019; Yu et al., 2015) rely solely on LCA without performing a sensitivity or scenario analysis.

Considering the additional challenges that arise when applying LCA to PSS, four publications adapted LCA to account for PSS characteristics and combined it with a scenario or sensitivity analyses: Alfarisi et al. (2024), Amaya et al. (2014), Bech et al. (2019), and Kjaer et al. (2018). More specifically, Amaya et al. (2014) introduce an approach that facilitates the comparison of different PSS during the design process through PSS modelling and by identifying key life-cycle indicators focused on the use phase. The approach consists of the following steps (Amaya et al., 2014): defining the functional unit, modelling the product life cycle in five phases (i.e., raw material extraction, product manufacturing, product distribution, use phase, and end-of-life), and evaluating the environmental impact for each phase using the life cycle parametric model.

Similarly, Kjaer et al. (2018) propose a set of guidelines consisting of six steps to address the specific challenges of applying LCA to PSS. These steps involve (Kjaer et al., 2018): (i) guiding the goal and scope definition of the LCA; (ii) supporting in defining the reference system to identify relevant substitutions; (iii) ensuring functional equivalence between the systems being compared (comparability assessment); (iv) supporting system boundary definition to guarantee completeness; (v) supporting different approaches (i.e., pre and post assessment; full LCA and more simplified approaches); (vi) promoting a scenario-based approach and focus on qualitative learnings rather than solely on quantitative results. These guidelines are intended to ensure three outcomes (Kjaer et al., 2018): (i) the proper definition of the reference system to identify the relevant system to consider; (ii) the comparability between the systems to be analysed to support the definition of the functional unit; (iii) the inclusion of the processes induced by the PSS. Bech et al. (2019) apply these guidelines to evaluate the transition from a conventional BM based on selling to a use-oriented PSS.

Finally, Alfarisi et al. (2024) advance LCA for PSS by proposing a dynamic PSS-LCA approach that incorporates system dynamics to evaluate the environmental and economic performance over time.

Focusing on industrial symbioses, Aissani et al. (2019) discuss the methods and parameters used to define and design a reference scenario for comparison with the investigated industrial symbiosis scenario using LCA. The study highlights that the definition of an appropriate reference scenario largely depends on the type of industrial symbiosis scenario under analysis: for industrial symbiosis initiatives already implemented at an industrial scale, a hypothetical non-symbiotic scenario is generally used as a reference; however, for prospective industrial symbiosis scenarios, the most suitable reference is typically a current, real-world non-symbiotic scenario (Aissani et al., 2019).

#### 4.2.2. Life cycle assessment combined with other quantitative methods

Eight publications combine LCA (including sensitivity analysis and/or scenario analysis) with a variety of quantitative methods, such as discrete event simulation, net present value analysis, battery fleet model, stock flow model, and energy flow model (see Table 1). These methods are used to achieve various goals: obtaining a more comprehensive evaluation as in the case of discrete event simulation (Mann et al., 2022); conducting a complementary assessment to LCA, for example, to evaluate economic impacts through net present value analysis (Gonzalez-Salazar et al., 2023); providing the information required for a more robust LCA through methods such as surveys, stock flow models or the energy flow models (Schulz-Möninghoff et al., 2021; Sigüenza et al., 2021; Zheng et al., 2019).

Specifically, Mann et al. (2022) employ LCA and discrete event simulation—a method used for planning and assessing the effectiveness

and efficiency of manufacturing systems—to compare the environmental impacts of two remanufacturing plants. According to the authors, LCA and the discrete event simulation are a suitable combination for analysing the causes and effects of various scenarios where factors such as time, energy, and location influence sustainable production design (Mann et al., 2022).

Houssard et al. (2022) propose an assessment framework to measure eco-efficiency in a comprehensive and consistent manner. Their framework uses LCA and value assessment and is structured into four phases: (i) defining the goal and scope (i.e., aim, functional unit, audience, boundaries); (ii) simultaneously conducting a LCA and a value assessment; (iii) quantifying eco-efficiency by integrating the environmental and value dimensions into specific eco-efficiency metrics; (iv) interpreting the results. This framework, which relies on the concept of shared value (i.e., the value generated for society) allows to evaluate the trade-offs between value components, environmental performance, and the different interests of various stakeholders in the value chain across individual, territorial, and societal levels (Houssard et al., 2022).

In their study on electric vehicle fleets, Gonzalez-Salazar et al. (2023) combine LCA with two additional methods to assess and compare the economic and environmental impacts of a conventional BM and a use-oriented PSS (i.e., leasing): net present value analysis to evaluate economic impacts; battery fleet model that considers various driving profiles to calculate battery usage and replacement needs.

Zheng et al. (2019) combine LCA with a questionnaire-based survey designed to identify how travel patterns change after introducing a use-oriented PSS for bike sharing.

Schulz-Möninghoff et al. (2021) introduce a two-step framework to assess the environmental benefits of repurposing lithium-ion batteries for electric vehicles. The first step involved energy flow modelling to assess the reduction in energy consumption in an industrial direct current micro-grid when a second life battery energy storage systems is employed. The second step involved LCA to compare the environmental impacts of repurposing versus alternative CBMs (i.e., remanufacturing and direct recycling) for these batteries. A sensitivity analysis was also performed.

Ioannidou et al. (2022) perform LCA, a techno-economic evaluation, and a scenario analysis on a biorefinery that use winery waste streams to produce bio-based succinic acid and value-added co-products. Their techno-economic assessment is based on the estimated fixed capital investment, the estimated cost of manufacture, a discounted cash flow analysis, and three techno-economic evaluation indicators (i.e., net present value, the discounted pay-back period, and the minimum selling price).

Sigüenza et al. (2021) combine LCA with a stock flow modelling and a scenario analysis to compare the long-term environmental impacts of a conventional BMs based on selling and a large-scale adoption of a use-oriented PSS (leasing) and a result-oriented PSS (pay-per-wash) in the washing machines market. The methods combined enable the modelling and measurement of business-related factors (i.e., adoption rate, sales, and installed base), technical aspects (i.e., production, obsolescence rates, material uses, material stocks, emissions, and impacts), as well as technological aspects (e.g., product composition, product energy use, manufacturing processes, end-of-life processes, and energy mixes) throughout the transition to CBMs (Sigüenza et al., 2021).

Lastly, Krassnitzer et al. (2025) combine LCA with several circularity indicators (i.e., a material reutilisation score, market endurance, a material circularity indicator, and a material efficiency metric) to compare the environmental and economic impacts of a traditional BM and a CBM for wood parquet flooring.

#### 4.2.3. Life cycle assessment combined with other qualitative methods

Six publications combine LCA (including sensitivity analysis and/or scenario analysis) with a variety of qualitative methods, including business model canvas, user interviews, focus groups, user trials, user survey, provider interviews, workshops, and sociological assessments

(see Table 1). These qualitative methods are invoked to meet various goals, including understanding the current situation, identifying potential CBMs and scenarios, testing CBMs, and providing complementary insights to the analysis (e.g., Allais and Gobert, 2016; Kambanou et al., 2024; Mukoro et al., 2022).

Kambanou et al. (2024) integrate LCA with other qualitative methods (e.g., user interviews, focus groups, user trials, user survey, provider interviews, and workshops) to understand the current state of the workwear market, develop alternative product designs and CBMs, and assess them from multiple perspectives (i.e., provider, user, customer, and environmental). Similarly, Gray et al. (2025) used interviews and a large-scale consumer survey to collect detailed data (e.g., number of garments, average lifespan, fabric type, and product characteristics) for the LCA of clothing-related CBMs.

Zilia et al. (2023) combine LCA business model canvas and a scenario analysis to evaluate the potential benefits of reusing sea urchin exoskeleton waste to develop environmentally sustainable products.

To evaluate the environmental impacts of transitioning from a conventional BM to a CBM, Mukoro et al. (2022) design a framework integrating LCA, sensitivity analysis and other qualitative methods (i.e., participatory decision making and business model canvas). Their framework comprises nine steps (Mukoro et al., 2022): (i) identify internal and external stakeholders (e.g., employees, customers, investors, and actors in the supply chain and in the distribution network) who are impacted by the BM; (ii) conduct a qualitative analysis of the current conventional BM (baseline case); (iii) quantify the environmental impacts of the conventional BM using LCA; (iv) identify the environmental impacts hotspots and drivers within the conventional BM and propose CE strategies to innovate it; (v) assess the environmental impacts of the CBM (i.e., the innovated BM) through LCA; (vi) conduct a sensitivity analysis to validate the LCA results; (vii) engage customers to determine if the new CBM is feasible and if it will be accepted and to what extent; (viii) perform a cost-efficiency analysis to evaluate the viability of implementing the proposed CBM with minimal resource use; and, lastly, (ix) test the proposed CBM to understand what works or fails and why and, if necessary, redesign it.

