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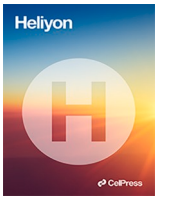

Research article

FLAVIA-LCT - Framework for systematic literature review to analyse vast InformAtion in life cycle thinking studies

Teresa Maria Gulotta *, Roberta Salomone, Giovanni Mondello, Bruno Ricca

University of Messina, Department of Economics, Piazza Pugliatti 1, Messina, 98122, Italy

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ABSTRACT

With the increasing interest in Life Cycle Thinking (LCT) applications for assessing the sustainability of processes, products and services, up-to-date syntheses and evidence-based critical outcomes analysis are required to guide future studies and policymakers. The systematic literature review is probably the most suitable approach for highlighting evidence of effects, impacts, and methodological choices, mapping the current knowledge and gaps in LCT fields, including methods such as Life Cycle Assessment, Life Cycle Costing, Social Life Cycle Assessment and Life Cycle Sustainability Assessment. Although several statements and guidelines for health care and ecology disciplines and one checklist for systematic literature review limited to Life Cycle Assessment (STARR-LCA) exist, it is still missing a framework for conducting systematic literature reviews in LCT field. This paper proposes a "Framework for systematic Literature review to Analyse Vast InformAtion in Life Cycle Thinking studies" (FLAVIA-LCT) to assist and guide researchers in structuring the processes of gathering, synthesising, and reporting outcomes from search strategy development to critical evaluation, considering the essential information to be included in a review manuscript. This framework can be used by anyone planning a literature review on one or more LCT methods.

1. Introduction

The sustainability assessment of processes, products and services through Life Cycle Thinking (LCT) based approaches has become a central topic in both theoretical and practical forms in recent years, and the usefulness of the life cycle perspective has been recognised globally in many policies and business models and strategies (Sonnemann et al., 2017). In Europe, for example, the eco-design directive suggests that goods and services design shall account for the potential environmental impacts generable during their whole life cycle using the Life Cycle Assessment (LCA) method with proper consideration of the social and economic effects of the measures envisaged [1].

Over the last 30 years, the LCA has been continuously developed, with remarkable improvements, reaching a good level of maturity to allow the move from its academic origins to a more robust approach that can support decisions from stakeholder choices to public debates [2]. In addition, the LCA has shifted from mere environmental evaluation to a more global assessment by developing the Life Cycle Sustainability Assessment (LCSA) [2,3]. The latter is a framework that complements the environmental dimension of LCA, with the economic (through the - conventional, environmental, and societal - Life Cycle Costing method, LCC) and social aspects (through the Social Life Cycle Assessment, S-LCA) [4].

* Corresponding author.
E-mail address: teresamaria.gulotta@unime.it (T.M. Gulotta).

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While LCA has been standardised with the series ISO 14040 [5,6], an ISO standard is still missing for the other assessment methods, despite developing guidelines to support their application published by other organizations [7–9]. Each LCT-based approach is characterised by similar perspectives and aims and is based on the same methodological steps underlined in the ISO 14040:2006, namely: Goal and Scope Definition, Inventory Analysis, Impact Assessment, and Interpretation [10]. However, LCC and S-LCA approaches could differ from LCA in terminology and content (e.g., the time horizon, the level of stakeholder engagement and the level of methodological development), making the integrated reading of results a challenge [2,11]. In addition, when reviewing and analysing the methodological assumptions made in LCT studies on specific objects or sectors, some authors identified high discrepancies during the application of LCT assessments: from the chosen functional units to the applied life cycle impacts assessment methods [12–14].

Indeed, these assessment methods are still characterised by limits and gaps that shall be identified, solved, or analysed. For example, among others, it is necessary to: 1) make the LCT methods more accessible, 2) develop more generic/specific LCT datasets for background processes, 3) develop reliable social impact pathways for S-LCA, 4) create reliable and flexible approaches to integrate results among the three dimensions, 5) propose a comparable impact assessment step in LCC, 6) develop guidelines for specific products and sectors to support LCT practitioners and harmonise LCT models [2,9,15].

These many open questions and gaps on the one hand, and the increasing need for sustainability assessment methods on the other, therefore, explains why research on these topics is continuously growing [16] and new studies frequently appear using LCT-based methods to evaluate the sustainability of new technologies and scenarios, also proposing new tools or methodological frameworks - such as the sustainability assessment dashboards presented by Finkbeiner et al. (2010) and Traverso et al. (2012) [3,17].

To ease the proper and coherent implementation of LCT approaches, up-to-date syntheses and evidence-based critical outcomes analyses are required to guide future studies and policymakers. These syntheses can contribute to increasing the quality of LCT studies by finding the right balance between their results' comparability and flexibility, which is needed to assess very different technologies or processes [15]. They usually take the form of critical literature reviews and state-of-the-art. Indeed, proper and thorough literature reviews could help to underline issues and identify best practices and relevant elements in the literature [18]. The systematic literature review (SLR) is probably the most suitable among the existing literature review approaches for this purpose, being the one that allows highlighting evidence of effects, impacts, and methodological choices, as well as mapping the current knowledge and gaps in specific fields [16,18,19]. The SLR aims to reduce subjectivity and improve transparency in the literature analysis, suggesting developing new or using existing registered protocols to reduce extensive and challenging endeavours and bias and make the research transparent, transferable, and replicable [20,21].

