SUSTAINABLE DESIGN, MSC IN ENGINEERING

MASTER THESIS – SPRING 2025

Academic Article

Master Thesis

Clarifying LCA application: Framework and guide for facilitation of goal definition and decision support

AALBORG UNIVERSITY

Marius Rønne Christensen & Sofie Kjøller Jørgensen

Title Page

Title

Clarifying LCA application: Framework and guide for facilitation of goal definition and decision support

Education

MSc. Sustainable Design, 4th semester, Aalborg University

Project

4th-semester master thesis

Project period

1st of February 2025 – 17th of June 2025

Supervisor

Louise Laumann Kjær

Number of characters

82.420

Number of standard pages

40

Group members

Marius Rønne Christensen

Study no. 20195122

Sofie Kjøller Jørgensen

Study no. 20194829

Preface

This paper concludes the Master's thesis for the MSc in Sustainable Design, Engineering program at Aalborg University, Copenhagen. The thesis was developed over 16 weeks, from February 1st to May 28th, 2025, under the supervision of PhD Louise Laumann Kjær.

The AI language model ChatGPT (OpenAI, 2025) was used to support the writing process, particularly for text refinement and the drafting of a hypothetical design case. All AI-generated content was carefully reviewed and edited for accuracy and clarity.

While this thesis adopts the visual format and structure of an academic article from the journal Sustainability, it is important to note that the paper serves solely as a design template and has not been submitted for publication.

Throughout the project, our supervisor has served as an LCA expert, offering indispensable feedback and actively contributing to the co-development of the framework. While this guidance has not always been formally documented, it has been integrated through meeting minutes and direct modifications to the framework. In the following, feedback from our supervisor will be referred to simply as “Supervision,” reflecting their central role in shaping the project's direction and outcomes.

In parallel, a LCA consensus project has been ongoing, with Kjær (Supervision) as an integral member. Throughout the process, we have continuously received inspiration and updates from their work. This will be referred to as the Consensus Project 2025.

A supplementary document titled *Appendices* has been prepared to accompany this paper. Reviewing this material is essential for a complete understanding of the research presented. The document will be referenced as *See Appendix X* throughout the article. Furthermore, a document titled *Additional Reading* has been prepared to further deepen the understanding of the negotiations with stakeholders throughout the project. References to this document will appear as AR followed by the corresponding number (e.g., AR1, AR2). This research presents five frameworks within the main text and a sixth, a consultant's guide, provided in Appendix I

This work builds upon the third-semester project report by Marius Rønne Christensen. Both authors were also employed as junior consultants at Norion Consult during the thesis period, where they participated in activities related to LCA processes. Their professional roles did not influence the research outcomes.

Acknowledgements

We would like to extend our deepest gratitude to our supervisor, Louise, whose expertise and unwavering support have been invaluable throughout this project. Her guidance in clarifying complex problems, as well as her methodological and theoretical insights, were instrumental in structuring our entire research process.

Louise's extensive knowledge and connections within the LCA field provided us with access to insights and perspectives that significantly enriched our understanding of the issues addressed in this thesis — opportunities we would not have had otherwise. Her thoughtful feedback and availability throughout the project were truly exceptional. Thank you for your genuine interest, dedication, and invaluable input.

We are also sincerely grateful to Norion for allowing us a glimpse into their processes and openly sharing their experiences. A special thanks to all the companies and experts who generously contributed their time and knowledge, providing valuable insights critical to this work.

Thank you all for your contributions and support.

Learning objectives

Project specific

Types	Learning objectives	Stages
Application	Structure and manage a research project based on the Design Research Methodology	*General, RC*
Comprehension	Explain how staging negotiation spaces can help design for sustainable transition	*General*
Comprehension	Explain which research gap is present and why it is important to close it	*DSI*
Analysis	Define approaches which support LCA findings, more practical and helpful for real-world decision-making	*DSI*
Analysis, Synthesis, Evaluation	Apply and reflect on the hypothetico-deductive process to develop, test, and refine support that meets LCA practitioners' needs while advancing a sustainable agenda	*PS*

Analysis, Synthesis	Analyse how frameworks and guidance can encourage practitioners to set more ambitious, sustainability-driven intended applications and goals in the early stages of an LCA process.	*PS*
Synthesis	Design a visually intuitive framework that helps LCA practitioners and sustainability leads define the intended application and goals of LCA findings, ensuring these findings effectively support decision-making for environmental improvements	*PS*
Evaluation	Develop evaluation methods to assess and improve the usability of the support, and critically reflect on its effectiveness in practice.	*PS/DSII*

AAU MSc. Sustainable Design

Knowledge: The student can:

- Demonstrate advanced knowledge in sustainable design, transitions, and organisational change processes.
- Integrate cross-disciplinary knowledge to address systemic sustainability challenges.
- Apply designerly thinking to explore and address sustainability issues.

Skills: The student can:

- Define a research-based problem statement on critical sustainability challenges.
- Apply advanced methods to develop effective design solutions.
- Communicate research findings to academic and non-academic audiences.
- Facilitate design processes involving diverse stakeholders.

Competencies: The student can:

- Lead interdisciplinary research projects on sustainability challenges.
- Manage the research process independently, maintaining scientific rigour.
- Reflect on and develop personal research competencies.
- Produce original research contributing to sustainable design

Clarifying LCA application: Framework and guide for facilitation of goal definition and decision support

Marius Rønne Christensen, Sofie Kjøller Jørgensen

Department of Development and Planning, Aalborg University, A.C. Meyers Vænge 15, 2450, Copenhagen, SV, Denmark

Article info

Keywords:

Life Cycle Assessment

Intended application

Decision-making

Goal definition

Staging Negotiation Spaces

Environmental improvement

Abstract

A key gap identified in this research is that, while Life Cycle Assessments (LCAs) are intended to inform decision-making for environmental improvement, existing guidance, such as the ISO 14040/44 standards and officially recognised handbooks, provides limited support for helping organisations explore how an assessment can be effectively applied in decision-making contexts.

This project explores how LCA consultants and organisations' sustainability leads can facilitate the definition of the goal and the application of an LCA in ways that inspire, support, and promote change and decision-making. Applying the Design Research Methodology, the study progresses through three phases: Research Clarification, Descriptive Study I, and Prescriptive Study. Literature analysis and empirical data address how the goal phase links to LCA outcomes (RQ1) and what mechanisms currently support this (RQ2). Based on these insights, a design support was developed using sustainable design methods (RQ3). Staging Negotiation Spaces and Boundary Objects theory have supported the development of a framework that aims to structure reflection, foster collaboration, and align LCA application with decision-making. The study presents a structured goal definition process that enhances the relevance and impact of LCA by clarifying its intended use and embedding it in the decision-making context. It introduces a typology of LCA applications and a six-step goal formulation framework, which support transparent, participatory definition of purpose. Moreover, organisational learning is identified as a valuable and often overlooked application of LCA.

1. Introduction

The late 1990s and early 2000s marked LCA's formalisation and global dissemination. The International Organisation for Standardisation (ISO) published the ISO 14040 and 14044 standards, which defined the four main phases of LCA: goal and scope definition, inventory analysis, impact assessment, and interpretation (ISO, 2006a). These standards provided a clear framework, enabling wider adoption by industry, governments, and NGOs worldwide.

LCA as a Reporting Standard

LCA has become an increasingly important tool in sustainability reporting, driven by growing regulatory and stakeholder demands for transparency and comprehensive environmental disclosure (Finnveden et al., 2009; Stewart et al., 2018). LCA's cradle-to-grave perspective allows organisations to quantify and communicate various environmental impacts, such as greenhouse gas emissions, resource depletion, and pollution, across the entire value chain (Huijbregts et al., 2017). This aligns closely with new regulatory requirements, including the European Union's Corporate Sustainability Reporting Directive, which mandates detailed environmental impact reporting.

Despite its recognised value, the integration of LCA into sustainability reporting remains uneven. Many companies reference LCA in their reports but often lack detailed results, partly due to methodological complexity or unfavourable findings (Silva et al., 2019). However, organisational-level LCA approaches, such as the Product Environmental Footprint and Organisation Environmental Footprint, are gaining traction and may facilitate broader adoption in reporting frameworks (*European Platform on LCA | EPLCA*, n.d.; *OEF Method - European Commission*, n.d.). Overall, LCA is increasingly seen as essential for robust, transparent sustainability reporting, supporting regulatory compliance and stakeholder engagement by offering a credible, science-based assessment of environmental performance (Stewart et al., 2018).

While such applications are valuable for reporting and compliance, they often shift the focus away from LCA's original purpose of supporting decision-making. As a result, LCAs are increasingly used for external communication and competitive advantage rather than for fostering internal reflection and process improvement (Konradsen et al., 2024), thereby becoming an end in itself rather than a means to an end. This shift is problematic as it limits LCA's potential to drive transformative sustainability improvements. As noted in ISO 14040 (2006a), LCA is not intended for contractual or regulatory purposes. Yet the widespread use of LCA for such purposes undermines their ability to function as decision-support tools.

LCA is being used more frequently; however, research on its influence on decision-making and real-world impact remains limited (Subal et al., 2024). This paper is motivated by the recognition of a significant but underexplored gap in the practical application of LCA. While LCA provides comprehensive data and insights into the environmental impacts of product systems, these insights are frequently confined to descriptive analysis rather than being strategically leveraged to promote environmental improvement through organisational decision-making. The authors have experience with consultancy work and have encountered this issue firsthand in practice, where the potential of LCA to inform decision-making is often underutilised.

Limited support from ISO standards for clearly defining the intended application of LCA and its role beyond regulatory compliance has further diminished its capacity to drive substantive environmental action. As a result, many organisations struggle to effectively translate LCA results into strategic initiatives or innovative practices, thereby constraining their impact on tangible sustainability outcomes (Dong et al., 2018; Stewart et al., 2018). Thus, the critical challenge is not merely conducting LCAs but integrating them meaningfully within organisational processes to inspire and facilitate actionable change. Consequently, there is a growing need for enhanced guidance and frameworks to support consultants and sustainability leads in defining the application of LCA to promote sustainability-focused decision-making.

Method for Assessing the Environmental Impact of Product Systems

ISO 14040 (2006a) is the current framework for conducting LCA and is structured into four distinct phases as illustrated in Figure 1: goal and scope definition, inventory analysis, impact assessment, and interpretation.

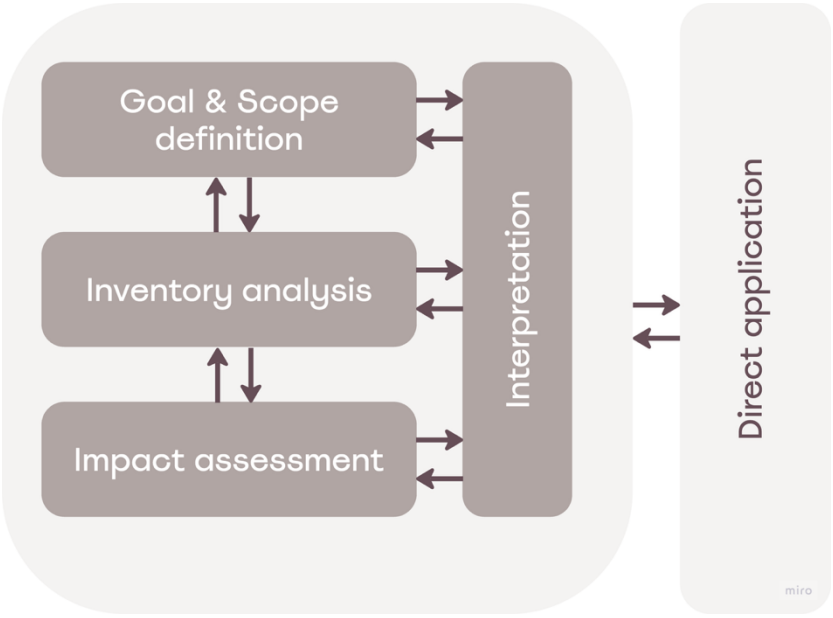

Figure 1 Phases of an LCA according to ISO 14040/14044

The initial phase, goal and scope definition, establishes the foundation for the LCA by clarifying the study's purpose, targeted audience, and system boundaries. This phase is critical as it determines the methodological framework, data requirements, and level of detail for subsequent analyses (ISO, 2006b).