Focusing on PSS, Otterbach and Fröhling (2024) propose an assessment framework that integrates LCA, scenario analysis, sensitivity analysis, and other qualitative methods (i.e., business model analysis and hotspot analysis) to identify and evaluate PSS designs that are both viable and environmentally sustainable. The framework includes four consequential analyses (Otterbach and Fröhling, 2024): (i) a PSS analysis to identify the environmentally beneficial or detrimental characteristics; (ii) a hotspot analysis of products to determine which cycle phases contribute the most to environmental impact; (iii) a systematic literature review of the environmental assessments of PSSs for the analysed product; and (iv) a LCA to quantify the potential for reducing environmental impacts through promising and feasible PSS strategies.

Lastly, Allais and Gobert (2017) develop a multidisciplinary methodology combining LCA scenario analysis, sensitivity analysis, and other qualitative methods (i.e., sociological assessment) to assess PSS sustainability. Their methodology, first presented by Allais and Gobert (2016), is divided into three phases. In the first phase, prior to the experiment, data is collected through quantitative and qualitative interviews with service providers to gather insights on their motivation, concerns, and expectations; analyse their organisational and logistic activities; collect technical data; perform a comparative LCA; and model the logistic chain (Allais and Gobert, 2016). In the second phase, which occurs during the experiment, LCA and logistic models are implemented, and the motivation, concerns, and expectations of service providers are monitored to identify any changes (Allais and Gobert, 2016). Finally, after the experiment, recommendations are made regarding product and service design, challenges and issues for the involved organisation, and the impact of this consumption model on customers (Allais and Gobert, 2016). In this way, the LCA and the sociological study provide complementary insights: the LCA focuses on the environmental impact of a

single product throughout its life cycle, while the sociological study examines the entire value creation network, with a focus on the PSS implementation and its consequences (Allais and Gobert, 2016).

#### 4.2.4. Life cycle assessment combined with life cycle costing

The combination of LCA (including sensitivity analysis and/or scenario analysis) and LCC allows for an integrated and effective analysis of the environmental and economic consequences of CBMs: LCA assesses the environmental aspects and impacts, while LCC evaluates the costs incurred and/or benefits generated (e.g., Böckin et al., 2022; Mura et al., 2024). Their combined use enables to identify which factors cause the largest impacts (Mura et al., 2024).

Three publications (Lindahl et al., 2014; Mura et al., 2024; Zhang et al., 2018) combine LCA with LCC (see Table 1). More specifically, Zhang et al. (2018) develop an evaluation tool that assesses the economic and environmental aspects of a PSS for high energy-consuming equipment. This tool follows a seven-step framework (Zhang et al., 2018): (i) defining the evaluation goal(s) and scope; (ii) determining system boundaries and the evaluation period(s); (iii) identifying the evaluation methods, tools, and assumptions; (iv) determining the evaluation scenarios (i.e., traditional BM, PSS, key process recognition); (v) gathering environmental and economic data, including data compilation and forecasting; (vi) conducting a quantitative evaluation of the environmental and economic benefits; (vii) interpreting the results.

Lindahl et al. (2014) combine LCA and LCC to: (i) assess the environmental and economic benefits arising from a conventional BM and a PSS; (ii) identify the activities generating these effects.

Similarly, Mura et al. (2024) perform a scenario analysis alongside LCA and LCC to evaluate the environmental and economic benefits of transitioning from a conventional BM to a CBMs focused on extending product life in the wine industry.

#### 4.2.5. Business model life cycle assessment

Recognising that LCA focuses on the product function even when assessing BMs, and that combining it with economic analyses (e.g., LCC) does not allow to evaluate the BM performance, Böckin et al. (2022) proposed the BM-LCA. This innovative form of LCA shifts the focus to the BM and considers economic performance rather than the product's physical function as the basis of the comparison (Böckin et al., 2022). Thus, the BM-LCA addresses the lack of a systemic approach to assessing the environmental impacts of BMs (Böckin et al., 2022). The BM-LCA consists of two phases. The first phase (the descriptive phase) defines the analysis goal, the BMs to be compared (at least two), the system boundaries, and the environmental impact categories. The BMs are described based on the type of customer transactions (i.e., ownership transfer or retention) and product stock management, while associated products are detailed based on their relevant characteristics (e.g., material composition, function, and lifetime). Additionally, the relationship between production and the number of transactions is also defined in this phase. In the second phase (the coupling phase), the functional unit (i.e., the amount of profit that should be earned over a period associated with certain products and a particular BM) is determined. This functional unit is used to compare the BMs and to define the equations linking the material and monetary flows. For each BM, the number of transactions and the level of production needed to reach the defined profit level are then calculated.

The BM-LCA is considered to be a promising method (Goffetti et al., 2022) and the first framework that integrates both qualitative and quantitative information to assess the environmental performance of BMs (Desclaux and Pereira, 2024). The BM-LCA helps to identify the specific parameters in a BM that significantly influence the environmental impact (Böckin et al., 2022). Thus, the BM-LCA can help companies to enhance their environmental performance while still maintaining profitability (Goffetti et al., 2022). However, the BM-LCA has some limitations: for example, its profit margin analysis does not account for the time value of money, nor does it consider the effects of

depreciation and taxes over time (Gonzalez-Salazar et al., 2023).

Only two publications use the BM-LCA (see Table 1): Böckin et al. (2022), who propose the BM-LCA, and Goffetti et al. (2022), who apply the BM-LCA combined with a sensitivity analysis.

4.2.6. Life cycle assessment combined with life cycle costing and other qualitative and quantitative methods

Fargnoli et al. (2018) is the only publications that combine LCA with LCC, other qualitative methods (i.e., quality function deployment method), and other quantitative methods (i.e., screening life cycle modelling) with the aim of exploring how manufacturing companies can successfully implement PSS in a regulated market while enhancing customer satisfaction and environmental sustainability (see Table 1). Their analysis comprises two phases (Fargnoli et al., 2018). In the first one, market demand and customer satisfaction, needs, and priorities are analysed using the quality function deployment method. In the second phase, LCA, LCC, and the simulation of life-cycle scenarios through the screening life cycle modelling method are used to evaluate potential life cycle scenarios.

4.3. Relationships among methodologies

By examining the usage of each method and their interrelations, the central role of LCA becomes evident. LCA is primarily used independently, though it is often combined with other methods, i.e. (see Fig. 2):

- i) LCC, for an integrated and effective analysis of the environmental and economic consequences of CBMs (e.g., Böckin et al., 2022; Mura et al., 2024);
- ii) other qualitative methods (e.g., business model canvas, user interviews, focus groups, user trials, user survey, provider interviews, workshops, and a sociological assessment), for understanding the current situation, identifying potential CBMs and scenarios, testing CBMs, and providing complementary

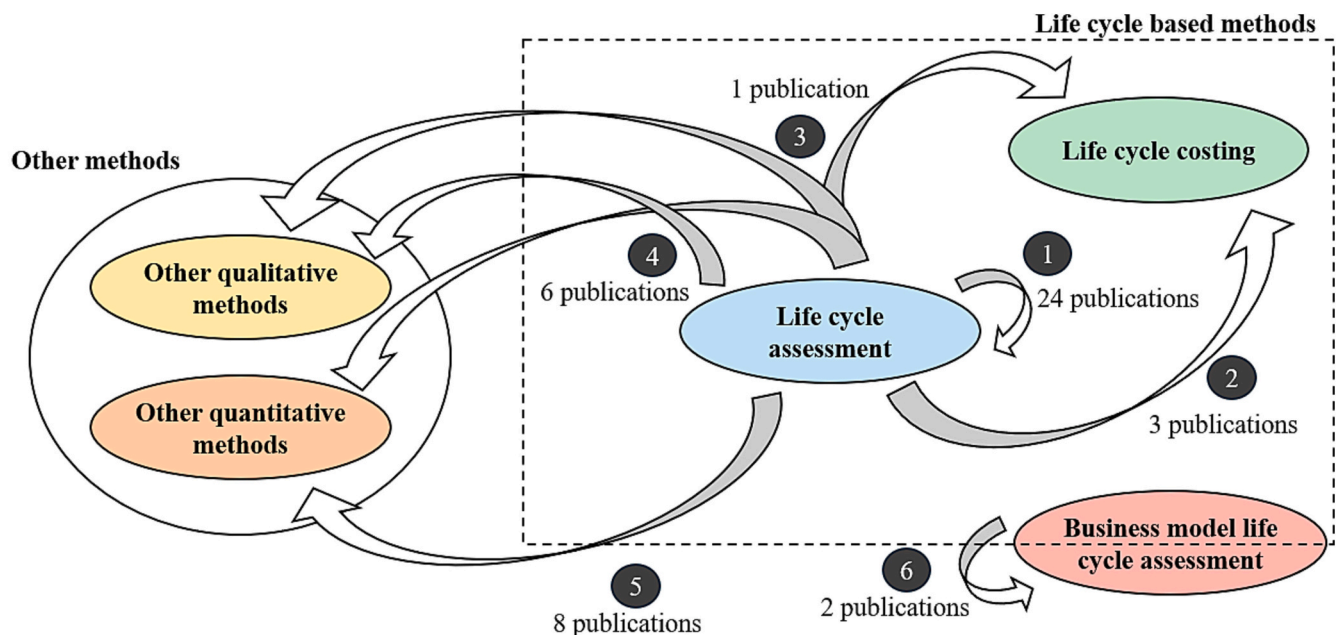
insights for the analysis (e.g., Allais and Gobert, 2016; Kambanou et al., 2024; Mukoro et al., 2022);