Considering the high number of papers published on LCT[1] and the vast amount of information included in each study to be processed, many researchers have recently recognised the importance of applying SLR in this field to summarise the evidence emerging from the state-of-the-art [16,22]. However, not all the LCT reviews self-identified as systematic[2] are truly systematic, making their findings not transparent and/or replicable. For example, some lack of reporting in the manuscript: i) the search strategies adopted (as key terms, the search queries, the selected databases) to identify papers, ii) how and why specific eligibility criteria are chosen, iii) how and which data were extracted, or iv) how they were harmonised. Nonetheless, LCT reviews would benefit from better aligning with criteria in systematic review protocols to present the findings emerging from LCT studies more transparent and coherent to LCT standards and guidelines [22]. Following this reasoning, some researchers proposed a list of requirements, suggested as checklists/protocols, that a SLR should include. Currently, only one standardised technique is widely recognised for reporting systematic reviews for the LCT field: the STARR-LCA [16]. It primarily focuses on how to write or appraise systematic reviews of LCA studies in both attributional and consequential approaches. However, it lacks in providing a guide on how to build and present a search strategy, collect reliable and affordable data to improve the quality of systematic literature review, and report and highlight evidence for the whole research's sample of LCT studies. Furthermore, to the author's knowledge, no statements/frameworks allowing to help researchers in carrying out a systematic literature review of LCC and S-LCA studies have been proposed yet among the international and grey scientific literature. Probably, for this reason, many LCT reviews refer to statements/frameworks built for health sciences (Prisma) [23], social sciences (Cochrane Handbook) [24], and environmental management (CEE) [25,26], or to guidelines developed for other disciplines [18,27–29]. However, it should be highlighted that, although the fundamental ethos of systematic review remains unchanged, LCT data and outcomes often differ fundamentally from human health or ecology disciplines and not all LCT reviews can comply with the various requirements proposed by statements developed for other fields [22]. Nonetheless, the use of existing guidelines might confuse beginners and junior researchers on how to conduct a literature review in the LCT field due to the use of items, terms, or procedures developed explicitly for other scientific areas (e.g. registering the protocol in PROSPERO or Conchare database valid for medical science[3]), neglecting specific elements to account for carrying out a LCT SLR (e.g., methodological assumption in LCT studies, harmonisation of life cycle phases, quality of LCT studies, reference to LCT standards or guidelines, creation of specific coding schemes, etc.). Considering this situation, this paper proposes a "Framework for systematic Literature review to Analyse Vast InformAtion in Life Cycle Thinking studies" (FLAVIA-LCT) to reduce these gaps. The main aim of this framework is to assist in structuring the processes of gathering, synthesising, and reporting evidence from search strategy development to critical evaluation, considering the essential information to be included in a review manuscript (Section 2). FLAVIA-LCT is a concise and

[1] More than 52,000 manuscripts were identified with the following search query carried out on the 27/07/2022 on Scopus database ((TITLE-ABS-KEY (("Life cycle assessment" OR lca)) OR TITLE-ABS-KEY ("Life cycle costing" OR "Life cycle cost analysis" OR lcc OR elcc) OR TITLE-ABS-KEY ("Social life cycle assessment" OR slca OR s-lca OR solca OR so-lca) OR TITLE-ABS-KEY ("Sustainability Life Cycle Assessment" OR lsca))).

[2] An analysis of a representative sample of 58 systematic reviews on LCT is reported in Supplementary materials (file SM1).

[3] Both databases include register protocols on health disciplines.

comprehensive practical guide to help researchers familiar with LCT concepts in conducting a systematic review (Section 3). This framework can be used by anyone planning a literature review on one or more LCT methods. In addition, the supplemental material accompanying this article provides a template to develop the data collection form needed for a systematic literature review of LCT studies and proposes a checklist to create the manuscript and a flowchart to represent how the sample is designed during the search. This paper's scope is to help researchers produce a transparent and systematic analysis of LCT studies, identify gaps and common elements selected for LCT modeling, and calculate the potential impacts of the object of studies, reducing bias during the search of literature studies.