The goal definition specifies the intended application of the LCA, outlining *why* the assessment is conducted, *how* the results will be applied and to *whom* the results are intended to be communicated. It includes identifying whether the study is intended for product comparison, identifying environmental hotspots, supporting product development, or informing policy decisions and is crucial for shaping the focus and practical applicability of the assessment by explicitly defining the intended application (Cottafava et al., 2024). The intended application is thus inherently connected to the goal, as it frames the context in which the findings will be interpreted and the extent to which they may influence decision-making. A clearly defined goal ensures that the LCA remains focused, relevant, and methodologically sound, aligning the assessment process with the desired outcomes (Hauschild et al., 2018). Despite this, many LCA studies fail to adequately specify the intended application during this phase, undermining the practical impact of their findings (Roßmann et al., 2021). This study sees the existing LCA framework as insufficient in supporting practitioners in bridging the process of conducting an LCA to its actual application in decision-making

3.1.3 Life Cycle Management as a Framework for Applying LCA Findings

Recognised worldwide, Life Cycle Management (LCM) serves as a practical framework for applying LCA in organisational decision-making. While LCA provides detailed environmental analysis, LCM translates these insights into actionable strategies for sustainable business practices. As Hauschild et al. (2018, p. 521) note, *"LCM puts LCA into practice,"* positioning LCA as a critical tool in a broader decision-support framework. LCM, unlike LCA, does not follow a standardised methodology. It is shaped by various factors, such as business model, market position, and regulatory context, making it adaptable to different organisational needs. LCM involves identifying relevant sustainability issues through LCA and other assessments, then connecting these to concrete managerial actions—defining who will act, what needs to be done, and when (Hauschild et al., 2018). LCM can be seen as fundamental to defining the goals of an LCA process, raising the question of whether LCA can effectively support decision-making without it

While LCM provides a framework for managing life cycle considerations in organisations, it does not provide a guide for how the LCA process is conducted to support organisational decision-making. Therefore, this study aims to develop a framework that supports practitioners in bridging the gap between the LCA process and the application of the results in decision-making.

Given this context, the paper is driven by the following research question:

How can a framework support consultants and sustainability leads in defining the intended application and goal of an LCA in ways that ensure the outcomes promote decision-making for environmental improvement?

By addressing this question, the paper aims to develop support promoting LCA as a driver for sustainable action.

2. Methodology

This section is structured into three parts: the first outlines the design process, the second discusses the main theories applied, and the third presents the methods used in this study.

2.1 Design process

This paper has applied the Design Research Methodology (DRM) developed by Blessing and Chakrabarti (2009), which provides a structured and iterative research framework to improve design practices by developing a deep understanding of the context before generating and validating solutions. The research up until the delivery of this article unfolded across the three stages of DRM: Research Clarification (RC), Descriptive Study I (DSI) and Prescriptive Study (PS). After the delivery of this article, the research will move into the Descriptive Study II (DSII) phase. Each phase contributed to addressing a specific set of research questions and ensured a balance between academic insight and practical application. The overall process of the thesis can be seen in Figure 2.

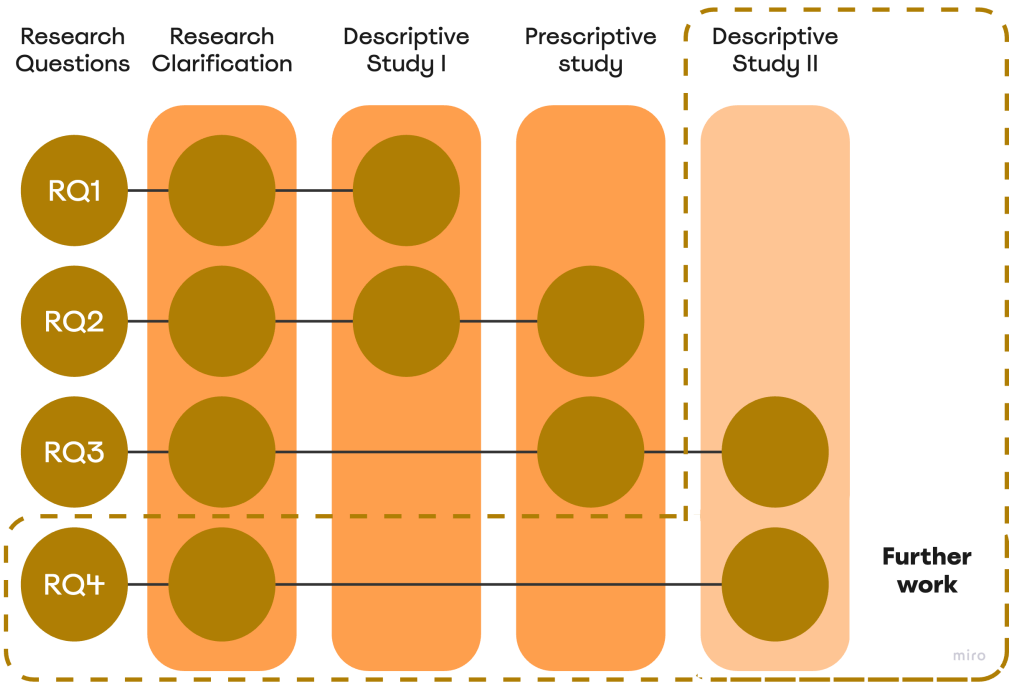

Figure 2 Research process in DRM stages

In the RC phase, the scope and objectives of the project were defined, leading to the following formulation of four guiding research questions:

RQ1: *How is the goal definition stage of LCA connected to its purpose and the application of its results?*

RQ2: *What approaches currently exist that support consultants and sustainability leads in ensuring that LCA findings are used to promote decision-making?*

RQ3: *How can a framework exploring the intended application and goal of an LCA be developed?*

RQ4: *How usable is the support, and how can it be improved?*

During the DSI phase, two parallel literature analyses were conducted. The first surveyed ISO standards, LCA guidelines, and practitioner resources to understand how the goal phase, where the intended application is specified, is normatively framed and linked to the use of LCA outcomes. It revealed a gap between the formal intent and the practical implementation of goal formulation.

The second analysis surveyed methods and tools that support LCA in decision-making. It found limited research on how to effectively formulate goal definitions, particularly in relation to intended application, and emphasised that LCA findings alone are insufficient for decision-making. It also highlighted a significant gap concerning the role of consultants in facilitating the integration of LCA into decision-making processes.

Building on these insights, the PS phase applied a hypothetico-deductive (H-D) approach to structure and validate the conceptualisation process. This approach, which focuses on attempting to refute rather than confirm theories, guided the development of the support. This method involves building on existing knowledge and theories to formulate hypotheses, which are tested across various contexts (Gill et al., 2010).

This research hypothesis (RH) is a more comprehensive support for guiding the intended application and goal definition in LCA would enhance the effectiveness of the assessment process. The hypothesis suggests that clearer support for setting well-defined, actionable, and accountable applications would better support LCA practitioners and sustainability leads in turning intended environmental improvements into reality. In this context, the proposed support serves as the theoretical foundation developed in this research. Theory formulation and testing were primarily conducted through the deliberate framing of spaces that enabled the negotiation and refinement of the framework.

The development process of the support, as depicted in Figure 3, provides an overview of the H-D structure employed in designing all five frameworks. It illustrates the sequential stages and key activities involved, offering insights into the systematic and iterative nature of the process. While this represents the overall development approach, individual frameworks have undergone varying numbers of iterations, reflecting differences in complexity, stakeholder input, and contextual requirements.

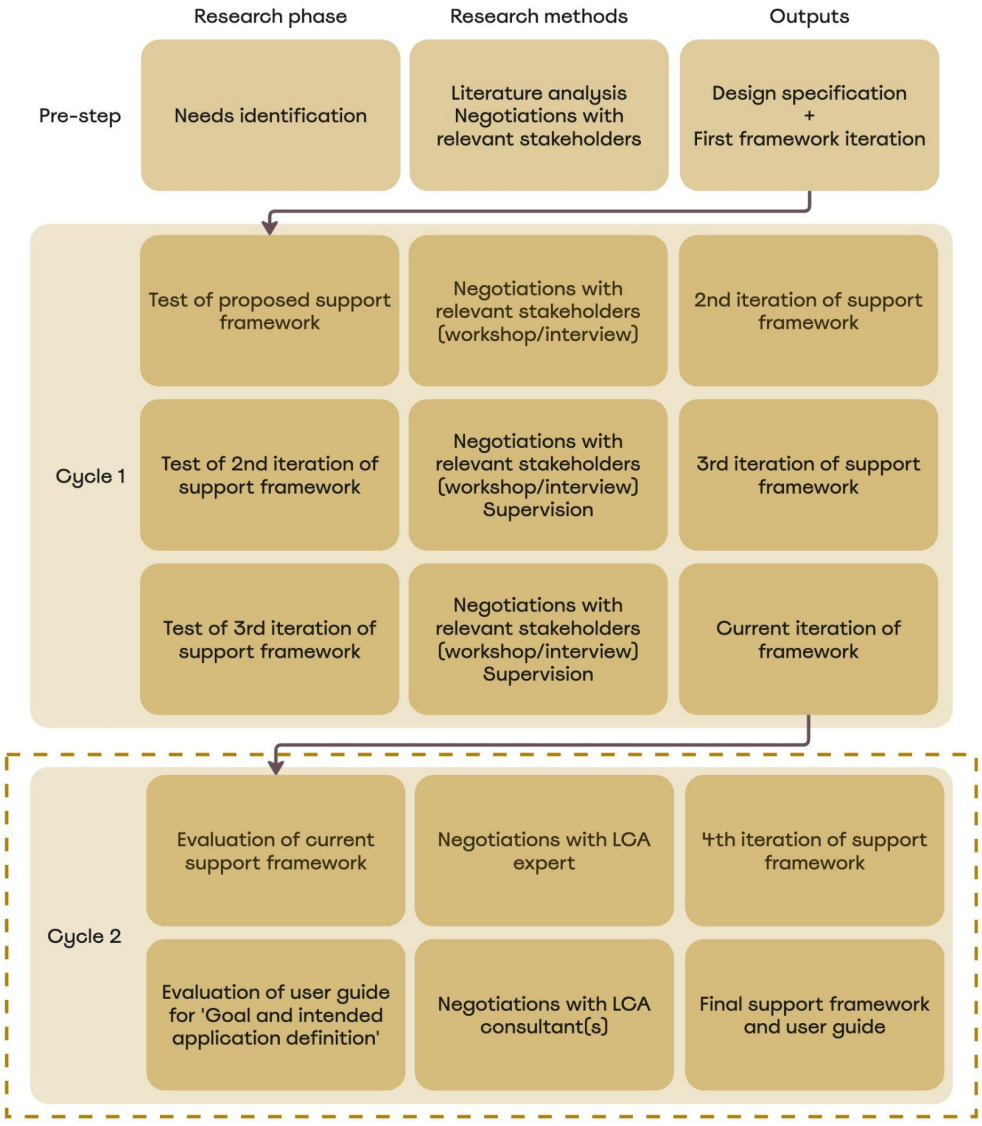

Figure 3 The framework development process following the hypothetico-deductive approach

Notably, the DSI and PS phases were conducted simultaneously, allowing for a dynamic exchange between design formulation and problem solving. Insights from the negotiations continuously informed the process and contributed to answering RQ 2 and 3.