- iii) other quantitative methods (e.g., discrete event simulation, net present value analysis, battery fleet model, stock flow model, and energy flow model), for obtaining a more comprehensive evaluation, conducting a complementary assessment to LCA or providing the information required for a more robust LCA (Gonzalez-Salazar et al., 2023; Mann et al., 2022; Schulz-Mönnighoff et al., 2021).

Among all the methods identified, the BM-LCA emerges as a distinct, standalone method.

The combined use of two or more methods (i.e., LCA, LCC, other qualitative methods, and other quantitative methods) occurs in four distinct ways (see Fig. 3):

- i) simultaneous and independent application: LCA is combined with LCC or other quantitative methods in a simultaneous but independent manner and the results derived from the various methods are integrated at a later stage. This is the most common type of combined application (e.g., Gonzalez-Salazar et al., 2023; Houssard et al., 2022; Ioannidou et al., 2022);
- ii) simultaneous and interactive application: LCA and other qualitative methods are used interactively and iteratively in the various stages of the analysis and the results obtained from each phase are integrated into the following stage (Allais and Gobert, 2017; Kambanou et al., 2024; Mukoro et al., 2022);
- iii) sequential application: LCA is applied either before or after the use of other methods. Typically, qualitative or quantitative methods are employed prior to LCA to gather the necessary information for a more informed and comprehensive LCA (Otterbach and Fröhling, 2024; Schulz-Mönnighoff et al., 2021; Sigüenza et al., 2021). However, in one publication, LCA and LCC were used first, followed by other qualitative and quantitative



Legend:  
 1. Life Cycle Assessment (including sensitivity analysis and/or scenario analysis)  
 2. Life Cycle Assessment (including sensitivity analysis and/or scenario analysis) combined with Life Cycle Costing  
 3. Life Cycle Assessment (including sensitivity analysis and/or scenario analysis) combined with Life Cycle Costing, other qualitative methods, and other quantitative methods  
 4. Life Cycle Assessment (including sensitivity analysis and/or scenario analysis) combined with other qualitative methods  
 5. Life Cycle Assessment (including sensitivity analysis and/or scenario analysis) combined with other quantitative methods  
 6. Business Model Life Cycle Assessment (including sensitivity analysis)

Fig. 2. Relationships among LC-based (Life cycle based) methodologies to assess Circular business models (CBMs). Note: The figure considers quantitative analyses only, excluding literature reviews, meta-analyses, and qualitative analyses.

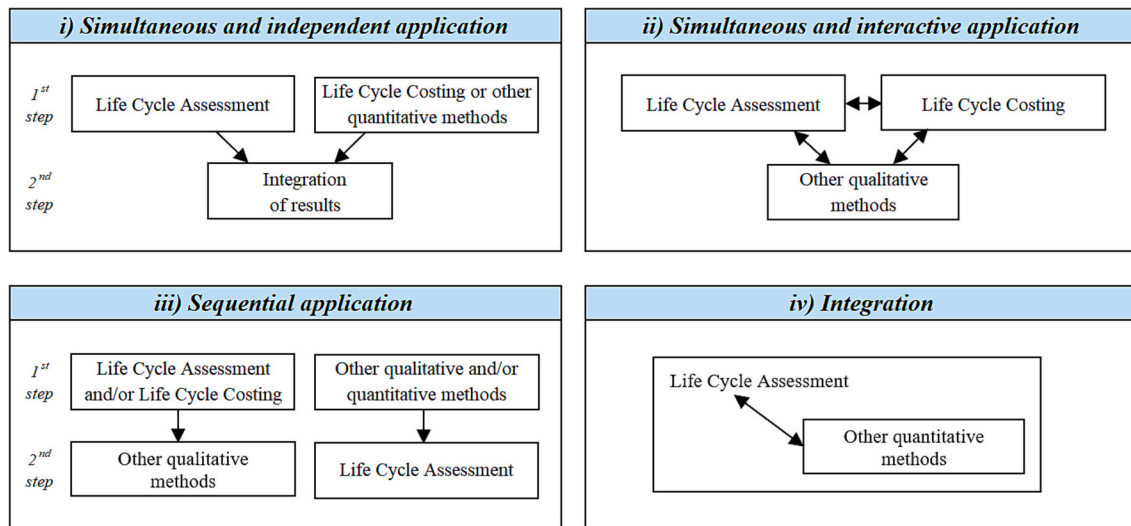


Fig. 3. Ways in which two or more LC-based (Life cycle based) methodologies have been combined.

methods, which were used to conduct a feasibility analysis (Fargnoli et al., 2018);

iv) integration: LCA and other quantitative methods are combined to perform a more comprehensive analysis (Mann et al., 2022).

4.4. Evolution of methodologies over time

As trends over time show, the use of LCA alone is increasingly being replaced by its combination with other methods (i.e., LCC, other qualitative methods, and other quantitative methods) or the adoption of BM-LCA (see Fig. 4). This shift indicates a growing need for approaches that complement LCA or offer alternatives to achieve more comprehensive analyses.

4.5. RQ2: purpose of analysis

To identify the main purposes of analysis, we examined relevant publications and gathered key information regarding their purpose. Subsequently, we compared the information with each other and identified the following four main purposes:

- i) to evaluate the environmental impacts of singular CBMs, i.e., their environmental performance in relation to one or more impact categories;
- ii) to compare the environmental impacts of BMs and/or CBMs, with the aim of highlighting the advantages and disadvantages of each BM and CBM in terms of environmental performance and determining which model is the most environmentally friendly;