2. Systematic literature reviews of life cycle thinking studies: an overview

SLR methods have been designed to prevent the primary evidence included in the review from being affected by selective reporting and research biases, as well as to summarise findings clearly and comprehensively [19]. SLRs have foremost been developed for evidence-based medical sciences in reporting and synthesising findings to avoid biased conclusions that can engage human lives [30]. Their execution has been supported by documented guidelines and checklists, such as the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) statement. PRISMA was published first in 2009 [31], proposing minimum reporting standards for authors of systematic reviews of healthcare interventions, and it has been continuously updated and integrated with several extensions to adapt it to suit different types of assessments (e.g. PRISMA for Protocols, PRISMA for Network Meta-Analyses, and PRISMA for individual patient data). Over the last decades, PRISMA has been used and adapted for topics and fields differently. However, not all requirements proposed in PRISMA could be applied to different disciplines, as Henriksson et al. [22] highlighted when reviewing seven food LCA systematic reviews using PRISMA.

Other researchers created standardised protocols for conducting and reporting systematic reviews in different fields, such as ecology [25,30,32], software engineering [33] and LCA [16]. Some of them are based mainly on the PRISMA statement that was appropriately modified to include the main terms or features of studies in that discipline and/or to provide advice to SLR practitioners.

For example, O'Dea et al. [30] designed a PRISMA extension for ecology and evolutionary biology (PRISMA-EcoEvo) to cover some issues that reviewers in these fields might meet (such as statistical non-independent variables, summarise patterns across multiple data items and/or environmental conditions), not comprehensively evaluated by PRISMA. For the same discipline, Parker et al. [32] focused on reporting environmental evidence, neglecting, in some cases, explanations and examples of meta-analysis writing items.

Snyder [18] highlighted the basic steps and essential choices in conducting a literature review for business research based on the author's practical experience and influenced by various standards and guidelines suggested for literature reviews (such as PRISMA). The author also proposed a framework for evaluating the quality of own review independently from the type of review conducted. However, information on how to perform a search or summarise evidence is missing.

Haddaway et al. [19] propose a pro forma and flow diagram designed for systematic reviews and maps in the conservation and environmental management field, respecting the indication presented in the CEE Guidelines for Systematic Reviews in Environmental Management [34]. The authors highlighted some of the critical limits for PRISMA [31] applicability in conservation and environmental management reviews, such as: i) it did not strictly require a protocol, but it refers to the registration of protocol (see PRISMA checklist number 5); ii) it only refers to report search in "at least one database" (see PRISMA checklist number 8); iii) it does not provide minimal requirements on which databases are accessed via Web of science (e.g., web of science core collection, data citation index, etc.) (see PRISMA checklist number 7); iv) it focuses on medicine and health topics (e.g., requiring a research question structure in terms of population and interventions), v) PRISMA checklist did not require to describe why studies are excluded during critical appraisal of data extraction or evaluation studies quality; vi) PRISMA checklist did not provide information within the processes required to complete it. However, it should be highlighted that some of these limits have been resolved in the last update of PRISMA [35].

The fact that the PRISMA is not a guideline has also been noticed by other healthcare researchers that proposed step-by-step approaches, mainly for beginners and junior researchers, on how to conduct an SRL and meta-analysis [19,20,27] correctly. Although the guidelines proposed by Refs. [20,27], and [19] provide comprehensive and exhaustive detail on each step, they include specific processes or items on review in the discipline proposed (e.g., the use of particular databases, such as the healthcare literature database, or applying existing protocols available on the review register databases) that might not be used for LCT field.

Some of these limits are also valid in the only widely recognised checklist on SLR of LCA: the Standardised Technique for Assessing and Reporting LCA (STARR-LCA) checklist [16]. In their study, Zumsteg et al. (2012) [16] presented a starting point for improving the utility of systematic reviews in the LCA field. Mainly based on the PRISMA statement [31], they proposed differences in recommended question format (such as PIFT: products, impacts, flows, and life cycle assessment types), evaluated the main issues noticed in LCA's SLR and included a few relevant LCA concepts providing a checklist of 9 points. However, STARR-LCA lacks practical examples for conducting and developing good search strategies, neither a specific flowchart nor data form that could be used to simplify the efforts linked to SLR in LCT fields.

Therefore, the described limits of existing checklists/protocols fail to satisfy LCT reviewers' needs for a detailed reporting guideline for systematic review, from identifying the scope of studies to the synthesis and appraisal of evidence transparently. For this reason, based on a representative sample of 58 self-identified systematic reviews on LCT[4], on previous checklists proposed by Refs. [19,30,35]

[4] The full description of the analysis carried out on the sample in available in the supplementary material (file SM1).

and the authors' practical experience with previous systematic reviews [12,13], a checklist of essential elements of SLR of LCT is summarised in Table 1, identifying a correlation between conventional manuscript sections and key steps in conducting a literature review of LCT studies. Then, the practical stages, from developing the research problem definition to results reporting, are explained in detail as part of the FLAVIA-LCT framework proposed here.

In Table 1, the checklist is integrated with terms and items reported in existing LCT-related standards and guidelines [5,6,8–10]. Although some points of the list are essentially part of the SLR (e.g., identify the review as a systematic review, and summarise the evidence), others, such as evaluating the quality of studies and critically evaluating the limitations of the sample, should be provided respecting the LCT requirements.