The **DSII** phase, which will take place in the three weeks between the submission of this article and the researcher's master thesis defence, will involve evaluating the developed support in practice through interviews with LCA consultants and sustainability leads to assess its usability and effectiveness. The support will be iteratively tested and refined in collaboration with LCA experts and practitioners from industry. The evaluation will centre on whether the support effectively facilitates the goal definition process within LCA practice.

The **success criteria** for this study are that consultants and sustainability leads find the framework useful in formulating and defining the goal and application of an LCA. The **success criteria** for this study is that the support enables consultants and companies to effectively explore and define clear, actionable applications of LCA findings to inform decision-making.

To answer this criterion, the **measurable criterion** is whether consultants and sustainability leads find the framework usable in defining the goal and application of an LCA.

2.2. Theories

As the framework is co-developed with stakeholders, each interaction shapes the outcome. Negotiations between the research team and stakeholders are therefore prepared and analysed to guide development. The framework serves as a mediating object, creating a space for shared understanding. This research adopts the Staging Negotiation Spaces framework to support this process.

2.2.1 Staging Negotiation Spaces

Staging negotiation spaces (SNS) builds on participatory design and actor-network theory, conceptualising design as the facilitation of spaces of negotiation among diverse actors (Brodersen & Pedersen, 2019; Pedersen, 2020). Spaces are framed to facilitate specific negotiations where relevant stakeholders and objects are introduced to one another to co-design a common solution. Interventions throughout the project have been staged as negotiations of the framework for implementing the intended application in the LCA process, framing the current LCA process as unsupportive in promoting decision-making (Pedersen, 2020). The SNS approach provides the tools to frame and stage negotiations with relevant stakeholders, creating a space for them to co-develop the framework. Negotiations are used for network alignment processes, with stable innovation emerging through strategic facilitation, translation of knowledge, and reframing of issues among human and non-human stakeholders (Brodersen & Pedersen, 2019; Pedersen, 2020). The SNS approach is used concurrently with the H-D approach to negotiate the respective hypotheses and accommodate frameworks with LCA practitioners, consultants, and relevant organisations and sustainability leads in an iterative process.

2.2.2 Design objects

Different objects used in the design process have distinct properties that influence the development of the intended application framework.

Boundary objects are tools or artefacts that bridge knowledge between different domains, enabling collaboration across boundaries (Carlile, 2002). Positioned "in the middle," these objects allow actors to represent, negotiate, and transform knowledge, making localised or tacit understandings actionable (Carlile, 2004). As knowledge is often context-specific and embedded in practice, boundary objects support the co-creation of meaning and promote sustainable change through mutual understanding and pragmatic knowledge exchange. In LCA consultancy, they facilitate the integration of consultants' technical expertise with clients' contextual knowledge by creating a shared space for dialogue and learning. Consultants need the necessary competencies to facilitate the use of boundary objects effectively.

Intermediary objects travel from actor to actor, mediating, representing, and translating the knowledge they inscribe in the object. Throughout its travel, the object is changed, designed and developed as a testament to the interactions with the different actors (Vinck & Jeantet, 1995). This research utilises intermediary objects to allow interested and involved actors to affect and co-create the framework by inscribing their knowledge, conflicts, and interests.

2.3 Methods

This section outlines the methods used in this study. The first part describes the two literature analyses conducted, and the second part details the participatory design and ethnographic methods applied in the empirical research.

2.3.2 Literature analysis

Two separate literature analyses were conducted to address RQ1 and RQ2, respectively.

Literature search: Identification of relevant standards and guidelines

To explore how the goal definition phase of LCAs is connected to its purpose and the application of its results (RQ1), a focused analysis was conducted on ISO 14040, 14044, 14049, and 14072 standards, emphasising their intent to guide decision-making for environmental betterment. Key supporting documents included the ILCD Handbook (European Commission. Joint Research Centre. Institute for Environment and Sustainability., 2010) and *Life Cycle Assessment – Theory and Practice* (Hauschild et al., 2018), both selected in consultation with an LCA expert. Grey literature from Danish authorities, *Kom godt i gang med livscyklustankegangen!* (Miljøministeriet, 2002) and *Status med LCA i Danmark i 2003* (Miljøministeriet, 2007), helped contextualise national interpretations from a time when LCA served more as a decision-support tool than a reporting framework.

Literature search: Approaches to utilise LCA in decision-making

The second part of the literature analysis consisted of two separate reviews. Two search strings were defined to support the second research question. Scopus was chosen as an appropriate database for this literature review, as it encompasses relevant publishers. The first search string investigates which mechanisms (support, guidelines, frameworks, methods, tools) support the application of LCA in decision-making. The search string presented 113 articles from which 36 were relevant based on their title and abstract. Three articles were added from baseline literature as they represent relevant research on the topic.

The second research string seeks to understand how consultants support their clients in utilising LCA for decision-making. As illustrated in Figure 4, the search string identified 22 articles, from which 4 were seen as relevant based on title and abstract. One article was added from baseline literature because it researches consultants' roles in helping organisations with sustainability work.

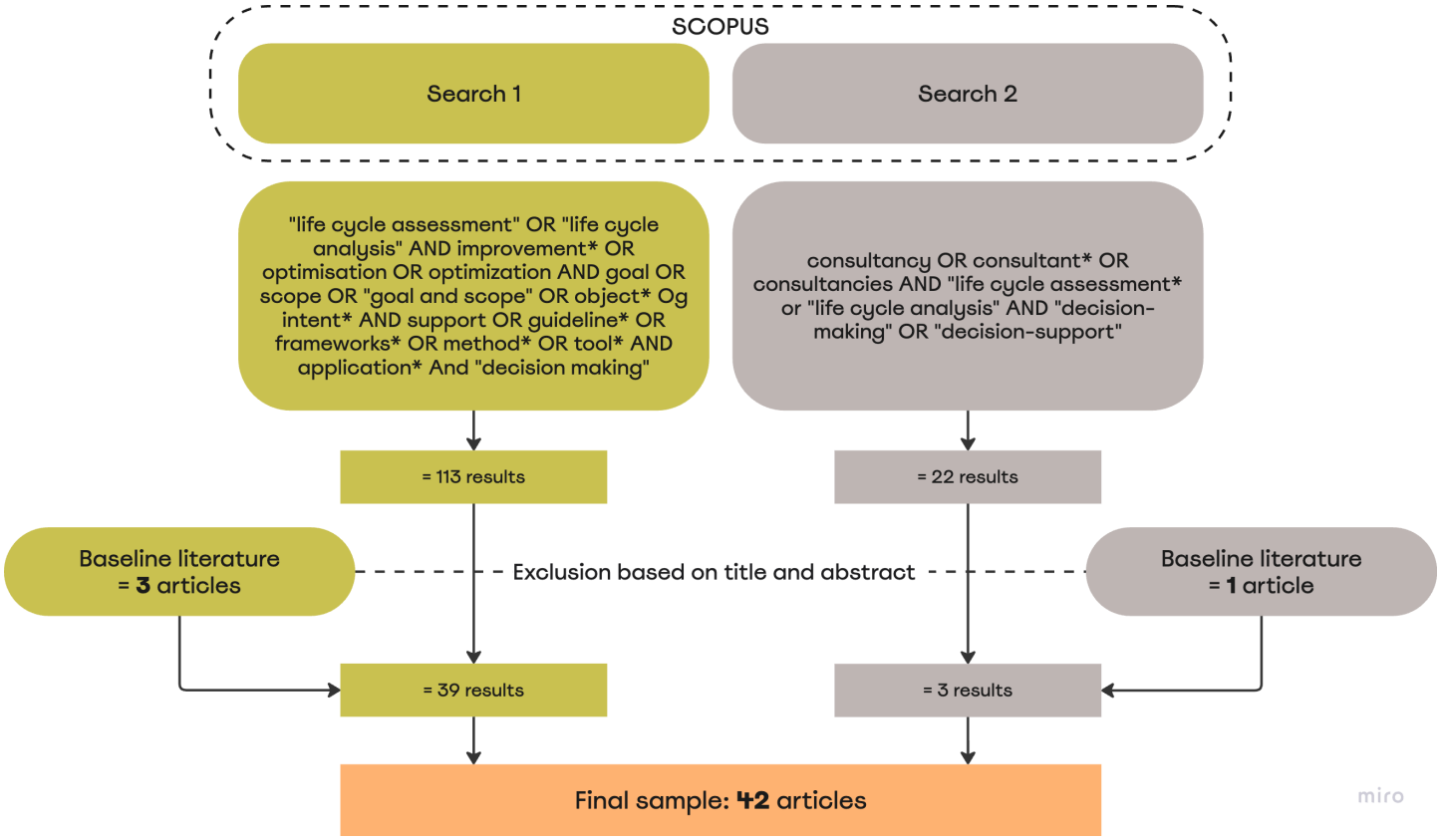

Figure 4 Selection process of literature analysis

2.3.3 Negotiations

9 interventions have been conducted throughout the project, with more planned after submission.

Workshops & Interviews

Table 1 summarises all project negotiations. Observations were recorded in note form, while Miro boards captured key inputs during workshops.

Additional reading	**Ethnographic approach**	**Participants**	**Organisation**	**Framing of negotiations**
1	Observations	2 x LCA consultants + client CEO and project manager	Norion Consult + Cup producer company	Clarify how Norion facilitates the initial goal-setting phase.
2	Semi-structured interview	Business developer and project manager	Erhvervshus Nordjylland	Discuss the preparatory steps before starting the LCA process.

3	Workshop	2 x LCA consultants	Norion Consult	Gain insights from experts on enhancing the goal and scope definition phase to better support sustainable decision-making.
4	Observation	LCA build experience group (+20 member org.)	Dansk Industri	Observe which challenges the member organisations experience with LCA work
5	Observation + participant	2 x consultants from Norion + client CEO and project manager	Norion Consult + Cup producer company	Observe Norion's LCA Goal & Scope workshop, using design-focused methods and visual tools to map the company's flowchart.
6	Semi-structured interview	LCA expert	Independed	Explore LCA development from decision-support to broader applications
7	Semi-structured interview	LCA expert	AAU professor	Explored aligning LCA Goal and Scope with sustainable decision-making, introducing frameworks to enhance ISO standards.
8	Semi-structured interview + evaluation of support	Standardisation & Product Regulation Manager	Ventilation production company	The interview aimed to understand a company's LCA use and gather feedback on the initial support version.
9	Workshop	Supervisor + thesis group		Testing the usefulness of the framework

Table 1 Negotiations made throughout this project

Staging negotiations

The SNS framework guided the framing and facilitation of interviews and workshops as dynamic negotiation spaces, where diverse actors, concerns, and knowledge could be staged and aligned, and the support could be co-created. By carefully introducing objects such as prototypes and LCA visuals, the sessions allowed participants to articulate and negotiate their matters of concern. Facilitators acted as spokespersons for absent actors, helping navigate evolving perspectives. Objects either worked as boundary objects, allowing participants to interact and change the object during negotiations, or as intermediary objects where findings

are inscribed in the framework, mediating insights between relevant stakeholders throughout their development. Empirically collected information gained from the negotiations informed the specification of the framework design.

Ethnographic conversation & observations

In this project, ethnographic conversation and observation have been essential for understanding the dynamics of LCA processes, from the side of experts and practitioners. The researchers have been engaged in both structured interviews and informal conversations with employees and clients, providing insight into how LCA is practised and communicated in a consultancy context. Through participant observation, the researchers documented everyday interactions, meetings, and project work, using field notes to capture reflections. These methods enabled a contextual and situated understanding of conducting the goal and scope definition phase of an LCA process within a consultancy practice (Coffey, 2018).