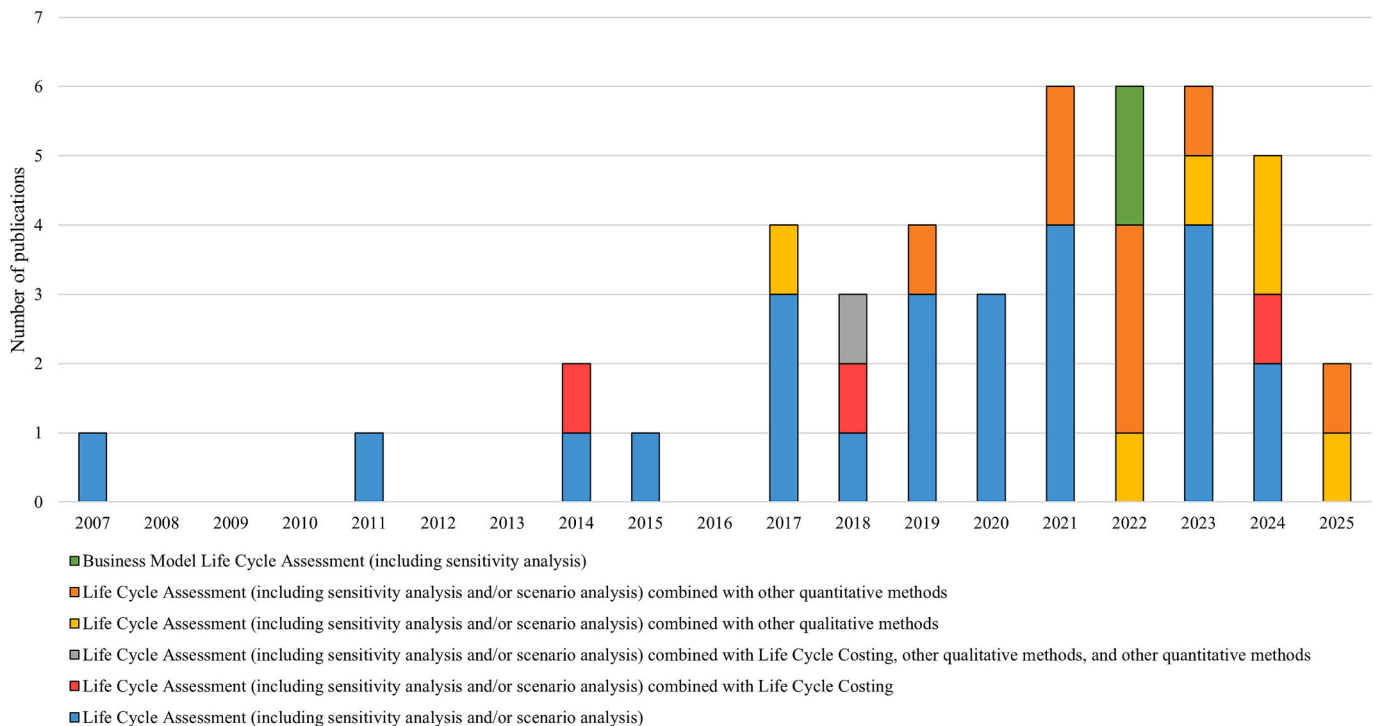


Fig. 4. Evolution of LC-based (life cycle based) methodologies over time. Note: The table reports quantitative analyses only, excluding literature reviews, meta-analyses, and qualitative analyses.

- iii) to evaluate the transition from a BM to a CBM, with the aim of determining if the designed CBM leads to lower environmental impacts compared to the current traditional BM, while also quantifying any potential environmental benefits arising from this transition;
- iv) to design and implement CBMs, where effective CBM implementation is facilitated by evaluating the environmental impacts of different design alternatives and identifying any potential issues with each option.

Almost all publications undertake their analysis with just one of these objectives in mind (e.g., [Martin et al., 2021](#); [Wrålsen and O’Born, 2023](#)). The only exception is [Daddi et al. \(2017\)](#), who applies LCA to an industrial symbiosis for two distinct purposes: i) assessing the environmental impacts of the current industrial symbiosis and ii) designing and implementing a new CBM based on initiatives proposed by local policymakers.

Most publications (22 publications) compare the environmental impacts of various BMs or CBMs (e.g., [Johnson and Plepys, 2021](#); [Maliqi et al., 2024](#); [Sai et al., 2023](#)) (see [Table 2](#)). For instance, [Chun and Lee \(2017\)](#) and [Monticelli and Costamagna \(2023\)](#) compare the environmental impacts of a PSS based on renting with a conventional BM, whereas [Mann et al. \(2022\)](#) and [Sivaraman et al. \(2007\)](#) examine multiple CBMs.

The second most frequent purpose is to evaluate the transition from a BM to a CBM, as explored in nine publications (e.g., [Bech et al., 2019](#); [Schulz-Möninghoff et al., 2021](#)). For example, [Mura et al. \(2024\)](#) and [Zilia et al. \(2023\)](#) evaluate whether the adoption of CE strategies for extending a product’s life or extending resource value resulted in environmental benefits compared to the current situation.

An evaluation of the environmental impacts of singular CBMs is also performed in nine publications. Individual CBMs considered in the analysis include an industrial symbiosis ([Capucha et al., 2023](#); [Yu et al., 2015](#)), a CBM designed to slow or close resource loops ([Barbieri and Santos, 2020](#); [Ioannidou et al., 2022](#)), and a use-oriented PSS ([Mao et al., 2021](#)).

Lastly, the analysis performed to design and implement CBMs is conducted in only five publications (e.g., [Amaya et al., 2014](#); [Zhang et al., 2018](#)). For example, [Liu et al. \(2011\)](#) explore the design and implementation of an industrial symbiosis considering different scenarios, whereas [Fargnoli et al. \(2018\)](#) examine customer needs and satisfaction and consider alternative scenarios to inform the design and implementation of a PSS.

Analysing the trend over time, it becomes evident that the publications that focus on comparing the environmental impacts of BMs and/or CBMs and those evaluating the transition from a BM to a CBM were published throughout the period considered in the analysis (2007 to 2025) and have seen an increase in the last four and two years,

**Table 2**

Purpose of analysis of LC-based (life cycle based) methodologies to assess circular business models (CBMs).

Purpose of analysis	Number of publications	Percentage of publications
Compare the environmental impacts of business models/circular business models	22	49 %
Evaluate the transition from a business model to a circular business model	9	20 %
Evaluate the environmental impacts of singular circular business models	9	20 %
Design and implement circular business models	5	11 %
<b>Total</b>	<b>45</b>	<b>100 %</b>

Note: The table considers quantitative analyses only, excluding literature reviews, meta-analyses, and qualitative analyses. Publications addressing multiple purposes of analysis were included in the count for each corresponding purpose.

respectively. Instead, publications evaluating the environmental impacts of a singular CBMs have remained steady across the period. Conversely, publications aimed at designing and implementing CBMs were exclusively published before 2018. This highlights a temporal shift in the purposes for which LC-based methodologies are being used to assess the environmental impacts of CBMs.

#### 4.6. RQ3: types of circular business models

To identify the types of CBMs analysed, we employed a two-step procedure. Initially, we conducted a comparative analysis of existing CBM classifications found in the literature. From this, we identified eight distinct types of CBM (see [Table 3](#)): product-oriented PSS, use-oriented PSS, result-oriented PSS, extending product life, encourage sufficiency, extending resource value, industrial symbiosis, and circular supplies. Subsequently, we categorised the CBMs analysed in the relevant publications, mapping them to the identified CBMs.

Of the analysed publications, 35 focus on a single type of CBMs (e.g., [Bech et al., 2019](#); [Chun and Lee, 2017](#)), and six publications consider two types CBMs (e.g., [Barbieri and Santos, 2020](#); [Hoffmann et al., 2020](#)). Only two publications, namely, [Kjaer et al. \(2018\)](#) and [Zhang et al. \(2018\)](#), consider three types of CBMs.

Use-oriented PSS are the most analysed type of CBM, appearing in 25 publications (see [Table 4](#)). For example, [Martin et al. \(2021\)](#) and [Kerdlap et al. \(2021\)](#) evaluate the environmental impacts of a use-oriented PSS based on renting of electric chainsaws and prams, respectively. [Zamani et al. \(2017\)](#) explore a use-oriented PSS centred around collaborative consumption, specifically a clothing library where members pay a monthly fee to borrow a set number of garments for a specific period. Four publications (e.g., [Mao et al., 2021](#); [Zheng et al., 2019](#)) focus on use-oriented PSS for bike sharing, for example examining the impact of different sharing systems (i.e., station-based and dock-less sharing) ([Luo et al., 2019](#)) or different bike characteristics, redistribution systems, and maintenance support ([Amaya et al., 2014](#)).

Result-oriented PSS are analysed in eight publications. An example is [Otterbach and Fröhling \(2024\)](#), which examine a result-oriented PSS involving washing-as-a-service, where customers pay a fee based in part on usage to access a fully functional washing machine. Similarly, [Hoffmann et al. \(2020\)](#) analyse a result-oriented PSS that implements a pay-per-service system for modern cloth diapers. [Lindahl et al. \(2014\)](#), on the other hand, investigate a case in which the provider delivers an exterior

**Table 3**

Types of circular business models (CBMs) identified in the literature and the corresponding CBMs used in this review, where PSS stands for product service systems.

Type of CBM identified in the literature	Corresponding CBM used in this review
Access and performance model ( <a href="#">Bocken et al., 2016</a> )	See product service systems classification
Sharing platforms ( <a href="#">Accenture, 2014</a> )	See product service systems classification
Product as a service ( <a href="#">Accenture, 2014</a> )	See product service systems classification
Product-oriented product service systems ( <a href="#">Tukker, 2004</a> )	Product-oriented product service systems
Use-oriented product service systems ( <a href="#">Tukker, 2004</a> )	Use-oriented product service systems
Result-oriented product service systems ( <a href="#">Tukker, 2004</a> )	Result-oriented product service systems
Extending product value ( <a href="#">Bocken et al., 2016</a> )	Extending product life
Product life extension ( <a href="#">Accenture, 2014</a> )	Extending product life
Classic long-life model ( <a href="#">Bocken et al., 2016</a> )	Extending product life
Encourage sufficiency ( <a href="#">Bocken et al., 2016</a> )	Encourage sufficiency
Extending resource value ( <a href="#">Bocken et al., 2016</a> )	Extending resource value
Resource recovery ( <a href="#">Accenture, 2014</a> )	Extending resource value
Industrial symbiosis ( <a href="#">Bocken et al., 2016</a> )	Industrial symbiosis
Circular supplies ( <a href="#">Accenture, 2014</a> )	Circular supplies

**Table 4**  
Types of Circular Business Models (CBMs).

Type of CBM	Number of publications	Percentage of publications
Use-oriented product service systems	25	45 %
Result-oriented product service systems	8	15 %
Extending product life	7	13 %
Industrial symbiosis	6	11 %
Extending resource value	4	7 %
Product-oriented product service systems	4	7 %
Circular supplies	1	2 %
Encourage sufficiency	0	0 %
<b>Total</b>	<b>55</b>	<b>100 %</b>

Note: The table considers quantitative analyses only, excluding literature reviews, meta-analyses, and qualitative analyses. Publications assessing multiple CBMs were included in the count for each corresponding CBM.

building cleaning service.