3. FLAVIA-LCT – the framework step-by-step

The "Framework for systematic Literature review to Analyse Vast InformAtion in Life Cycle Thinking studies" (FLAVIA-LCT) is a step-by-step framework for conducting a systematic literature review of LCT methods, providing useable examples, tools, and advice for analysing LCT studies and synthesising results. A step-by-step overview of the framework process is illustrated in Fig. 1. This process has been: i) developed from practical previous review experiences [12,13]; ii) influenced by various standards and guidelines suggested for systematic reviews [16,19,20,26,30,36]; and iii) built as a synthesis of these previous experiences and guidelines, including necessary adjustments for LCT studies.

The proposed framework is articulated in five main stages - representing the material and methods and the results and discussion sections of an eventual manuscript - and key steps within each. They are listed in the following and illustrated in Fig. 1:

1) research problem definition: i) define research aims, ii) define research question(s);
2) search strategy design: i) design selection criteria, ii) design conceptual boundaries;
3) sample preparation: i) identification of documents (searching) and elimination of duplicates (screening I), ii) skimming the identified documents (screening II), iii) selection of final documents sample (screening III);
4) data collection and analysis: i) create a data extraction form, ii) define data gathering and harmonisation processes, iii) define data analysis and synthesis;
5) result reporting: i) summary of the type of synthesis conducted as part of the systematic review, ii) provide a summary of key characteristics for reported outcomes, iii) describe the individual study quality, iv) draw a summary flow chart.

An explanation of each stage and steps of related issues is expanded below.

3.1. Research problem definition

The research problem definition is the first and most crucial stage guiding the literature review process. Defining the research problem is an iterative process that could be affected by studies' availability and existing literature review on the same topics. It documents the research's scope and context, from describing the aim and rationale for the review in comparison with existing knowledge to formulating the research question(s).

3.1.1. Define research aims

To know the main concepts of the field of investigation and to present the main literature gaps the review wants to address, a preliminary analysis of the knowledge available in the literature on the specific topic should be conducted by performing a scoping search. This initial search could be done in different ways, e.g., by searching the topics in literature databases, reading the most cited literature reviews on the field, or identifying which review manuscripts have been mentioned in the most recent published papers to collect the needed information for starting the research contextualization. In addition, this step helps to identify potential research question(s) not yet evaluated, which could warrant a new literature review and the preliminary terms generally associated with key concepts. Moreover, it allows identifying existing reviews proposed in the literature that has to be cited in the introduction section to underline the innovative aims of the manuscript. The iterative process of the research problem definition stage implies that several feedbacks will be done to look at more details, to include relevant inputs emerging from the shared knowledge on LCT[5], and to refine the problem contextualization and research aim description progressively.

Other systematic reviews on similar research questions are not an obstacle if a new analysis or assessment closes gaps and adds value [20]. In addition, since new publication in LCT disciplines frequently appears, more systematic literature reviews may also be conducted to update the evidence. This difference may refer to the topic evaluated and the analysis approach applied to the gathered data (e.g., statistical analysis, quality and quantitative, etc.). Indeed, for example, during this iterative stage, it is possible to identify

[5] it is essential to know and consult the standards and official guidelines developed to support LCT practitioners. These documents could be searched online in the International Organization for Standardization website (www.iso.org/home.html) or on the Life Cycle Initiative website (https://www.lifecycleinitiative.org/), in which the last updates of the frameworks are generally reported. Furthermore, these websites report and explain official glossary terms used in this discipline and the correct definition of words and concepts that must be used when reviewing the LCT studies. Moreover, considering that literature review could guide future studies, using correct definition could help improve the quality and harmonisation of future LCT studies.

Table 1
Checklists for conducting an LCT systematic review.