3. Results

This section is structured into two parts, following the DRM framework. The first part presents the findings from the two literature analyses (DSI) and findings from negotiations with LCA practitioners, experts, and companies. The second part synthesises insights from the literature and the negotiations into a design specification, and outlines the conceptualisation process of the framework (PS).

3.1 Analysis of existing standards and guidelines

3.1.1 ISO Standards: Normative Foundations and Limitations in Goal Definition and Application

The ISO 14040 and 14044 standards provide a foundational framework for conducting LCA, positioning it as a tool for supporting environmentally informed decision-making across product systems. They emphasise LCA's role in identifying environmental improvement opportunities and influencing strategic and organisational decisions (ISO, 2006a, 2006b). However, despite this normative clarity, the standards fall short in operational guidance, particularly regarding how to define the LCA goal and apply results in practice. ISO 14040 explicitly acknowledges that no universal approach exists for applying LCA results and that such application depends heavily on contextual factors like organisational size, culture, and strategic aims.

Although ISO/TR 14049 (ISO, 2012) was introduced to support goal and scope definition, it offers limited practical direction, focusing primarily on inventory analysis and bypassing the nuanced process of goal formulation. As such, while ISO standards stress the importance of goal definition, they offer little support for translating this into an actionable, context-sensitive application.

The standards define *intended application* as the specific use of LCA results (e.g., product development, policy-making), and describe *decision-making* as the outcome of the interpretation phase, where LCI or LCIA results inform recommendations. *Improvement* is defined as the ultimate aim, achieving environmental benefit through informed decisions. Yet, the mechanisms through which this improvement is to be realised remain underspecified, leaving practitioners without adequate tools for navigating the path from analysis to impact.

3.1.2 Guidance on the Application of LCA Results

Several handbooks and guides have been developed to support the operationalisation of LCA. Notably, the ILCD Handbook (2010) builds on ISO 14040/44 and aims to strengthen methodological clarity, particularly around goal and scope definition. It emphasises aligning the scope with the intended application to ensure LCA outcomes support informed decisions. It is therefore particularly disturbing that the ILCD also presents a decision tree that includes the option of not using LCA for decision-making purposes, potentially undermining its role as a strategic tool for guiding environmental improvements (European Commission. Joint Research Centre. Institute for Environment and Sustainability., 2010, p. 38).

Similarly, the LCA Handbook by Hauschild et al. (2018) offers a comprehensive methodological guide and integrates a range of established practices, particularly those informed by the ILCD. While it reinforces LCA's relevance in decision-making, it primarily addresses how to *perform* an LCA rather than how to *use* the results. The authors themselves describe the handbook as *"a cookbook offering recipes with concrete actions needed to perform an LCA" (Hauschild et al., 2018, p. 6)*, but not a manual for applying it in real-world decisions. Crucially, it lacks direction on how organisations should define expectations for LCA as a decision-support tool or how to operationalise the findings.

Early Danish guidance on LCA, such as that by the Danish Environmental Protection Agency (Miljøministeriet, 2002, 2007), placed strong emphasis on LCA as a decision tool rather than a scientific end in itself. These publications highlighted the importance of clearly articulating the intended use of results and considering the complexity of decision contexts. However, they too struggled with bridging methodology and application. For example, the 2002 guide noted that environmental efforts often became bogged down in data collection at the expense of actionable insights, while the 2003 guide acknowledged the challenge of providing practitioners with practical guidance on implementing methodological choices.

In an annotated Danish translation of ISO 14040/44, it is emphasised that while the standards provide valuable guidance for life cycle thinking, there is a risk of over-interpreting their requirements. This includes the mistaken assumption that all ISO 14044 criteria must be applied uniformly, potentially resulting in rigid or overly narrow applications. Concerns are also raised regarding eco-labels that focus solely on single indicators, such as carbon footprint, as such reductionism may compromise the comprehensive perspective essential to LCA (Jerland et al., 2001).

A similar finding, highlighted by Rosmann et al. (2021) in their review of the application purpose, is that various references in the ISO standards emphasise the importance of considering the intended application as a central aspect of the LCA study. However, these references do not provide clear guidance on how to effectively achieve the application's purpose within the LCA process. This gap in the standards led to the conclusion that a more structured approach is needed to incorporate the intended application throughout the LCA process.

This first review highlights a critical gap: both the ISO standards and LCA guides fail to provide clear elaboration on how the intended application of LCA should be made actionable. In this sense, the gap can be viewed as twofold, encompassing both the lack of detailed specifications within the standards and the absence

of supporting guidance to facilitate their implementation. The latter is explored in the second literature analysis, focusing on identifying complementary approaches for using LCA in decision-making

3.2 Integrating LCA into Sustainability-Focused Decision-Making

3.2.1 LCA in Multi-Criteria Decision-Making

Half of the reviewed studies integrate LCA with multi-criteria framework approaches such as multi-objective (MO), multi-criteria decision analysis (MCDA), and Life Cycle Sustainability Assessment (LCSA). Azapagic (1999) notes that LCA alone is insufficient; instead, MO approaches help identify the Best Practicable Environmental Option (BPEO) by balancing environmental, economic, and social factors.

MCDA is mentioned as an integral part of utilising LCA findings in decision-making (El Dessouky, 2024; França et al., 2021; Müller-Carneiro et al., 2023). The MCDA provides a structured method for evaluating sustainable options and facilitates the communication of both cost and technical performance as well as environmental LCA findings (Müller-Carneiro et al., 2023). Researchers argue that incorporating an MCDA framework is essential for integrating LCA findings with other criteria, such as costs (França et al., 2021). Jade Müller-Carneiro (Müller-Carneiro et al., 2023) highlights that identifying stakeholders and involving them in defining potential applications is crucial in LCA-MCDA analysis, yet no guidance is provided on how to facilitate this process. In contrast, Dr. Naglaa Fathy El Dessouky (El Dessouky, 2024) argues that participatory approaches and training programs are essential for effective stakeholder engagement and for maintaining decision-making frameworks aligned with evolving sustainability goals

To support environmental improvement LCA are combined with Social-LCA (S-LCA) (Lenzo et al., 2018) or with Life Cycle Costing (LCC) (Auer et al., 2017), or in the holistic approach LCSA approach where environmental (LCA), social (S-LCA), and economic (LCC) dimensions are combined to support comprehensive decision-making (Lenzo et al., 2018; Valdivia et al., 2013).

3.2.2 Facilitating the Goal Stage of LCA

Only two studies address how to structure the LCA goal definition phase for better decision-making. Niero et al. (2024) uses the Business Model Canvas (BMC) and stakeholder mapping to link LCA to business strategy and social value creation. Loiseau et al. (2018) emphasises participatory methods, interviews, surveys, and consultations, to engage stakeholders and align goals with local realities.

3.2.3 Designing for Integration: From Frameworks to Practice

Recent research has combined methods from Socio-Technical Studies (STS) with LCA to promote actionable decision-making. Actor-Network Theory (ANT) supports the identification of relevant actors, interests, conflicts, and opportunities for improving the sustainability performance of product systems (Andersen et al., 2024; M. Niero et al., 2021). Practice theory (PT) can identify current problematic consumption patterns and alternative scenarios to be modelled in LCA (M. Niero et al., 2021). These methods provide practitioners with

tools to contextualise the LCA process and to enrol and mobilise relevant actors to promote that LCA findings are used for decision-making and promote environmental betterment.

Further research suggests that integrating LCA with design methodologies may help overcome these challenges by embedding LCA within broader innovation and decision-making processes. A recent contribution in this direction is the article "The Role of LCA and Co-Design in Sustainable Development" by Dorland & Jørgensen (2024). This work introduces a typology for integrating LCA with LCM and Product Development (PD), aimed at supporting sustainable business innovation. Importantly, the article positions *design* as a unifying framework that facilitates the integration of LCA with transdisciplinary collaboration, stakeholder engagement, and the practical application of results. In doing so, it addresses a critical gap identified in earlier literature: the lack of frameworks that support both methodological rigour and real-world applicability.

3.2.4 LCA as a tool in Life Cycle Management

An established method for integrating LCA into decision-making is through LCM. Although only two studies explicitly identify LCM as a decision-making approach using LCA (Dorland & Jørgensen, 2024; Selech et al., 2014), we consider it a fundamental strategy for realising LCA's full potential. LCM is a concept for managing the total life cycle of products and services, from raw material extraction through production, use, and disposal, intending to minimise environmental, social, and economic impacts. It integrates economic, social, and environmental sustainability into decision-making processes across all stages of the value chain, promoting resource efficiency, circularity, and long-term value creation. Rather than a standalone method, LCM is a framework that incorporates tools such as LCA, environmental management systems, and eco-design principles to guide organisations in making informed, sustainability-oriented decisions (De Oliveira et al., 2021; Hauschild et al., 2018). LCM activities thereby mobilise LCA findings and apply them directly in decision-making (Hauschild et al., 2018). Thus, LCM activities should be defined and integrated in the formulation of the intended application in the goal & scope definition phase, to align the LCA process with the decision-making context.

3.2.5 Approaches to utilise in decision-making

The first part of the second literature analysis identified various approaches to incorporating LCA into decision-making, emphasising that LCA constitutes just one of many criteria within a broader decision-making context. Table 2 presents these approaches and illustrates the diversity in how LCA is applied depending on the surrounding decision context. This section highlights that LCA cannot be used in isolation for decision-making; rather, it must be contextualised within the broader set of criteria and considerations. Although the identified approaches have not directly informed the framework development of the support tool, they have underscored the importance of recognising and integrating the decision context when conducting and applying LCA results.

Table 2 Approaches to utilise LCA in decision-making

Approaches to utilise LCA in decision-making	Articles mentioning approach
ANT colony optimisation (ACO)	1
Business Model Canvas	1
Ecodesign	1
Experimental Knowledge	1
Green Performance Map	1
Life Cycle Costing	4
Life Cycle Sustainability Assessment	5
Life Cycle Thinking	2
Interviews, field surveys, participative approaches, consultations	1
Multi-criteria decision analysis	6
Multiobjective optimisation approach	5
No contributing method	2
Product Sustainability Index (PSI)	1
Prospective LCA approach	1
Techno Economic Analysis	1
Value of Information (VoI)	1
Life Cycle Management	2
Actor Network Theory	2
Practice Theory	2

3.2.6 The role of consultants in applying LCA in organisations

The second part of the second literature analysis focused on identifying the role consultants play in making LCA results actionable within organisations. Of the 22 articles reviewed, only two explicitly mention how consultants use LCA to support clients in making environmentally responsible decisions, revealing a notable gap in the literature. Collins et al. (Collin et al., 2018, 2019) describe LCA as a valuable tool that enables consultants to assess and communicate the environmental implications of product system changes. However, LCA is often constrained by time and budget limitations—factors that consultants must routinely navigate. Collins et al. (2019) argue that LCA screenings offer a practical compromise, allowing consultants and clients to make more informed decisions without exceeding resource constraints. Yet, the effectiveness of such

screenings largely depends on the consultant's competence and experience in translating results into actionable insights.

An additional article from the baseline literature highlights the consultant's pivotal role in helping sustainability leads operationalise abstract and evolving sustainability challenges by providing tailored tools and methodologies, such as LCA (Gond et al., 2024). While these tools can support the localisation and operationalisation of complex sustainability goals, their routinisation risks reducing sustainability to a business-as-usual exercise, where the tools themselves, including LCA, overshadow broader transformative ambitions. As such, consultants have the potential to both empower and legitimise sustainability work, but also risk undermining it by fostering dependency on technical tools and the expertise of consultants.

In summary, the literature reveals a significant gap regarding the availability of tools and frameworks to support consultants in operationalising LCA. While consultants are positioned to play a key role in translating LCA results into actionable insights, standards and official guidelines along with current research offers limited guidance on how this can be systematically achieved. This underscores the need for further development of practical support structures that enable consultants to effectively integrate LCA into organisational decision-making processes.