CBMs focused on extending product life are explored in seven publications. For instance, [Wrålsen and O’Born \(2023\)](#) study the environmental impact of a CBM to remanufacture li-ion batteries, where battery packs are dismantled into modules and reassembled into a second life battery pack. Similarly, [Mura et al. \(2024\)](#) investigate a CBM based on the take-back and refurbishment of wine packaging components.

Industrial symbiosis is analysed in six publications. An example is the study by [Liu et al. \(2011\)](#), which explores an industrial symbiosis to recover energy from municipal sewage sludge and re-refined oil. [Wang et al. \(2019\)](#) explore the potential of industrial symbiosis to mitigate environmental impacts within an energy-intensive industrial park. [Phi et al. \(2020\)](#) analyse the environmental impacts of implementing industrial symbiosis in insect production, comparing it to a scenario without symbiosis.

CBMs aimed at extending resource value are examined in four publications. For instance, [Ioannidou et al. \(2022\)](#) conduct a techno-economic evaluation and LCA of a biorefinery that uses winery waste streams to produce bio-based succinic acid and value-added co-products.

Product-oriented PSS are analysed in four publications. For instance, [Kjaer et al. \(2018\)](#) examine a product-oriented PSS where households purchase a shared lawnmower, supported by a repair-service contract. [Maliqi et al. \(2024\)](#) analyse a product-oriented PSS in which a heating system is offered alongside regular and corrective maintenance services, remote monitoring, and the option to upgrade the system.

Lastly, circular supplies emerged as the least analysed CBM. [Barbieri and Santos \(2020\)](#) is the only publication that considers a CBM integrating circular supplies and extending resource value through CE strategies such as reducing and optimising water consumption, reusing wastewater, reducing energy resources, and using recyclable or biodegradable materials.

No publication analysed the CBM aimed at encouraging sufficiency.

#### 4.7. Sectors

To identify the sectors analysed, we examined relevant publications and gathered key information regarding the sector or product analysed. Subsequently, we compared the information with each other and identified 12 sectors (see [Table 5](#)). Almost publications considered one sector in the analysis (e.g., [Daddi et al., 2017](#); [Ioannidou et al., 2022](#)). The few exceptions are [Lindahl et al. \(2014\)](#) who focus on two sectors (i.e., machinery & machinery components; cleaning services) and [Kjaer et al. \(2018\)](#) who analyse three sectors (i.e. vehicles; electrical & electronic equipment; cleaning services). Electrical & electronic equipment and clothing are the most analysed sectors (considered in 13 and 9 publications, respectively), whereas machinery & machinery components and

**Table 5**  
Sectors.

Sector	Number of publications	Percentage of publications
Electrical & electronic equipment	13	28 %
Clothing	9	19 %
Vehicles	5	11 %
Food & food packaging	4	9 %
Batteries	3	6 %
Energy production	3	6 %
Childcare products	2	4 %
Chemical & pharmaceutical	2	4 %
Cleaning services	2	4 %
Construction	2	4 %
Machinery & machinery components	1	2 %
Waste management	1	2 %
<b>Total</b>	<b>47</b>	<b>100 %</b>

Note: The table considers quantitative analyses only, excluding literature reviews, meta-analyses, and qualitative analyses. Publications focusing on multiple sectors were included in the count for each corresponding sector.

waste management are the least analysed, considered in only one publication each.

Specific sectors and products were also considered in some reviews and meta-analyses discussing CBMs and their assessment. Focusing on the biomass supply chain, [Longo et al. \(2024\)](#) observe that the CE principles of reuse, recycle, reduce, and recover are applied through three strategies (i.e., using innovative technologies, improving operational activities, and extending the biomass supply chain). Additionally, life cycle thinking is primarily used to assess environmental and economic sustainability, while social aspects are sometimes overlooked ([Longo et al., 2024](#)).

The review by [De Carvalho Araújo et al. \(2022\)](#) on the wood panel industry identifies the production areas where circularity can be improved, the most common impact categories analysed (e.g., global warming, ozone depletion, and photochemical oxidation), the CBM principles applied in the sector (e.g., reduction of materials from non-renewable sources, waste reuse, and use of renewable energy), the current CBMs in use (i.e., circular materials, promotion of renewable options, resource recovery, and product life extension), and the potential future CBMs (i.e., sharing platforms and product-as-a-service).

Finally, [Suckling and Lee \(2015\)](#) conduct a meta-analysis to examine the environmental impact of mobile phones and the shift from a conventional sales BM to a PSS based on a cloud service. They find that the extraction and manufacturing phases generate the highest greenhouse gas emissions, followed by the use phase, where the impact increases if a server or a network is integrated with the smartphone ([Suckling and Lee, 2015](#)). Promptly returning mobile phones for reuse and appropriate disposal can significantly reduce their environmental footprint and toxic emissions ([Suckling and Lee, 2015](#)). The introduction of a cloud-based PSS with end-of-life take-back solutions requires improved energy efficiency to reduce the use-phase impact but maximises the value recovery from the phones and their components ([Suckling and Lee, 2015](#)).

#### 4.8. Relationships among the key dimensions of analysis

To investigate the relationships among the methods, the purposes of analysis, the types of CBM, and the sectors, we built a Sankey diagram (see [Fig. 5](#)). This illustrates the flows and the distribution of key results using arrows, whose width indicates the magnitude of the flow ([Soundararajan et al., 2014](#)). This visual tool was chosen for its ability to represent complex, multidimensional relationships in a clear and intuitive way, allowing readers to immediately grasp the relative importance and frequency of specific connections ([Soundararajan et al., 2014](#)). Overall, the Sankey diagram is not only a descriptive device but also an

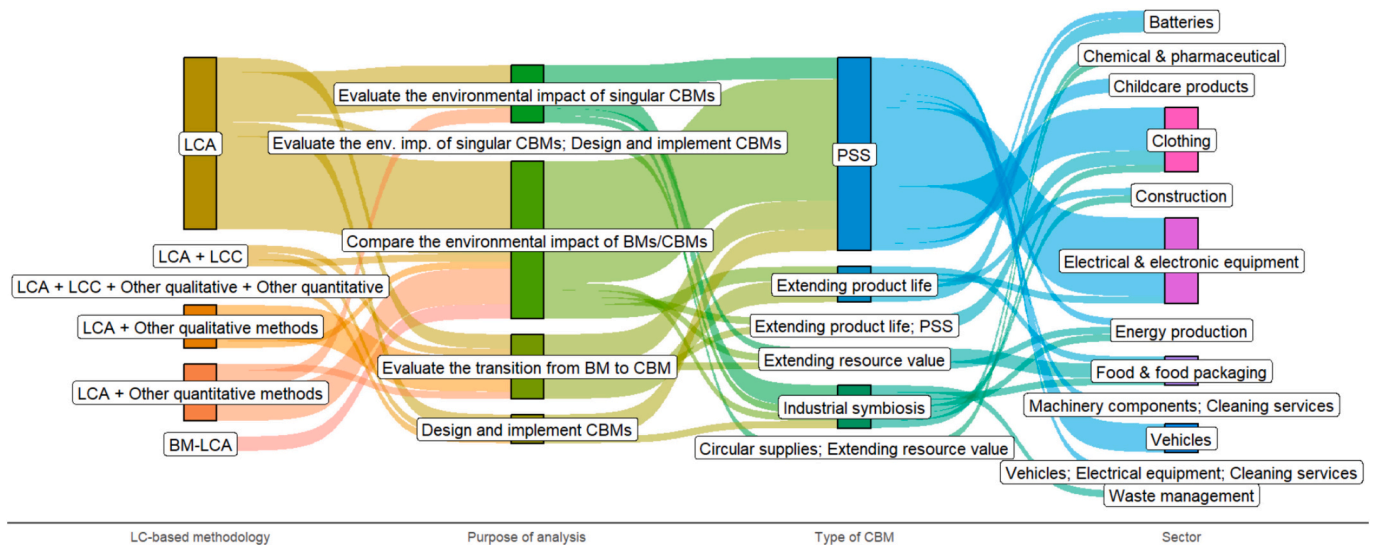


Fig. 5. Sankey diagram describing the relationships among the key dimensions of analysis, i.e., LC-based methodology used, purpose of analysis, type of CBM and sector.

analytical tool that helps to identify dominant patterns, underexplored areas, and opportunities for further research (Soundararajan et al., 2014).