Section	Checklist stages	Key steps
Title, abstract and keywords	Identification of manuscript	Identify the review as a systematic review Identify the review with LCT methods and/or objects evaluated
	Abstract development	Synthesise the aims and scope of the review State the results of the primary findings State conclusions State limitations
Introduction	Background	Report current knowledge on topics Break down and summarise question key elements, e.g., object, LCT method, evidence, the network of interest
	Research problem definition (aims and scope)	Evaluate state of the art and reference any previous reviews on the topic Provide a rationale for the review State the aims, scope, and innovation of the review State the primary questions the review addresses
Material and methods	Research problem definition (research questions)	State the research questions and sub-questions that the review addresses (e.g., research question: "which are the main methodological assumptions in LCA of agrifood?" sub-research question: "which is the most functional unit used?") Reference any review protocols/framework/guidelines used (e.g., systematic approach or method applied by other authors) Describe and justify deviations from the review aims and methods
	Search strategy design (selection criteria)	Report the specific bibliometric filter used for including or excluding studies when searching in the databases (e.g., journal, keywords, language, etc.) (Bibliometric criteria) Report the selection criteria (inclusion and exclusion criteria) used for screening documents, according to the aims of the systematic review (e.g., LCT applied, objects evaluated, etc.) (eligibility criteria) Justify criteria, if necessary (i.e., not evident from aims and scope)
	Search strategy design (conceptual boundaries)	Define keywords and database selected Justify keywords and databases selection, if necessary (i.e., not apparent from aims and questions) Take note of the exact search strings used in each database with keyword combinations and Boolean operators and report them in the manuscript with results
	Sample preparation	State what sources and type of studies included (e.g., published or pre-print articles, case studies, grey literature) Provide enough information to reproduce the search (if possible), reporting the timespan covered (start and end dates) Describe how duplicates are removed, if necessary (e.g., the use of specific software for managing or merging bibliometric data) Describe the process for screening studies at each stage (e.g., use of decision trees, screening software, reference management software) Justify reasons, if necessary (i.e., not apparent from aims and scope) Report the number of studies screened Report the number of studies excluded for each stage of the screening process Report brief reasons for exclusion from the full-text stage
	Data collection and analysis	Report the data extraction form and coding scheme used Describe where data were collected from manuscripts (e.g., text, tables, or figures) Describe how data are collected (e.g., software used to digitize figures, coding software (e.g., MAXQDA, NVivo)) Describe which types of data are used for each sub-question (e.g., report in a table) (it could be part of the coding scheme) Describe how missing or ambiguous information was dealt with during data gathering (e.g., contacting authors of original studies and/or accounting missing data as unavailable data or own interpretation based on definitions reported in ISO 14040) Justify the decisions made to deal with missing or ambiguous data List and define all outcomes for which data were sought from each study following LCT standards and guidelines definitions Describe items or modeling features that do not appear in the main results or which could not be extracted due to insufficient information Describe the main assumptions or simplifications that were made (e.g., clustering functional units in mass, energy, time, volume, unit-related) Justify the decisions made to cluster data Describe and justify any studies excluded after critical appraisal of data Describe the software used to manage items and data collected Describe how data or studies are synthesised or clustered Report the coding scheme or procedures used to harmonise data in LCT studies Define terms and data coding coherent with ISO standards and UNEP guidelines If Meta-analysis is performed, explain each statistical method or calculation used to identify correlation among data If Meta-analysis is performed, describe how impacts are harmonised and define, if needed, reference scale approaches used

(*continued on next page*)

Table 1 (*continued*)

Section	Checklist stages	Key steps
	Results reporting	Report the number of studies and related scenarios for data included in the analysis or meta-regressions
		State the type of synthesis conducted as part of the systematic review (narrative only, narrative and quantitative, narrative and qualitative, narrative, qualitative and quantitative, narrative and mixed-methods, content analysis, meta-analysis, bibliometric analysis)
		Check the studies' quality following the requirements of LCT standards and guidelines
		Describe whether the quality of LCT studies included in the systematic review or meta-analysis was assessed (e.g., blinded LCI data collection, transparency, and completeness of reporting)
		Describe how information about study quality was incorporated into analyses (e.g., meta-regression and/or sensitivity analysis, uncertainty analysis or case studies)
		Describe which type of analysis is applied to provide an overview of studies (e.g., bibliometric analysis, network analysis)
		Provide a summary of key features for reported outcomes (either in text or figures)
		Provide a summary of the limitations of coding
		Provide an overview of features related to individual study quality (risk of bias within or across studies)
		Describe if the sample is divided into groups and justify why
		Present a flowchart from the identification step to the sample design, adding eventually information on data extracted
Results, Discussion and Conclusion	Results	Provide an overview of selected studies (e.g., from objects to method analysed)
		Report a flowchart detailing the varying system boundaries, if not obviously
		Synthesising the main findings in terms of their similitude and differences using tables and graphs
		Synthesise the main findings in terms of the magnitude of choices and effects using tables and graphs
		Summarise the main findings in terms of their methodological/practical/technological/geographical relevance using tables and graphs
	Discussion	Critically discuss the main findings in terms of their similitude and differences
		Critically discuss the main findings in terms of the magnitude of choices and effects
		Critically discuss the main findings in terms of their methodological/practical relevance
		Compare results with previous reviews on the topic or with standards and guidelines on matters, if available
		Report limitations and their influence on conclusions and outcomes, such as gaps in the available evidence (e.g., quality of data, missing methodological choices)
		Describe the limits and quality of the review and any effects on the results
	Conclusions and recommendation	Introduce the aim of the research and the review method applied
		Synthesise the relevant findings
		Highlight future research needs
		Report any recommendations that can guide future studies on the topics
Other parts	Acknowledgement	List the contributions of each co-author for different steps of the literature review (author one collected data and critically discussed the findings)
	References	Report a reference list of all studies included in the systematic review
		List the included studies as referenced sources (e.g., rather than listing them in a table or supplement)

which method is used to synthesise results besides systematic ones (e.g., content analysis, bibliometric analysis, network analysis, meta-analysis or others).