3.3. Negotiations with LCA practitioners, experts and company representatives

The staging negotiations revealed significant challenges in establishing a shared understanding of the goal and the use of LCA findings. LCA is a valuable tool for quantifying environmental impacts in organisations, but results are always sensitive to assumptions, why careful consideration of system boundaries, data quality, and methodological choices is essential to ensure robust and meaningful outcomes (AR 4).

Participants emphasised that LCA is often conducted as a procedural formality rather than a meaningful tool for decision-making, described metaphorically as being lost in the "alphabet soup" of terminology (AR 2). Negotiations (AR 1, AR 5), staged by Norion, showcased how limited facilitation leads to a vague understanding and definition of the goal and intended application of an LCA. AR 5 further highlighted how objects, e.g. the flow chart visualisation, are key in transferring and translating knowledge between consultants and clients. The ISO framework is seen as overly academic, lacking practical relevance for real-world needs (AR 2). Instead of enhancing products, companies often adopt LCA due to regulatory pressure and consultant-driven demand (AR 7). A key issue identified was the limited involvement of decision-makers during the goal and scope phase, undermining strategic alignment (AR 3). The negotiations also highlighted the importance of physical meetings to support trust-building and more nuanced dialogue (AR 3). Visualisations emerged as a critical tool in creating shared references, clarifying complex business models, and surfacing otherwise hidden considerations (AR 3). Overall, the negotiations underscored the necessity of early clarification of needs and meanings to align expectations and avoid superficial application of LCA (AR 2, AR 3, AR 7).

3.4. Main conclusions from DSI

Building on the findings from the two literature analyses and the empirical insights gained through the negotiations, a set of design specifications for the support has been developed. These specifications are synthesised to address the identified challenges and opportunities, and are presented in Table 3.

Finding	**Source**	**Design requirements**	**Design criteria**
Application of LCA findings is out of scope and undersupported in ISO standards and analysed guidelines	Section 3.1	Explorations of LCA applications *must* be a phase in the support	
Conducting LCA can lead to positive unattended outcomes, such as organisational learning	Negotiation 8 Supervisor		The support *should* support organisational learning as a valuable outcome of an LCA process
LCA is a tool designed to support decision-making by prioritising actions that minimise environmental impacts.	Section 3.1 Negotiation 6 Negotiation 7 Supervisor		The support *should* help companies define how the LCA will be used to reduce environmental impact.
LCA is one criterion out of many in a decision-making context.	Section 3.2		The support *should* support the identification of the decision context in which LCA is applied.
The various applications of LCA are often ambiguously defined and lack clear distinctions.	Section 3.1 Negotiation 2 Negotiation 3	The support *must* clearly distinguish and communicate the different applications of LCA.	
The goal definition is fundamental for how an LCA is conducted.	Section 3.1 Section 3.2	The support *must* enable a clear and concise formulation of the LCA goal and the intended use of its findings.	

Consultants are constrained by time and budget when conducting LCAs	Section 3.1 Negotiation 3		The support *should* enable consultants to help their clients effectively define the goal and intended application, while taking into account the typical time and budget constraints they face.

Table 3 Design specification for support

3.5. Prescriptive Study

Following the H-D approach, it was hypothesised that the support could be developed and evaluated as a visual framework, with all components designed and refined through iterative testing and empirical validation. Based on this, the DSI phase transitioned into the PS phase, where the framework was systematically developed and negotiated to address key design challenges.

This section presents five key contributions of the framework, followed by a consultant's guide to aid in the goal formulation that integrates its elements. The frameworks are specifically designed for sustainability leads and LCA consultants in corporate settings and do not address applications in policy-making or political decision-making.

*3.5.1. First Contribution – **Framework 1**: A Modified Framework for the LCA Process*

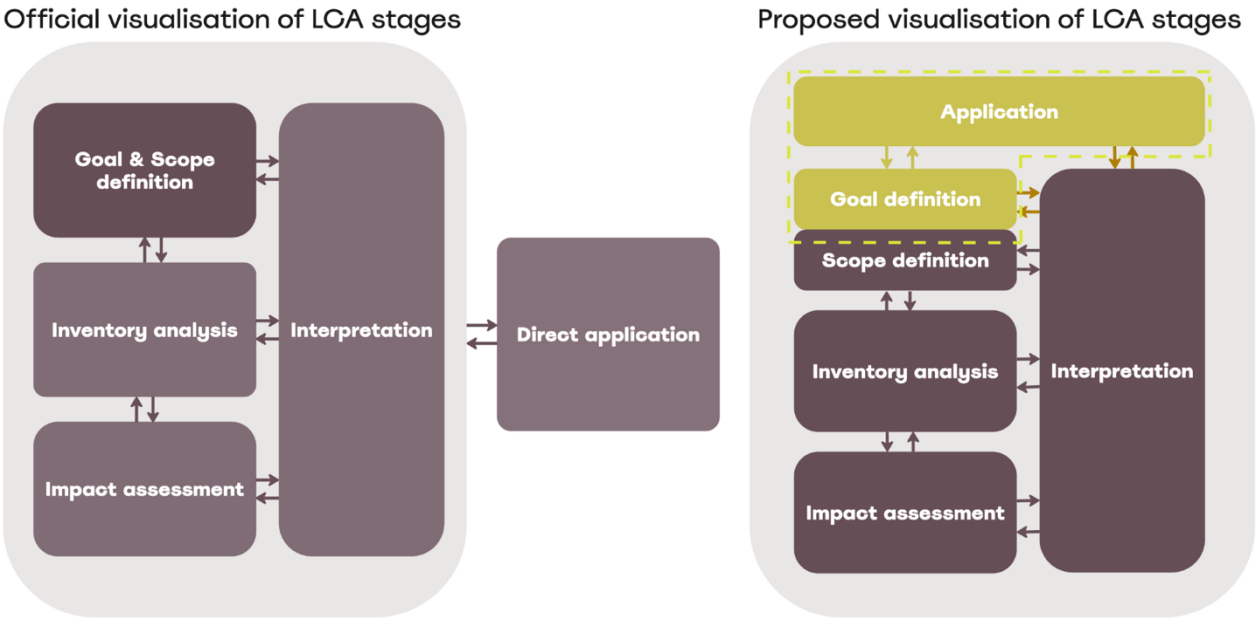

Figure 5 Proposed modified framework for LCA process compared to the ISO framework

What

The first research contribution presents a revised framework for visualising the LCA process (Figure 5). This new framework introduces substantial changes to the established models by ISO and ILCD, positioning the application of results as the foundational starting point of the analysis. The proposed framework integrates applications from the outset, ensuring continuous alignment with decision-making.

How

By introducing 'Application' as a phase, consultants and sustainability leads are required to explore how the LCA is conducted to support decision-making. By merely integrating it as a phase, practitioners are mandated to consider and evaluate LCA activities in its application.

Why

Framework 1 highlights that clarifying the application at the outset of an LCA process offers several advantages. Firstly, it manifests that the application of an LCA is essential for how the assessment is conducted. Secondly, it demands a formalisation of the process of defining the application and goal of an LCA, which will be presented in **Framework 3**. Most importantly, it ensures that results are aligned with strategic decision-making, increasing their potential impact. As LCA is inherently iterative, initial goals may still need to be revisited as new insights emerge.

See AR 10 for the development of **Framework 1.**

*3.5.2. Second contribution - **Framework 2:** Types of LCA Application*

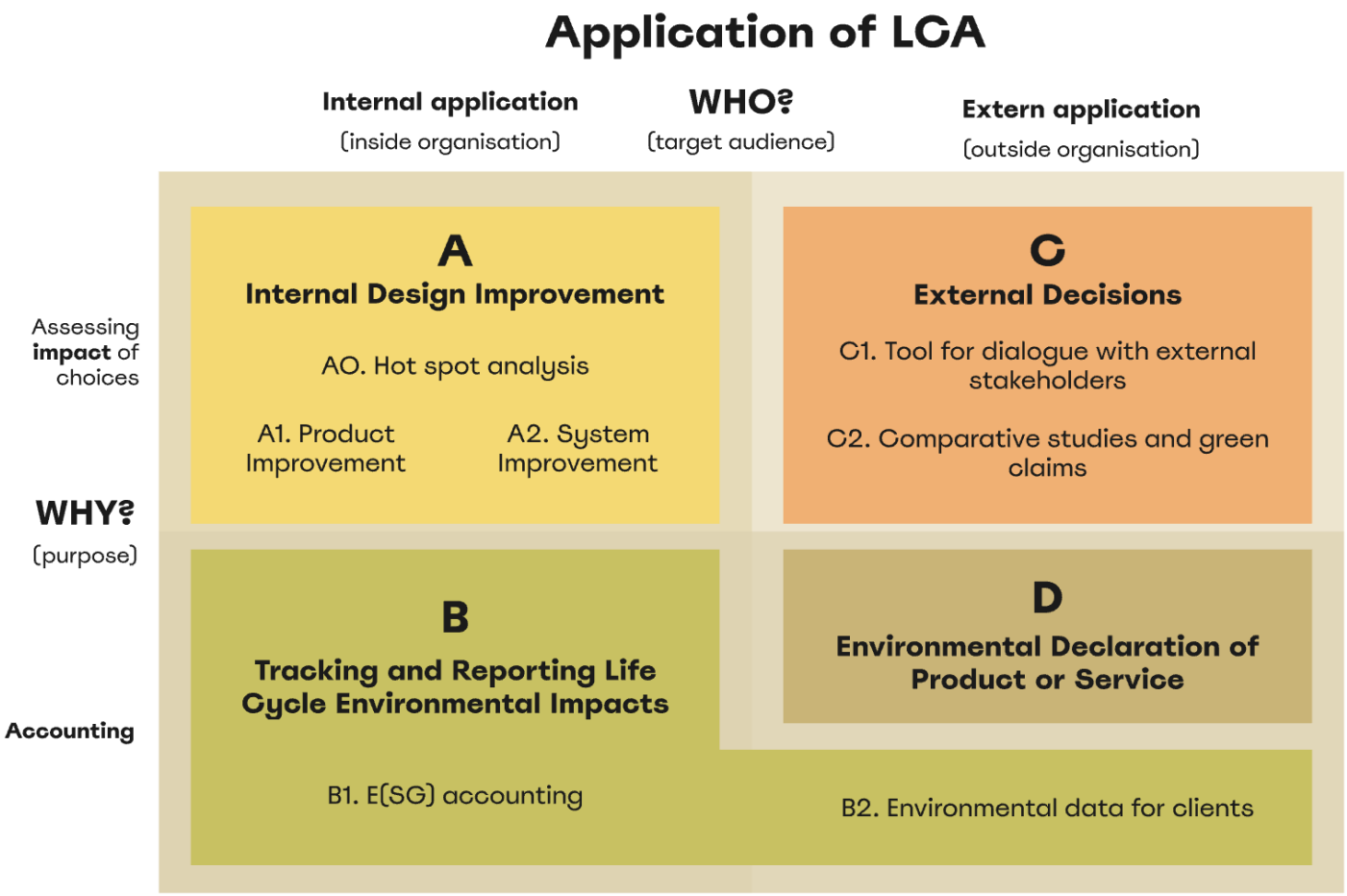

Figure 6 Matrix presenting LCA applications

What

The second research contribution, **Framework 2**, illustrated in Figure 6, is a matrix depicting the most commonly adopted types of LCA applications found in this research. The matrix is structured as a coordinate system, with the x-axis distinguishing between internal (left) and external (right) applications, and the y-axis differentiating between applications focused on assessing the impact of choices and those oriented toward tracking and reporting life cycle environmental impacts. This visualisation aims to clarify the diverse roles LCA can play depending on its intended use and audience, thereby supporting more deliberate and context-sensitive application of the methodology. By distinguishing between different applications of LCA the matrix can be used to facilitate a dialogue on how LCA can support decision-making.