Several key trends emerge from the Sankey diagram showing the results of this review. LCA is primarily used to compare the environmental impacts of BMs and CBMs, suggesting that environmental performance remains a central concern in the evaluation of circular strategies, with LCA offering a standardised and widely accepted framework for comparison. This type of analysis is mostly applied to PSS. This focus highlights the relevance of PSS within circular strategies, likely due to its potential to reduce material consumption and extend product life through services. Research is converging around the electrical & electronic equipment and clothing sectors, where the implementation of circular strategies such as reuse, refurbishment, and recycling is both impactful and actionable.

#### 4.9. RQ4: research gaps and future research avenues

While a variety of methods for assessing CBMs currently exist, further advancements are recommended. Our review has highlighted that LC-based methodologies for assessing CBMs require standardisation. As we have observed in the literature, a multitude of approaches and methods are available; however, research still lacks a standardised approach, which could undermine the reliability and comparability of findings. In this context, researchers should first focus on developing a procedural framework for LCA of BMs that can be standardised to ensure consistency and facilitate comparisons.

Refining frameworks to integrate the rebound effects of CBMs into LCA is also necessary. Reboundless design, i.e., the design of “products, product/service-systems and socio-technical systems that are resilient to rebound effects” (Pigosso, 2024, p. 9) is particularly relevant to this end, as it enables the consideration of rebound effects when assessing sustainability impacts through methodologies such as LCA (Pigosso, 2024). To this end, conducting a comprehensive literature review that systematically examines these phenomena within the context of CBMs can be useful. Such review should emphasise, for instance, the underlying mechanisms and triggers of rebound effects, while also exploring how LC-based methodologies can be adapted to capture both their direct and indirect impacts on sustainability outcomes.

Moreover, methods for evaluating complex CBMs, such as PSS, require improvement. Challenges associated with assessing PSS using LCA have been identified and discussed (Kjaer et al., 2016), with specific

guidelines proposed (Kjaer et al., 2018). However, these guidelines need further testing and refinement to account for both industry-specific characteristics and rebound effects (Kjaer et al., 2018). Future studies should not only test the guidelines proposed by Kjaer et al. (2018), but also advance and complement them with new guidelines and methods specifically designed to address the unique characteristics of complex CBMs.

The BM-LCA proposed by Böckin et al. (2022) is a promising method, but needs broader application and validation across various CBMs and sectors (Böckin et al., 2022; Goffetti et al., 2022). Additionally, the BM-LCA could be expanded to include the social impacts of CBMs alongside environmental considerations (Böckin et al., 2022). Based on these observations, future studies should test and validate the BM-LCA while also refining it to incorporate social impacts and address potential methodological and application limitations. Furthermore, integrating the BM-LCA with other qualitative and quantitative methods could further enhance the analytical scope of this new method.

A comprehensive approach to CBM analysis that simultaneously considers environmental, economic, and social impacts is strongly recommended given the importance of promoting sustainability in all its dimensions. Current practices typically evaluate environmental and economic impacts separately, merging the results later (Zhang et al., 2018). An integrated evaluation, however, is preferable as it better supports decision-making during CBM development (Zhang et al., 2018). Procedures for integrating these evaluations through LCA and LCC have been proposed (Zhang et al., 2018), and the BM-LCA represents an advancement in this area (Böckin et al., 2022). Nevertheless, greater effort is needed to deepen the understanding of the environmental and economic impacts of CBMs. Similarly, social impacts are often overlooked when assessing CBM despite their potential as significant benefits (Koide et al., 2022). Considering that CBMs aim to foster not only environmental and economic sustainability but also social well-being, incorporating social impact evaluations is crucial to ensure a truly holistic and equitable transition toward sustainability. To this end, the LCSA framework provides a promising avenue for simultaneously evaluating environmental, economic, and social impacts (Mura et al., 2024).

Regarding the purposes of CBM assessments, existing studies have addressed a wide range of objectives. However, further research is needed to assess CBMs during their design and implementation stages, as this type of evaluation is crucial for informing design and strategy adjustments at an early stage (Kjaer et al., 2016, 2018; Wrålsen and

O'Born, 2023). These ex-ante evaluations of the impacts of CBMs should then be compared with ex-post assessments to determine whether the expected impacts have materialised. In addition, if discrepancies arise, it is crucial to identify the factors that contributed to the observed outcomes. Gaining this insight is particularly valuable, as it can inform the design and implementation of future CBMs to ensure more effective and sustainable BM transitions. Nevertheless, addressing the challenges of ex-ante assessments, including the high uncertainty (Kjaer et al., 2016), requires methodological advancements, making this a key focus for future research.

Existing studies have examined various types of CBMs. Use-oriented and result-oriented PSS are the most researched, while other CBMs (i.e., extending resource value, product-oriented PSS, circular supplies, and encourage sufficiency) have received comparatively less or no attention. This disparity partly stems from the challenges in assessing certain CBMs, such as industrial symbiosis (Daddi et al., 2017). Consequently, we agree with Johnson and Mont (2025) in that there is a clear opportunity for further research on underexplored CBMs, but this will only be possible if improvements are made to the methods and the way data are collected and analysed.

Further, future research should simultaneously explore multiple CBMs. Studies often focus on comparing two types of CBMs, usually two different types of PSS. However, we recommend expanding these comparisons to include three or more CBMs of different types to determine which CBM is the best one depending on the context in which it is implemented and the outcomes that are sought. If this comparison takes place when designing and implementing the CBM, it could help maximise the benefits by ensuring the adoption of the most suitable CBM.

Finally, our review reveals a broad sectoral coverage of analysed CBMs. Nevertheless, we encourage further studies focusing on CBMs in less studied or unexplored sectors to enrich existing knowledge.

#### 4.10. Managerial suggestions

The environmental impacts of CBM vary significantly across cases, with some demonstrating comparable, higher, or lower impacts relative to conventional BM (Johnson and Mont, 2025). The results of our review confirm these findings.

Specifically, CBMs can reduce greenhouse gas emissions and cut economic costs if well-designed (Mura et al., 2024). Similarly, washing-as-a-service consistently outperforms ownership models in all environmental categories (Otterbach and Fröhling, 2024). Design innovation plays a crucial role in reducing environmental impacts. Product and BM innovations such as design for durability, repair, design for washing, and workwear-as-a-service can improve environmental performance, but their effectiveness depends on user acceptance, logistics, and economic viability (Kambanou et al., 2024).

Conversely, some studies suggest that CBMs can fail to deliver environmental benefits when not appropriately designed. For instance, shifting from product sales to a PSS for small household equipment may not generate environmental value (Allais and Gobert, 2017). Similarly, offering a Merino t-shirt through a PSS instead of a traditional BM increases greenhouse gas emissions since poorly designed PSS can negatively impact climate change (Bech et al., 2019).

For high-impact sectors such as batteries, second-life applications present both benefits and trade-offs. Repurposing lithium-ion batteries is the most beneficial CBM option for manufacturers, especially when considering delayed end-of-life and additional recycling gains (Schulz-Möninghoff et al., 2021). Yet, energy consumers experience lower climate benefits in multi-use cases than in single-use ones (Schulz-Möninghoff et al., 2021). Similarly, second-life lithium-ion batteries must avoid more than 16 % of new battery production emissions to be environmentally advantageous (Wrålsen and O'Born, 2023). Finally, in bio-waste management, CBMs involving the reuse of sea urchin waste significantly reduce the negative environmental impacts compared to traditional municipal organic waste disposal systems (Zilia et al., 2023).