3.1.2. Define research question(s)

After the problem context is outlined and contextualised and the aim of the analysis is clearly stated, the next step consists in building one (or more) structured research question(s) that is (are) essential for guiding the development of the search strategy - the primary questions the review addresses should be first stated in the introduction section of an eventually manuscript. Then, sub-questions could be presented in material and methods or supplementary materials to guide data collection and coding scheme steps.

In literature, valuable tools have been created to facilitate the definition and development of the research question (RQ). Among these are included PICO (Population, Intervention, Comparison and Outcomes) [36], PECO (Population, Exposure, Comparator And Outcome) [26], and PIFT (Product or process, impact (s) of interest, Flows or economic sectors included and type (s) of life cycle assessment) [16].

However, considering that a good research question should be manageable in scope (not too broad, but not too narrow), the proposed framework includes a new tool, WOMEN, for developing an answerable RQ. This tool includes five guiding elements: i) use at least one of the question words (W) (Who, What, When, Where, Which, Whom, Why, and how), ii) define the Object(s) (O) of the study (e.g., product, process, service), iii) define the LCT Method(s) (M) to be investigated (e.g. only LCA, both LCA and LCC, etc.), iv) give Evidence(s) or Effect(s) (E) the review wants to evaluate (e.g., impact categories, methodological issues, inventory data, etc.), and v) highlight the Network (N) of interest (such as people, features, or things included in the group or system assessed). The last letter refers to all those relevant parameters (such as geographic location, technology type or stage, or level of analysis (organisation or product)) or connections (such as other methods or strategies complementary to life cycle approaches) that could be added to RQs.

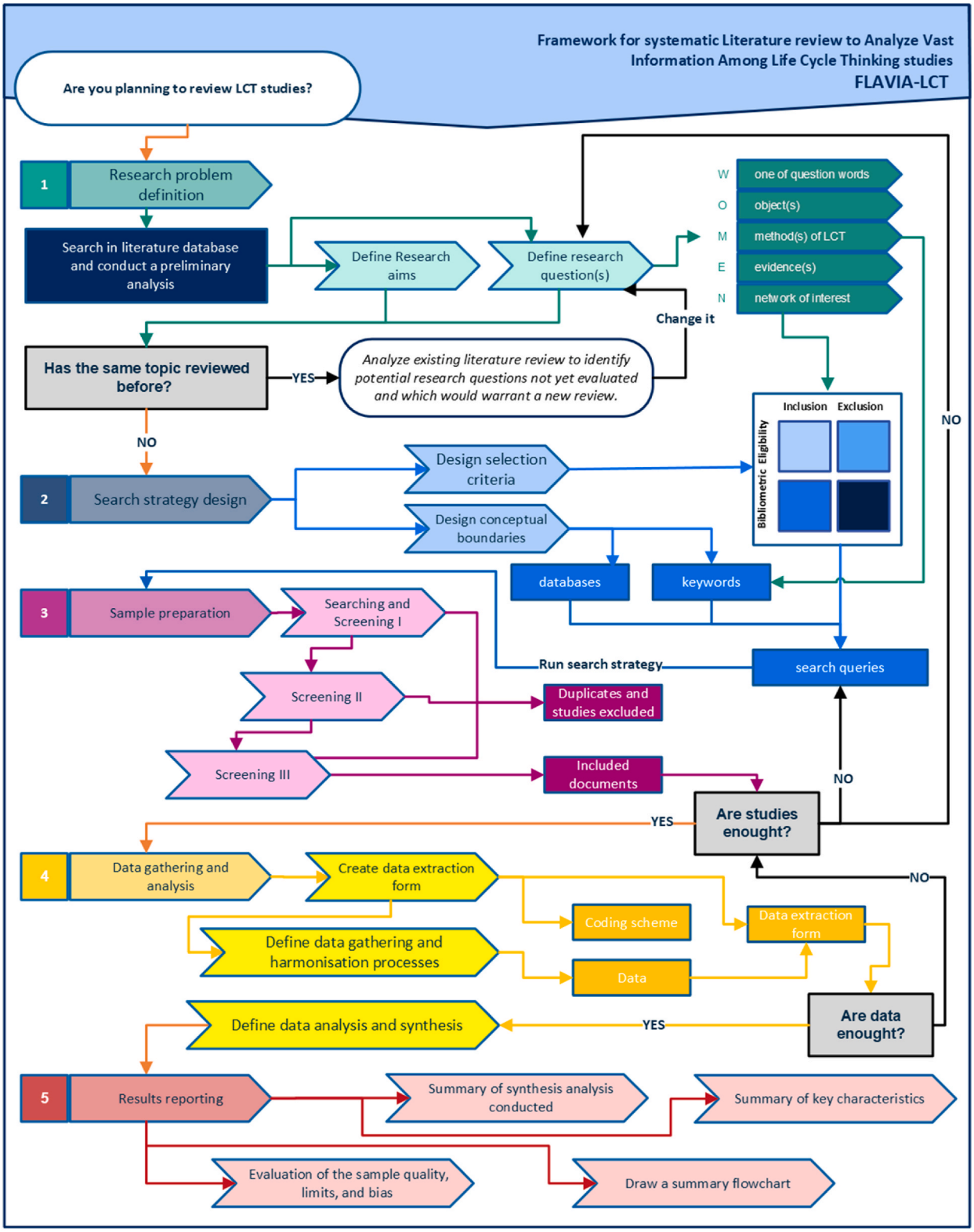

Fig. 1. A step-by-step overview of FLAVIA-LCT.