The identified LCA application types are elaborated in Appendix E. These descriptions provide detailed insights into the purpose, typical use cases, and decision-making contexts associated with each application type. They are intended to support practitioners in selecting and applying the most appropriate type of LCA for their specific organisational needs, while maintaining a clear focus on enabling environmental improvement.

Regardless of the chosen application, decision-making is an essential component of any LCA. Therefore, **Framework 2** and the accompanying descriptions of the identified application types have been designed to ensure that, irrespective of which application is selected, users are encouraged to actively consider how the assessment will support decision-making aimed at environmental improvement. E.g. instead of the category 'accounting', 'tracking and reporting life cycle environmental impacts' is used to highlight that accounting and reporting can be used to track the process and outcome of sustainability strategies.

How

The intention is for sustainability leads and/or LCA experts to use the framework as the initial step in defining the application of an LCA. When combined with the written elaborations for each application type Appendix E, the framework is intended to support a reflective consideration of which application is most appropriate at this stage of the process. Consultants can use the matrix as an object to frame a negotiation with their clients about the different applications of LCA.

Why

Framework 2 is valuable because it brings clarity to the selection of LCA applications, addressing a common challenge in both research and practice: aligning the assessment with its intended purpose and audience. By mapping common application types across internal vs. external use and impact assessment vs. accounting, it helps practitioners choose the most appropriate approach from the outset. This improves the relevance, transparency, and strategic value of LCA in supporting decision-making.

*3.5.3. Third contribution - **Framework 2.1:** Decision tree for LCA application*

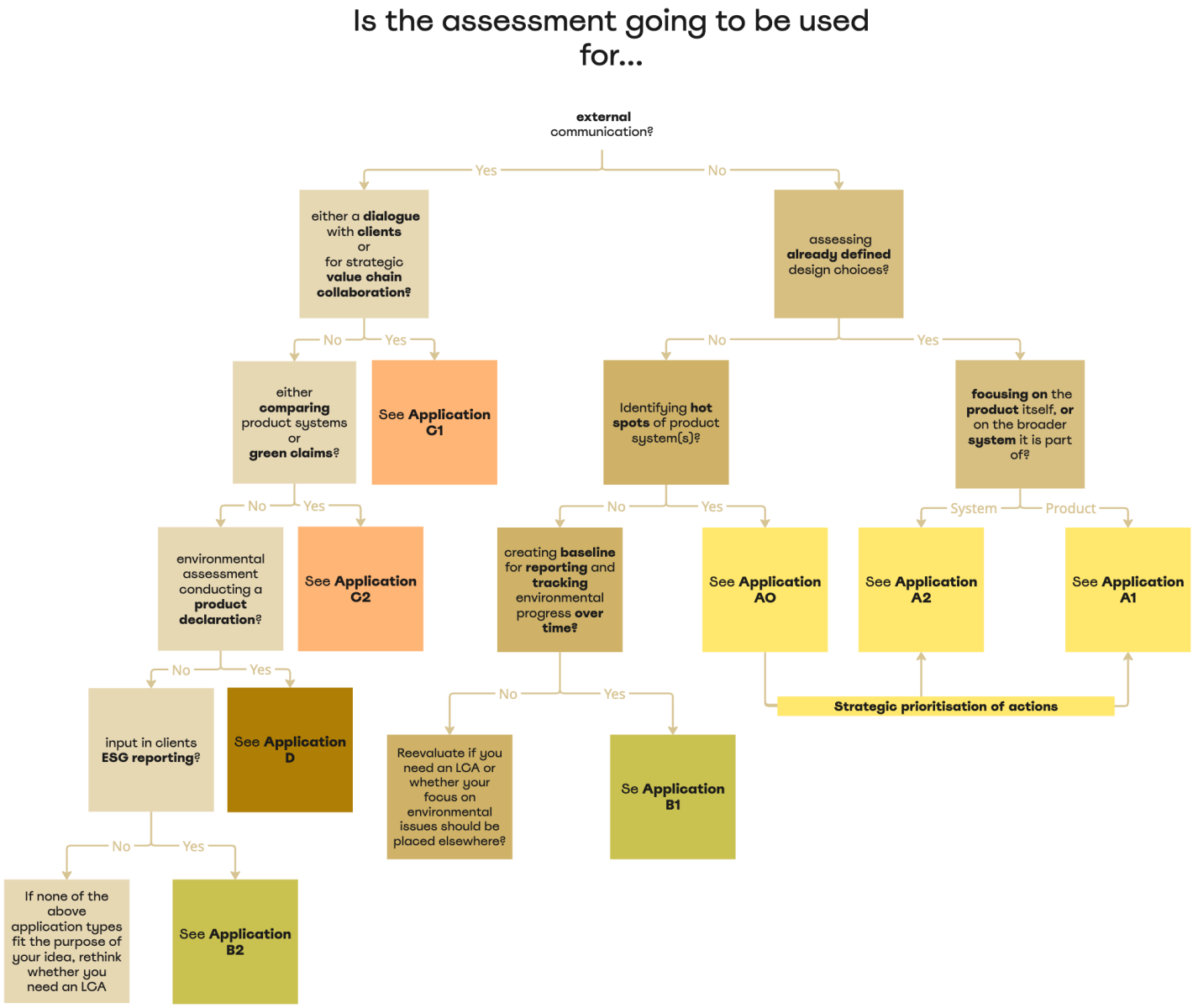

Figure 7 Decision tree guiding choice of LCA application

What

Framework 2.1, illustrated in Figure 7, is a supplement to **Framework 2** and is designed to support organisations that lack clarity on the intended application or do not see their context reflected in **Framework 2.**

How

The framework takes the form of a decision tree that guides sustainability leads—either independently or in collaboration with an LCA consultant—through a series of clarifying questions. These guide the user toward identifying the most appropriate application type, as defined in **Framework 2**. The decision tree can be used as

an object to facilitate a negotiation, framed by the presented questions, to make sure that all relevant aspects are considered before conducting an LCA.

Why

Framework 2.1 adds value by operationalising the application selection process, ensuring that all relevant questions are negotiated. It enables a structured, question-led approach to exploring purpose, ensuring that the LCA is better aligned with the organisation's decision-making needs. This helps increase the usability and impact of LCA in real-world corporate contexts.

Notably, the decision tree also helps assess whether an LCA is appropriate for a given context. If none of the guiding questions apply, this may suggest that LCA is not the right tool. A key part of goal definition is ensuring that the method supports relevant decision-making. LCA should only be conducted when its results can actively inform environmental improvements.

*3.5.4. Fourth contribution - **Framework 3:** Goal Definition Process*

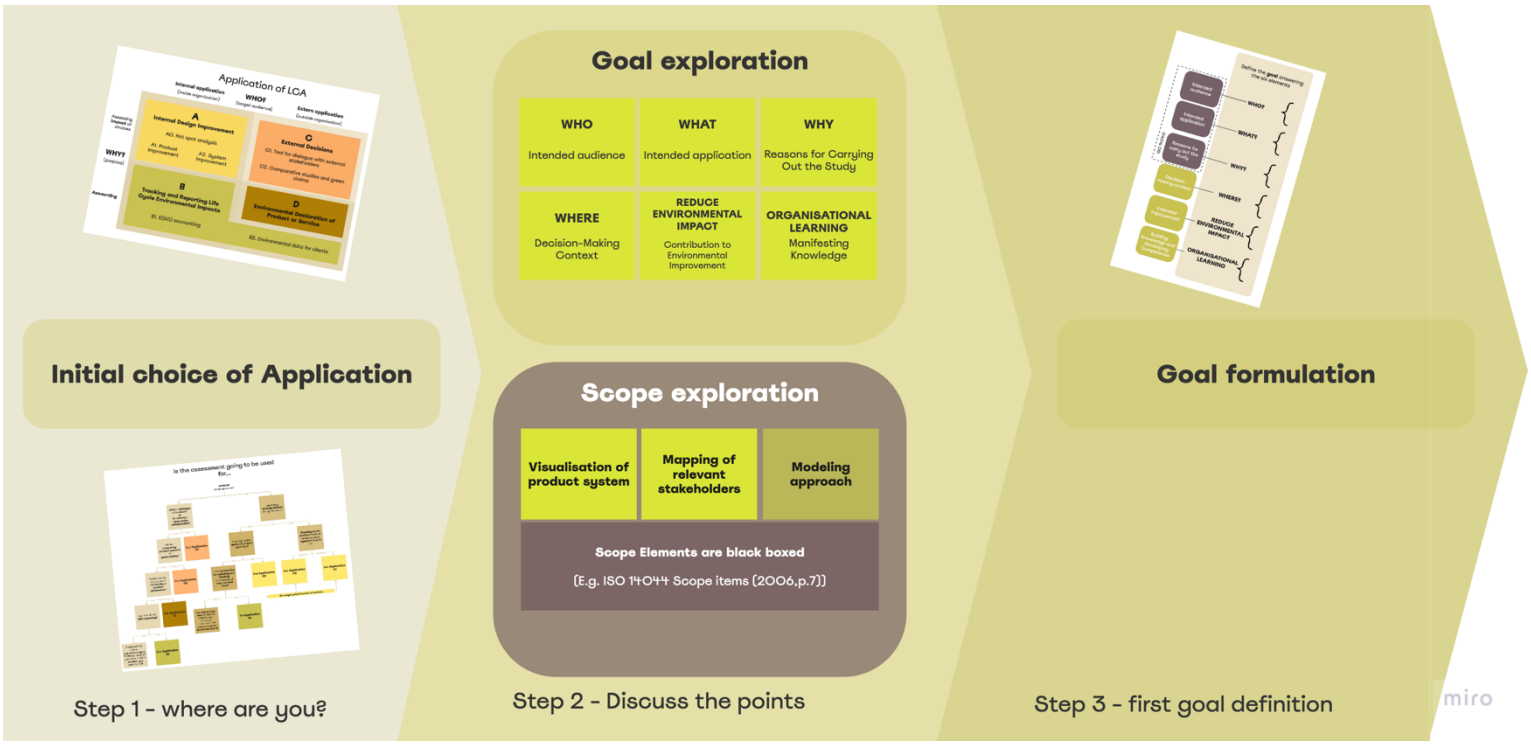

Figure 8 Process stages to formulate goal and application of LCA

What

Framework 3, presented in Figure 8, is the fourth contribution of this research. It offers a structured, practical process for formulating the initial goal definition of an LCA by operationalising the previously presented frameworks. Building on **Framework 2**, it begins with identifying the intended application and motivation for conducting the LCA. The next step depends on whether the investigated product system is clearly defined. If not, the framework suggests exploring the scope of the study by visualising the product system, as well as creating an overview of important decision-making stakeholders, to get a better understanding of the

decision-making context. Afterwards, the 6 goal elements can be explored. Conversely, if the product system is clearly defined, the goal elements can be explored from the outset. Importantly, the framework is an iterative exploration phase, where you can freely move from goal to scope exploration depending on the context. The last step of the process is to formulate a goal for the LCA, which is explained in **Framework 3.1**.

How

Framework 3 guides sustainability leads and LCA practitioners through a series of structured steps to clarify the purpose, scope, and strategic value of an LCA. It formalises discussions that typically occur informally at the outset of an assessment, aligning stakeholder expectations and clarifying decision-making needs. By distinguishing between clear and undefined product systems, the framework tailors the LCA planning process to the specific maturity level of the project, ensuring a relevant and focused goal definition.

Why

The framework formalises the goal formulation by offering a clear and visual method for constructing a robust initial goal definition, grounded in prior exploration of the application and scope. This connection transforms LCA from a technical compliance task into a decision-making tool that supports sustainability goals, regardless of the type of LCA application that is applied. This approach challenges the application framework presented in the ILCD handbook, ensuring that all LCAs consider how they will promote decision-making.