These results suggest that CBMs can significantly reduce environmental impacts, but only under specific conditions: careful system design, economic and logistical feasibility, user engagement, and accurate life cycle assumptions. Instead, poorly implemented or misaligned CBMs may lead to increased emissions, rebound effects, or less favourable outcomes than conventional BMs. Thus, environmental gains are not inherent to CBMs, but rather conditional and a case-by-case assessment is therefore recommended. Moreover, the evaluation of the environmental impacts of CBMs should be performed both before and after the CBM is implemented (Kjaer et al., 2018). Ex-ante assessments are crucial as they help to forecast the environmental impacts before the adoption of CBM (Das et al., 2022). They also allow for radical changes in design and strategy to be proposed and implemented at an early stage, thereby supporting decision-making (Kjaer et al., 2016, 2018; Wrålsen and O'Born, 2023). However, they are inherently more uncertain due to their reliance on estimates and limited system knowledge (Kjaer et al., 2016). Conversely, post-assessments are crucial for evaluating the actual effects of CBMs, accounting for rebound effects, determining whether the intended environmental benefits have been achieved, and identifying the contextual factors that influenced the outcomes (Kjaer et al., 2018; Wrålsen and O'Born, 2023).

As mentioned, evaluating CBMs poses significant challenges (Kjaer et al., 2016) and no single procedure is applicable to all types and characteristics of CBMs (Barbieri and Santos, 2020). Therefore, the next section outlines some managerial suggestions for assessing the environmental impacts of CBMs based on insights from previous literature.

##### 4.10.1. Collection of detailed information

Using complementary methods (e.g., LCA, LCC, qualitative or quantitative methods) is essential for obtaining a holistic understanding of the potential and limitations of a CBM (Allais and Gobert, 2016). However, the lack of sufficient data has been identified as a frequent barrier in assessing CBMs (Das et al., 2022). To address this problem, companies can leverage big data analytics and digital technologies (e.g., the Internet of Things) to collect relevant insights, facilitate more efficient and comprehensive analyses, and support decision-making (Tamym et al., 2023). Robust data collection also relies on strong collaboration across business functions. Establishing a structured and continuous process for gathering and updating company information is essential to ensuring data accuracy, granularity, and reliability. Without such a system, analysing CBMs may become difficult or lead to compromised results. Finally, involving experts and key stakeholders (e.g., manufacturers, providers, and customers) improves the analysis by incorporating diverse perspectives and comprehensive information and analysis (Koide et al., 2022; Otterbach and Fröhling, 2024; Schulz-Möninghoff et al., 2021). Businesses must therefore play an active role in creating collaborations with experts and key stakeholders.

##### 4.10.2. Implementation of sensitivity analysis

Advanced and comprehensive assessments are essential for understanding the impacts of CBMs. Sensitivity analysis plays a critical role in examining the effects of complex business aspects that are challenging to model in the primary evaluation (Böckin et al., 2022). Furthermore, global sensitivity analysis, which involves simultaneously varying all input parameters, can provide a more accurate and detailed understanding of the potential benefits and risks associated with a CBM (Koide et al., 2022). This approach enables a more comprehensive interpretation than a local sensitivity analysis, which focuses on altering individual parameters (Koide et al., 2022). Finally, expanding system boundaries, such as including transportation impacts, can also provide a more accurate assessment (Koide et al., 2022). For these reasons, we recommend always conducting a sensitivity analysis—preferably a global one—and expanding the system's boundaries to achieve the most advanced and comprehensive assessments possible.

#### 4.10.3. Implementation of economic and social analyses

It is also important to conduct economic evaluations since CBMs are typically only viable if they generate profit and assure economic sustainability (Bjørnbet and Vildåsen, 2021; Monticelli and Costamagna, 2023). However, caution must be taken to avoid misinterpreting results when economic and environmental impacts are assessed separately as problems with data collection, inconsistencies, and lower significance may emerge (Zhang et al., 2018). Similarly, as discussed, the evaluation of social impacts should be performed to assess the social and socio-economic impacts of a CBM on the various stakeholders involved (Koide et al., 2022). It is essential to verify not only the absence of negative environmental impacts, but also the absence of adverse social impacts (Bjørnbet and Vildåsen, 2021; Petti et al., 2018) since any negative effects could reduce the viability of CBMs while undermining the creation of social value (Allais and Gobert, 2016, 2017).

Since LCA only evaluates the environmental impacts of CBMs, and not their economic and social impacts (Bech et al., 2019), it is best to combine several different methods as to arrive at a full LCSA. In this context, social LCA (S-LCA) can be employed to evaluate social impacts; however, several limitations must be considered. The S-LCA methodology is at an earlier stage of development than LCA and LCC, and its standardisation has only recently been finalised (see ISO standard 14075:2024; ISO, 2024). Although there is rising interest in the scientific community to harmonise further methods and indicators, and the necessity to implement the S-LCA methodology in diverse sectors and products in order to define plausible assumptions and set specific rules (Traverso and Mankaa, 2025), social impacts are inherently complex to assess.

A thorough analysis that simultaneously evaluates environmental, economic, and social impacts is however highly recommended to ensure that the assessed CBM genuinely fosters sustainability across all its dimensions (Johnson and Mont, 2025).

#### 4.10.4. Consideration of contextual factors and customers

Several contextual factors should be considered when evaluating the environmental impacts of CBMs (Bhatnagar et al., 2022), especially since these impacts often depend on the socio-cultural context in which the CBMs is offered (Bech et al., 2019).

Consumer behaviour plays a critical role (Bech et al., 2019; Sigüenza et al., 2021). As noted by Johnson & Plepys (2021, p. 2), “it is not only the business model nor the product or design that determines the overall sustainability, but consumers' intentions, behaviours, and habits”. CBMs are designed to substitute linear BMs, but perfect substitution may not occur (Bączyk et al., 2024). PSS, for example, can significantly change consumption behaviour and, therefore, they have potential, but only if the right conditions exist (Johnson and Plepys, 2021). Hence, to ensure that CBMs effectively reduce environmental impacts, companies should provide environmental education and clear instructions to encourage sustainable product use (Chun and Lee, 2017). Incentive mechanisms (e.g., lower fees for longer rents of the same product) or strategies targeting brand loyalty can motivate customers to take care of a product and extend its life (Otterbach and Fröhling, 2024; Sigüenza et al., 2021).

Consumer acceptance should also be considered. PSS may face cultural resistance if consumers perceive a loss of economic and technical autonomy when depending on the service supplier to use the product (Allais and Gobert, 2016). Similarly, user acceptance may be lower if the consumer places a high value on product ownership (Kjaer et al., 2016). The reliability and quality of second-hand products may also be questioned (Kerdlap et al., 2021).

Finally, CBMs should be aligned with customer requirements, particularly in regulated markets (Bech et al., 2019).

Companies must therefore strive to ensure their CBM is accepted. Further, they must encourage changes in customer intentions, habits, and behaviours to maximise the expected environmental benefits. Providing clear guidance, environmental education, and incentives is essential to achieving this goal.

#### 4.10.5. Accounting for potential rebound and backfire effects

When interpreting CBM assessments, it is important to consider potential rebound and backfire effects, which may lead to an overestimation of the environmental benefits (Bączyk et al., 2024). As Kjaer et al. (2018, p. 677) observe, “rebound effects will inevitably occur”. Factors contributing to these effects include consumer behaviours when using a product and accessing a rental service, increased consumption, re-spending, product substitution, product life, maintenance, transport, and energy source and efficiency (Das et al., 2023; Johnson and Plepys, 2021; Koide et al., 2022). Rebound effects should be carefully considered when designing and implementing CBMs to ensure they achieve their intended environmental objectives (Das et al., 2023). They should also be integrated in the assessment model where feasible (Koide et al., 2022). If not, the results should be interpreted cautiously.

Given the potential significance of rebound and backfire effects, it is crucial to raise awareness of these issues and provide training for those evaluating CBMs. A thorough understanding of rebound and backfire effects is essential to ensure their proper consideration when assessing the impact of CBMs.

#### 4.10.6. Define subsequent actions based on the assessment outcomes

Insights derived from assessing CBM should be leveraged to enable more informed and strategic decision-making (Alfarisi et al., 2024; Manda et al., 2016). When a CBM is already in place, a key managerial priority should be to identify its critical weaknesses, with the aim of advancing and refining the CBM (Goffetti et al., 2022). This is particularly so in cases where the assessment indicates that the CBM does not deliver environmental benefits compared to a traditional BM. Conversely, if the assessment is conducted during the design and implementation phases, its results should directly inform further refinements to the CBM, ensuring that it is aligned with broader sustainability objectives (Bech et al., 2019). However, in both scenarios, it is wise to establish a continuous feedback loop that supports ongoing monitoring, evaluation, and iterative enhancement of the CBM over time.

Beyond optimisation, CBM assessments also represent strategic opportunities for sustainable value creation (Manda et al., 2016). For example, they allow organisations to articulate and communicate their environmental objectives to all relevant stakeholders (Bhatnagar et al., 2022). Also, by grounding sustainability commitments in rigorous, data-driven evaluations, organisations can effectively mitigate the risk of greenwashing and reinforce their credibility and legitimacy in their commitment to sustainability (Goffetti et al., 2022).