An example and advice for the definition of research questions are reported in Table 2.

3.2. Search strategy design

This stage is dedicated to designing a search strategy able to adequately address the research problem (how and where the search will be carried out), which includes the definition of a set of key elements, such as selection criteria (eligibility criteria for inclusion and exclusion of the documents to be reviewed) and conceptual boundaries (keywords and databases). This stage needs more careful planning and preparation than other stages [18]. A reliable and good search strategy allows: i) retrieving eligible studies, ii) maximising the probability of identifying relevant articles/studies, iii) minimising bias, and iv) reducing the time spent conducting the review.

The search strategies applied for the sample preparation stage shall be reported clearly in the manuscript to help readers reproduce the search method by verifying the review quality, reliability, correctness, and credibility. A clear outline of the steps undertaken in a review can provide the transparency needed for replication and appropriate updates when additional data are generated in future studies [16].

Each search strategy in the manuscript shall describe the reasons and limits that guide specific choices for defining the conceptual boundaries on selecting: 1) selection criteria, 2) databases, 3) keywords, and 4) search queries. A brief description of these and the main characteristics are reported in the following.

Some examples and advice for the design of search strategies are reported in Table 3.

3.2.1. Design selection criteria

The selection criteria should be performed before the sampling design processes and iterative declared for sizing and screening the sample. Selection criteria allow identifying relevant evidence during the screening process [20]. As well as for keywords search, the selection criteria shall be defined according to the research question, providing a set of characteristics the manuscript should have (or not have) for being included (or excluded) in the sample. These characteristics could be divided into two clusters and listed in a matrix divided for inclusion or exclusion criteria (see Fig. 1):

i) *Bibliometric criteria* include all the features connected to publication date, geographical location, type of manuscript, language, and subject area. They have also been indicated in PRISMA as automation criteria because they allow reducing the sample first of screening processes and are strongly affected by information included in databases. It is worthy of note that some bibliometric data could not be uniform or correct among databases, and maybe a bias could be generated that must be checked during the screening processes (e.g., some reviews may be indicated as articles in the database or year of publication is not updated).
ii) *Eligibility criteria* include all the parameters, methods or other features that studies should include to make them eligible. They are strongly affected by the aims and scope of studies but could be structured following, for example, the WOMEN elements of RQ(s). They generally regard how the study has been conducted and if they applied the declared method or if the quality of the study respects limits.

3.2.2. Design conceptual boundaries

Designing conceptual boundaries of research is essential to identify reliable and coherent studies to answer the RQ. This step regards the identification of: i) databases that contain the highest number of studies on the topics of reviews, ii) key terms that allow representing the existing knowledge on topics, and iii) search queries that combine terms respecting the logical functions of the database selected allow to identify the most representative sample of studies on topics. After the first identification of these items, they should be evaluated by an expert group to avoid bias in algorithms that could affect the reliability and representativeness of results.

1) **Databases:** different literature databases exist online. They are generally classified for the academic subjects or types of databases (abstract and citation databases, full-text databases, web search engines, search boxes on the library homepage or library catalogue). These characteristics are reflected in the types of documents that the database may include. More than one literature database shall be used because no single database can encompass all existing knowledge on a specific field [18,20]. In particular, the choice of the databases should be made coherently with the established selection criteria on document types (article, review, etc.), subject area (engineering, environmental science, social science, etc.), language and year of publication and source types (Journal, Conference Proceeding, Book Series, Report, and others).
2) **Keywords:** The keywords used for designing the sample should be identified based on the fundamental concepts of the RQs. Considering the RQ developed following WOMEN elements, the first key concepts that may be investigated are the object of

Table 2
Example and advice for the definition of research questions.

How to define research question(s)	
Example	An example of a research question for FLAVIA-LCT based on WOMEN for this issue is: Which are the main methodological choices in LCA and LCC applied to PEM-URFC? (W: Which, O: URFC, M: LCA and LCC, E: methodological choices, N: PEM technologies) [12].
Advise	Structuring the RQ(s) following the WOMEN tool allows practitioners to quickly identify the main selection criteria and key concepts coherently to the research problem. Concerning the manuscript, WOMEN could help structure the introduction to break down and summarise key elements

Table 3
Examples and advice for the design of search strategies.