Framework 3 is especially valuable for early-stage needs assessments, enabling organisations to produce ISO-aligned goal definitions that not only satisfy methodological requirements but also support actionable and impactful outcomes. It ensures that any subsequent LCA is purposeful, aligned with organisational objectives, and capable of driving meaningful environmental improvements. Strategically, it positions companies to respond effectively to regulatory and stakeholder demands while building internal capacity for sustainability-driven innovation. The framework also facilitates stakeholder communication by enabling transparent dialogue about the purpose of the LCA, ensuring a shared understanding of expectations and intended outcomes. By aligning the goal definition with the intended use of LCA findings, it enhances decision support and improves the relevance and integration of the assessment within organisational contexts. Ultimately, Framework 3 prepares users for the LCA process through a reflective and informed starting point, increasing the likelihood of producing results that are both meaningful and actionable.

*3.5.5. Fifth contribution - **Framework 3.1**: Goal formulation Elements*

What

Framework 3.1 represents the final support developed, guiding users through the last step of formulating an initial goal definition for an LCA. It supports the user in articulating a goal that incorporates the six key goal elements outlined in **Framework 2** (Figure 9). The six elements are elaborated in Appendix G.

How

At this stage, the user has explored application options and clarified key aspects of the goal and scope, using the matrix and decision tree as dialogue tools. Framework 3.1 helps transform these insights into a structured, ISO-aligned goal definition that is both tangible and actionable. Its visual format supports clarity, shared understanding, and effective communication with stakeholders, ensuring the goal is meaningful, strategically aligned, and relevant for decision-making.

Why

By integrating the six core goal elements, the framework enhances the completeness and impact of the LCA while defining a strong foundation for further iteration, negotiation, and implementation. By formulating the six goal elements, the choices and assumptions made in the subsequent LCA process are grounded in the context in which the results are intended to be used

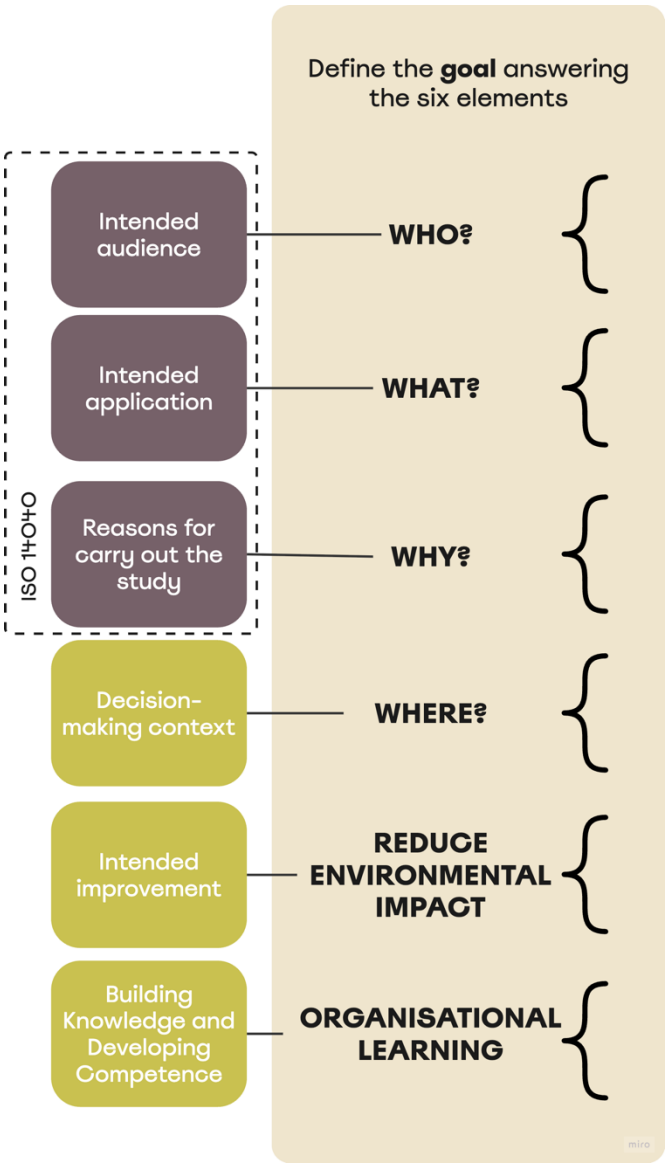

Figure 9 Six elements of goal formulation

Framework 3.1 positively supports the LCA process by:

- *Formalising the Goal Formulation*: Offer a clear, visual method for constructing a robust initial goal definition based on prior exploration of application and scope.
- *Facilitating Stakeholder Communication:* Enable transparent dialogue around the purpose of the LCA, ensuring that all involved parties share a common understanding of expectations and intended outcomes.
- *Enhancing Decision Support:* Ensure that the goal definition supports the intended use of LCA findings in decision-making, improving the relevance and integration of the assessment within *organisational contexts.*

- *Building a Strong Foundation:* Prepare users for the LCA process by fostering a reflective, informed starting point, increasing the likelihood of meaningful and actionable results.

Framework 3.1 is a practical tool designed to close the gap between intention and execution in LCA goal formulation, making it a valuable addition to the toolkit of LCA practitioners and sustainability professionals.

3.5.6. Sixth contribution: ***Consultant Guide***

To support practical application, the framework has been adapted into a consultant-oriented guide presented in the form of a slide deck. The guide is specifically designed to accommodate the time and resource constraints typically faced by consultants, enabling them to communicate and apply the framework effectively in workshop settings.

The presentation slides, which constitute the guide, are included in Appendix I. They are intended for direct use in facilitation and include speaker notes to support implementation. For further details on the Six Elements of Goal and the typology of LCA applications, please refer to AR 16 and AR 17, respectively. Between the submission of this report and the oral exam (DSII), the guide will be evaluated by consultants to gather feedback on its clarity, usability, and relevance for professional practice.

Discussion

4.1 The role of ALCA and CLCA in supporting informed environmental decisions

The distinction between attributional (ALCA) and consequential (CLCA) life cycle assessment is critical for understanding how LCA can inform decision-making. ALCA typically evaluates the environmental impacts directly associated with a product's life cycle, whereas CLCA accounts for broader system-level changes resulting from specific decisions or interventions (Ekvall, 2020). This distinction is especially relevant when considering the intended application of LCA results—a central concern of the present study.

Current consensus-building efforts are exploring how to guide the choice between ALCA and CLCA based on the intended application of the assessment. These efforts recognise that the selected modelling approach significantly influences both the framing of environmental questions and the resulting decisions (Consensus Project 2025). In this study, particular emphasis was placed on the goal definition phase, where a notable gap was identified in supporting practitioners to clarify the purpose and application of an LCA. While the scope definition phase—and its role in contextualising the decision-making environment—was addressed to a lesser extent, its relevance remains undeniable.

For future research, it will be important to investigate how the choice between ALCA and CLCA influences the LCA applications. One promising direction is aligning the framework proposed in this study with that of Ekvall (2020), who provides structured guidance for selecting appropriate LCA methods. His framework emphasises the importance of stakeholder negotiation during the goal and scope definition phase to ensure methodological choices are relevant, accurate, and communicative. These qualities are essential to ensure that LCA studies support meaningful decision-making and lead to environmental improvements.

Integrating these criteria into the proposed framework could enhance its practical value by helping consultants and practitioners select LCA approaches that are both scientifically robust and contextually appropriate. Such alignment would strengthen the relevance of LCA in real-world applications and contribute to its credibility as a decision-support tool..″

4.2 Enhancing organisational learning through LCA

The findings of this research suggest that LCA should not be viewed solely as a technical assessment tool but also as a valuable learning mechanism within organisations. Beyond its methodological contributions, LCA processes appear to play a significant role in enhancing employee competencies and deepening organisational understanding of life cycle thinking, an increasingly crucial capability in light of the escalating environmental crisis. This study thereby sees organisational learning and competence building as an LCA application along with the ones presented in **Framework 2**.

Although this research identifies organisational learning as an important dimension of the LCA process, it did not investigate this aspect in depth due to limited opportunities for empirical testing and validation. Further research is needed to explore the learning outcomes of LCA implementation more systematically and to understand how these can be effectively supported and measured in practice.

4.3 Interpretation Phase: Translating LCA findings into action

While the interpretation phase of the LCA was not addressed in this study, it is recognised as a crucial component for translating LCA results into meaningful and actionable insights. According to ISO 14040/44, interpretation involves integrating the findings from the life cycle inventory (LCI) and life cycle impact assessment (LCIA) in a way that aligns with the originally defined goal and scope. This includes ensuring consistency in the application of the functional unit and system boundaries. Moreover, interpretation plays an important role in communicating results clearly and transparently, enabling users to evaluate their robustness and understand any limitations or uncertainties (Hauschild et al., 2018). Although this study focused on the initial goal definition phase, the interpretation phase remains essential for ensuring that LCA outcomes are relevant within their intended decision-making context. Future research could explore how the proposed framework supports this process, particularly whether a more structured approach to defining the goal and intended application facilitates a more robust and accessible interpretation phase.

4.4. LCM or LCA framework?

The proposed frameworks outlined in this article contribute to a deeper understanding of the rationale behind conducting an LCA and clarify how such assessments can be strategically applied within specific decision-making contexts to mitigate environmental impacts. Notably, the article introduces 'application' as an explicit phase within the LCA process, rather than treating it as an external or subsequent consideration. This reconfiguration broadens the conventional boundaries of LCA by integrating it more directly into the decision-making workflow. However, this shift also raises an important question: does the framework primarily serve the practice of LCA, or does it more appropriately support the broader ambitions of LCM?

Life Cycle Management (LCM) is inherently strategic, encompassing not only the execution of assessments like LCA but also the contextual planning of when, where, and how such tools should be utilised to inform sustainable decision-making (Hauschild et al., 2018). In this sense, the proposed frameworks appear to operate at the interface between LCA and LCM. While they offer a structured approach to defining the purpose and scope of an LCA, their emphasis on embedding LCA into organizational and decision-making contexts suggests a stronger alignment with the goals of LCM. Rather than enhancing the technical conduct of LCA per se, the frameworks support LCM by guiding the selection and application of LCA in ways that are tailored to specific organizational needs and environmental goals. Thus, although rooted in the methodology of LCA, the frameworks can be more accurately characterized as tools for operationalizing LCM.

4.5 Research limitations

This study has several limitations that should be acknowledged. First, the majority of feedback was gathered from LCA experts and consultants, with limited input from company representatives or sustainability leads. As a result, the findings may primarily reflect the perspectives and priorities of practitioners who conduct LCAs, rather than those who commission or apply them within organisational decision-making contexts. Second, although a literature review was conducted to inform the development of the framework, it was not performed as a fully systematic review. Consequently, there is a risk that relevant studies or alternative approaches may have been overlooked, potentially limiting the comprehensiveness of the theoretical foundation. Future research would benefit from broader stakeholder engagement and a more structured review methodology to enhance the robustness and applicability of the findings.

Nevertheless, the introduction of this guide and framework within a facilitation context represents a novel approach with the potential to contribute significant value and practical support.

Conclusion

This paper explores how a framework can support consultants and sustainability leads in defining the goal and application of an LCA in a way that ensures the results contribute to meaningful decision-making for environmental improvement. A typology of LCA applications and a six-step process for structured goal formulation are presented. Together, these elements formalise the often vague and underdeveloped phase of goal definition, anchoring it more firmly in the decision context and intended use. The frameworks were developed through iterative, staged negotiations with multiple stakeholders, reflecting real-world complexities and enhancing practical relevance. They assist practitioners in clarifying not only why an LCA is conducted but also how its findings will lead to tangible environmental improvements. Crucially, this study identifies organisational learning as a legitimate and valuable LCA application, broadening the understanding of LCA's role in capacity building. Ultimately, for LCA to inform decisions effectively, its contribution to environmental improvement must be made explicit during goal definition, this is foundational to its credibility, relevance, and impact.