#### 4.10.7. Operational framework

Building on the findings of the review, Fig. 6 offers an operational guideline that reorganises the key concepts into a coherent structure, both thematically and temporally. Specifically, the proposed operational framework arranges the purpose of analysis, the LC-based methodology, and managerial recommendations along a chronological sequence, dividing them into three distinct phases: before the assessment, during the assessment, and after the assessment. For each phase, the framework identifies critical areas that require managerial attention, clarifies the underlying objectives, and offers practical guidance to support informed and sustainability-oriented decision-making throughout the process of evaluating CBMs.

Specifically, the operational framework includes 8 steps: 1) define the purpose of analysis, i.e., evaluate the environmental impacts of a singular CBM, compare the environmental impacts of different BMs and/or CBMs, evaluate the transition from a BM to a CBM, or design and implement CBMs; 2) select the LC-based methodologies, including deciding whether to combine two or more methodologies, and choosing among LCA, LCC, qualitative and/or quantitative methods, and BM-LCA; 3) collect detailed information, leveraging big data analytics and digital technologies, promoting collaboration across business functions, and involving experts and key stakeholders; 4) implement

## How to evaluate CBMs using LC-based methodologies

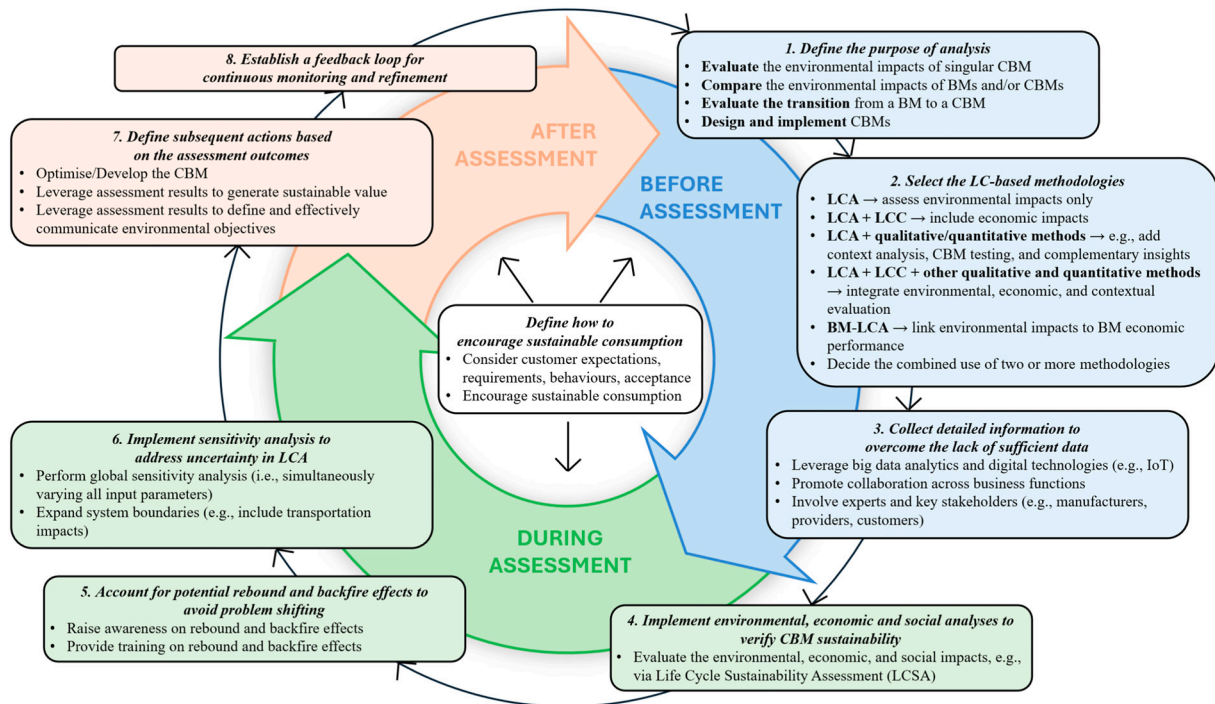


Fig. 6. Operational framework to support practitioners in evaluating CBMs using LC-based methodologies.

environmental, economic and social analyses, for example through LCSA; 5) account for potential rebound and backfire effects, by raising awareness and providing training on these unintended consequences; 6) implement sensitivity analysis, by performing global sensitivity analysis and/or expanding system boundaries; 7) define subsequent actions based on the assessment outcomes, including optimising/developing the CBM, generating sustainable value, and defining and effectively communicating environmental objectives; 8) establish a feedback loop for continuous monitoring and refinement of the CBM.

### 4.11. Limitations

This review presents some limitations that should be acknowledged. First, the keywords used to search for relevant publications in Web of Science and Scopus may have excluded relevant studies on the topic. To mitigate this issue, we applied an upstream and downstream snowballing process, where the reference lists of the retrieved publications and the citations received by the retrieved publications were examined to identify additional relevant studies. However, despite this effort, we cannot entirely rule out the possibility that some pertinent publications were omitted from this review. Second, our search for relevant publications was limited to academic papers. Hence, conference papers and gray literature such as reports, white papers, and consultancy publications, were excluded. Given that assessing CBMs extends beyond academic research, this restriction may have excluded publications that, while relevant, were not considered due to their non-academic nature. Finally, at least two authors independently reviewed, discussed, and reached a consensus on the inclusion or exclusion of publications and the classification of key information. Still, this evaluation process inevitably involved a degree of subjectivity. As a result, certain relevant publications may have been unintentionally excluded, or the classification of key information may not fully reflect the original intent and analytical focus of the authors. This limitation should be considered when interpreting the findings of this review.

## 5. Conclusions

This review explored how LC-based methodologies have been used to evaluate the environmental impacts of CBMs. The investigation focused on identifying the methods used, the purposes of these assessments, the specific types of CBMs evaluated, and the sectors analysed. Additionally, the study highlighted existing research gaps and offered managerial recommendations to inform and guide future research and practical assessments.

Specifically, the findings reveal that most studies rely on conventional LCA, despite its limitations in consistency, cost, and its exclusive focus on environmental impacts. LCA is often combined with LCC for an economic evaluation, or with other qualitative and quantitative methods to identify potential CBMs and scenarios, gather data for a more robust LCA, and achieve a more comprehensive evaluation. A growing interest in hybrid approaches, such as BM-LCA, is emerging. Our review shows that LC-based methodologies are used to serve various purposes: compare the environmental impacts of BMs and/or CBMs to identify the most sustainable one; assess the environmental benefits of transitioning from a BM to a CBM; evaluate the impacts of individual CBMs; and support the design and implementation of CBMs by identifying the potential challenges associated with different design alternatives. Among the assessed CBMs, use-oriented PSS and result-oriented PSS are the most common, while those focusing on extending resource value, product-oriented PSS and circular materials are less explored. Overall, the studies span a wide range of sectors.

To advance the field, future research should aim to: (i) standardise LC-based methodologies to ensure consistency and facilitate comparisons; (ii) include rebound effects in LCA to capture their impacts on sustainability outcomes; (iii) improve methods for complex CBMs such as PSS; (iv) integrate environmental, economic, and social dimensions to promote sustainability in all its dimensions; and (v) explore under-researched CBM types and purposes of analysis.

Importantly, our review confirms that managers should not assume that CBMs are automatically more sustainable. Accordingly, we

developed an operational framework to support practitioners in evaluating CBMs using LC-based methodologies building on 8 steps: 1) define the purpose of analysis, 2) select the LC-based methodologies, 3) collect detailed information, 4) implement environmental, economic and social analyses 5) account for potential rebound and backfire effects, 6) implement sensitivity analysis and 7) define subsequent actions based on the assessment outcomes, and 8) establish a feedback loop for continuous monitoring and refinement.

By consolidating fragmented knowledge, this review offers a comprehensive understanding of the topic, fostering the advancement of knowledge in the field. It underscores the importance of systematically evaluating the environmental impacts of CBMs to ensure their effectiveness and sustainability. Addressing the identified research gaps and implementing the proposed managerial suggestions will be crucial for refining existing methods and promoting more comprehensive and reliable assessments in the future.

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### CRediT authorship contribution statement

**Emilia Filippi:** Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Monia Niero:** Writing – review & editing, Validation, Methodology, Investigation, Conceptualization. **Filippo Corsini:** Writing – review & editing, Writing – original draft, Validation, Methodology, Investigation, Conceptualization. **Marco Frey:** Validation, Supervision, Project administration, Investigation.

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### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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