In response to the research question, the proposed framework supports consultants and sustainability leads by offering a structured and reflective approach to defining the goal and intended application of LCA. This

enhances the alignment between assessment and decision-making, increasing the likelihood that LCA results will lead to environmental improvement.

References

Andersen, A. W., Jørgensen, S. F., Gunn, W., & Niero, M. (2024). Remanufacturing as a circular design strategy in healthcare: Integrating socio-technical and environmental-economic assessments. *Proceedings of the Design Society*, *4*, 1179–1188. https://doi.org/10.1017/pds.2024.120

Auer, J., Bey, N., & Schäfer, J.-M. (2017). Combined Life Cycle Assessment and Life Cycle Costing in the Eco-Care-Matrix: A case study on the performance of a modernized manufacturing system for glass containers. *Journal of Cleaner Production*, *141*, 99–109. Scopus. https://doi.org/10.1016/j.jclepro.2016.08.096

Azapagic, A., & Clift, R. (1999). Life cycle assessment and multiobjective optimisation. *Journal of Cleaner Production*, *7*(2), 135–143. Scopus. https://doi.org/10.1016/s0959-6526(98)00051-1

Blessing, L. T. M., & Chakrabarti, A. (2009). *DRM, a Design Research Methodology*. Springer London. https://doi.org/10.1007/978-1-84882-587-1

Brodersen, S., & Pedersen, S. (2019). Navigating Matters of Concern in Participatory Design. *Proceedings of the Design Society: International Conference on Engineering Design*, *1*(1), 965–974. https://doi.org/10.1017/dsi.2019.102

Carlile, P. R. (2002). A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development. *Organization Science*, *13*(4), 442–455.

Carlile, P. R. (2004). Transferring, Translating, and Transforming: An Integrative Framework for Managing Knowledge Across Boundaries. *Organization Science*, *15*(5), 555–568. https://doi.org/10.1287/orsc.1040.0094

Coffey, A. (2018). *Doing Ethnography*. SAGE Publications Ltd. https://doi.org/10.4135/9781526441874

Collin, C., Linnet, A., & Secher, A. Q. (2018). *Life Cycle Engineering from the Perspective of an Engineering Consultancy*. *69*, 49–53. Scopus. https://doi.org/10.1016/j.procir.2017.11.077

Collin, C., Olesen, G. G. H., & Qvist Secher, A. (2019). *A case-based study on the use of life cycle assessment and life cycle costing in the building industry*. *323*(1). Scopus. https://doi.org/10.1088/1755-1315/323/1/012163

Cottafava, D., Brussa, G., Cavenago, G., Cespi, D., Rigamonti, L., Bala, A., Beigbeder, J., Refalo, P., & Sazdovski, I. (2024). Requirements for comparative life cycle assessment studies for single-use and reusable packaging and products: Recommendation for decision and policy-makers. *The International Journal of Life Cycle Assessment*, *29*(5), 909–911. https://doi.org/10.1007/s11367-024-02291-0

De Oliveira, J. A., Lopes Silva, D. A., Puglieri, F. N., & Saavedra, Y. M. B. (Eds.). (2021). *Life Cycle Engineering and Management of Products: Theory and Practice*. Springer International Publishing. https://doi.org/10.1007/978-3-030-78044-9

Dong, Y., Miraglia, S., Manzo, S., Georgiadis, S., Sørup, H. J. D., Boriani, E., Hald, T., Thöns, S., & Hauschild, M. Z. (2018). Environmental sustainable decision making– The need and obstacles for integration of LCA into decision analysis. *Environmental Science & Policy*, *87*, 33–44. https://doi.org/10.1016/j.envsci.2018.05.018

Dorland, J., & Jørgensen, M. S. (2024). From Assessment to Innovation: The Role of LCA and Co-Design in Sustainable Development. *Event Proceedings*.

Ekvall, T. (2020). Attributional and Consequential Life Cycle Assessment. In M. José Bastante-Ceca, J. Luis Fuentes-Bargues, L. Hufnagel, F.-C. Mihai, & C. Iatu (Eds.), *Sustainability Assessment at the 21st century*. IntechOpen. https://doi.org/10.5772/intechopen.89202

El Dessouky, N. F. (2024). *Sustainable Decision-Making for Sustainable Development Policy: Future Prospects, Opportunities and Challenges*. 2024 International Conference on Decision Aid Sciences and Applications, DASA 2024. Scopus. https://doi.org/10.1109/DASA63652.2024.10836408

European Commission. Joint Research Centre. Institute for Environment and Sustainability. (2010). *International Reference Life Cycle Data System (ILCD) Handbook :general guide for life cycle assessment: Detailed guidance.* Publications Office. https://data.europa.eu/doi/10.2788/38479

European Platform on LCA | EPLCA. (n.d.). Retrieved 27 May 2025, from https://eplca.jrc.ec.europa.eu/EnvironmentalFootprint.html

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Koehler, A., Pennington, D., & Suh, S. (2009). Recent developments in Life Cycle Assessment. *Journal of Environmental Management*, *91*(1), 1–21. https://doi.org/10.1016/j.jenvman.2009.06.018

França, W. T., Barros, M. V., Salvador, R., de Francisco, A. C., Moreira, M. T., & Piekarski, C. M. (2021). Integrating life cycle assessment and life cycle cost: A review of environmental-economic studies.

International Journal of Life Cycle Assessment, *26*(2), 244–274. Scopus. https://doi.org/10.1007/s11367-020-01857-y

Gill, J., Johnson, P., & Clark, M. (2010). *Research methods for managers* (4th ed). Sage.

Gond, J., Brès, L., & Mosonyi, S. (2024). Consultants as discreet corporate change agents for sustainability: Transforming organizations from the outside-in. *Business Ethics, the Environment & Responsibility*, *33*(2), 157–169. https://doi.org/10.1111/beer.12649

Hauschild, M. Z., Rosenbaum, R. K., & Olsen, S. I. (Eds.). (2018). *Life Cycle Assessment: Theory and Practice*. Springer International Publishing. https://doi.org/10.1007/978-3-319-56475-3

Huijbregts, M. A. J., Steinmann, Z. J. N., Elshout, P. M. F., Stam, G., Verones, F., Vieira, M., Zijp, M., Hollander, A., & Van Zelm, R. (2017). ReCiPe2016: A harmonised life cycle impact assessment method at midpoint and endpoint level. *The International Journal of Life Cycle Assessment*, *22*(2), 138–147. https://doi.org/10.1007/s11367-016-1246-y

ISO. (2012). *Environmental management—Life cycle assessment. Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis.*

ISO. (2006a). *ISO 14040 International Standard, Environmental management—Life cycle assessment—Principles and framework, International Organisation for Standardization.*

ISO. (2006b). *ISO 14044 International Standard, Environmental management—Life cycle assessment—Requirements and guidelines, International Organisation for Standardization.*

Jerland, J., Christiansen, K., Weidema, B., Jensen, A. A., & Hauschild, M. Z. (2001). *Livscyklusvurderinger—En kommenteret oversættelse af ISO 14040 til 14043*. Dansk Standard.

Konradsen, F., Hansen, K. S. H., Ghose, A., & Pizzol, M. (2024). Same product, different score: How methodological differences affect EPD results. *The International Journal of Life Cycle Assessment*, *29*(2), 291–307. https://doi.org/10.1007/s11367-023-02246-x

Lenzo, P., Traverso, M., Mondello, G., Salomone, R., & Ioppolo, G. (2018). Sustainability performance of an italian textile product. *Economies*, *6*(1). Scopus. https://doi.org/10.3390/economies6010017

Loiseau, E., Aissani, L., Le Féon, S., Laurent, F., Cerceau, J., Sala, S., & Roux, P. (2018). Territorial Life Cycle Assessment (LCA): What exactly is it about? A proposal towards using a common terminology and a research agenda. *Journal of Cleaner Production*, *176*, 474–485. Scopus. https://doi.org/10.1016/j.jclepro.2017.12.169

Miljøministeriet. (2002). *Kom godt i gang med livscyklustankegangen!*

Miljøministeriet. (2007). *Status for LCA i Danmark 2003—Introduktion til det danske LCA metode og konsensusprojekt*.

Müller-Carneiro, J., Rodrigues, C., Dias, L. C., Henggeler Antunes, C., Mattos, A. L. A., & Freire, F. (2023). A multi-criteria framework for the ecodesign of bio-based materials at early development stages. *Journal of Cleaner Production*, *427*. Scopus. https://doi.org/10.1016/j.jclepro.2023.139268

Niero, A., Brenes-Peralta, L., Pölling, B., & Vittuari, M. (2024). Exploring social handprints on well-being: A methodological framework to assess the contribution of business models in city region food systems. *International Journal of Life Cycle Assessment*. Scopus. https://doi.org/10.1007/s11367-024-02410-x

Niero, M., Jensen, C. L., Fratini, C. F., Dorland, J., Jørgensen, M. S., & Georg, S. (2021). Is life cycle assessment enough to address unintended side effects from Circular Economy initiatives? *Journal of Industrial Ecology*, *25*(5), 1111–1120. https://doi.org/10.1111/jiec.13134

OEF method—European Commission. (n.d.). Retrieved 27 May 2025, from https://green-forum.ec.europa.eu/environmental-footprint-methods/oef-method_en

OpenAI. (2025). *ChatGPT* (Version May 25) [Computer software].

Pedersen, S. (2020). Staging negotiation spaces: A co-design framework. *Design Studies*, *68*, 58–81. https://doi.org/10.1016/j.destud.2020.02.002

Roßmann, M., Stratmann, M., Rötzer, N., Schäfer, P., & Schmidt, M. (2021). Comparability of lcas—Review and discussion of the application purpose. In *Sustainable Production, Life Cycle Engineering and Management* (pp. 213–225). Scopus. https://doi.org/10.1007/978-3-030-50519-6_15

Selech, J., Joachimiak-Lechman, K., Klos, Z., Kulczycka, J., & Kurczewski, P. (2014). Life cycle thinking in small and medium enterprises: The results of research on the implementation of life cycle tools in Polish SMEs-Part 3: LCC-related aspects. *International Journal of Life Cycle Assessment*, *19*(5), 1119–1128. Scopus. https://doi.org/10.1007/s11367-013-0695-9

Silva, S., Nuzum, A.-K., & Schaltegger, S. (2019). Stakeholder expectations on sustainability performance measurement and assessment. A systematic literature review. *Journal of Cleaner Production*, *217*, 204–215. https://doi.org/10.1016/j.jclepro.2019.01.203

Stewart, R., Fantke, P., Bjørn, A., Owsianiak, M., Molin, C., Hauschild, M. Z., & Laurent, A. (2018). Life cycle assessment in corporate sustainability reporting: Global, regional, sectoral, and company-level trends. *Business Strategy and the Environment*, *27*(8), 1751–1764. https://doi.org/10.1002/bse.2241

Subal, L., Braunschweig, A., & Hellweg, S. (2024). The relevance of life cycle assessment to decision-making in companies and public authorities. *Journal of Cleaner Production*, *435*, 140520. https://doi.org/10.1016/j.jclepro.2023.140520

Valdivia, S., Ugaya, C. M. L., Hildenbrand, J., Traverso, M., Mazijn, B., & Sonnemann, G. (2013). A UNEP/SETAC approach towards a life cycle sustainability assessment—Our contribution to Rio+20. *International Journal of Life Cycle Assessment*, *18*(9), 1673–1685. Scopus. https://doi.org/10.1007/s11367-012-0529-1

Vinck, D., & Jeantet, A. (1995). *Mediating and Commissioning Objects in the Sociotechnical Process of Product Design: A conceptual approach* (pp. 111–129).