How to design the search strategy	
Selection criteria	
Example (Bibliometric)	if the sample is limited to peer-reviewed articles published from 2018 to now, the bibliometric criteria on Scopus could appear as: PUBYEAR >2018 AND LIMIT-TO (DOCTYPE, "ar")
Example (Eligibility)	Examples of eligibility criteria could be: i) only the paper the applied LCT studies on the object (O), ii) that applied the selected method (M) and that reported specific Evidence (E) on the impacts of the manufacturing phase (N) are included into the study. They should also be used for pretesting the quality of studies.
Conceptual boundaries	
Advice (Databases)	Considering the high variability of concepts, topics and studied objects analysed in LCT studies, selecting multidisciplinary databases (such as Scopus, Web of Science (WoS), Science Direct, and Google Scholar) is essential to provide a global overview of available studies and reach the highest number of documents representative of RQ. All database characteristics, search query rules, and manuals shall be checked before selecting them to avoid bias while running the search strategies.
Advice (Keywords)	after performing the first search, the keywords could be derived from abstracts and keywords of the existing collected LCT studies, discussed within an expert group and finally used for developing the final search queries. Other approaches, such as text-mining, citation screening, and cluster analysis, can be used to identify search terms and facilitate the screening [37].
Advice (Search queries)	To ensure that search queries are correct, it is advised to conduct a sensitivity analysis, testing the relevance or correctness of keywords and evaluating the effects a term could generate on the sample. In addition, keeping good records of the searches carried out is crucial to avoid repeating them if necessary to make edits. Also, avoid saving only search queries because the same search queries run at different times might return different results. Thus, including information on the timespan covered (start and end dates) for each run search and saving bibliometric data and studies could reduce the efforts.
Example (Search queries)	A good search query should include terms, phrases, and abbreviations, using techniques like truncation (*) and wildcards (?). Rules for writing a search query are reported in the databases (such as the Web of Science website) manuals. A simplified example for RQ proposed in section 3.1.2 could be: TITLE-ABS-KEY (("Life cycle assessment" OR LCA) OR ("Life cycle cost*" OR LCC)) AND TITLE-ABS-KEY ("regenerative fuel cell" OR RFC) AND TITLE-ABS-KEY ("Proton$exchange membrane" OR PEM). While the first part represents the methods and the second part is the object of analysis, the third part allows refining the search only to PEM technologies (group of interest). An example of table for presenting search queries is reported in supplementary materials (FLAVIA-LCT_literature database.xlsx – Sheet Search queries)

analysis (O) and LCT methods (M). The sample could be resized by adding another key concept such as Evidence (E) (e.g., emissions, impacts, qualitative or quantitative index, etc.) or related to a Network of interest (N) (e.g., country, temporal range, or specific sub-categories). Each key concept must be identified with the terms generally used to represent it in literature. The correct number of words and combinations is determined iteratively and should be verified at each search.

3) **Search Queries:** Developing a search query is one of the essential steps for identifying the correct sample to be analysed for answering the research questions. It is one of the most complex processes in the systematic literature review approach. Inadequate search queries or errors in search strategies may miss evidence, while untargeted, broad searches lead to superfluous articles and waste time [20,38]. A search query is an algorithm that groups the selected search terms identified for each key concept into blocks using specific logic functions called Boolean operators (AND, OR, NOT, etc.). The final search queries must be reported in the manuscript or supplementary materials, indicating the number of documents identified at each step, criteria, or filter applied [19].

Table 4
Advice for preparing the sample.

How to prepare the sample	
Searching and Screening I	
Advice	Key actions for preparing the sample during the first screening step are assembling the references into a library, using one or more bibliographic reference management tool(s) (such as EndNote, Mendeley, etc.) or other data management tools (such as Access, Excel, Google sheets, Rayyan, etc.) for identifying and removing any duplicate references [20,23]. Guidelines on removing or identifying and managing duplicates are available online for each of the software mentioned above. Generally, all studies that (1) have the same title and author and were published in the same year or (2) have the same title and author and were published in the same journal will be deleted [27]. It is essential to understand that with term "duplicate" also considers duplicate publications of research results that should not be treated as separate studies in the review. Some studies may have been published for various reasons, including translations, results in different follow-up periods, or focusing on other outcomes.
Screening II	
Advice	Generally, the analysis of titles and abstracts could be checked directly into the abstract and citation databases, or they could be extracted using specific platforms that allow their analysis [20,39]. However, selecting reference management tools depends on different factors, such as the reviewers' skills, the study's scope, and the amount and types of data reviewers aim to collect. For example, Muka et al. [20] did not recommend using Excel because it is complicated and time-consuming. However, based on the authors' experiences with LCT reviews, Excel or other opensource software allows the creation of a form for an orderly and transparent collection and management of the preliminary information on studies; indeed, matrix data organisation quickly provides an overview of the research context and fixing (if needed) the direction of review.
Screening III	
Advice	Full texts can usually be found in full-text databases (such as ScienceDirect) by searching local libraries or online search engines, such as Google Scholar or social networks, such as Research Gate, or by directly contacting the authors [20]. Instead, selection criteria could be reported in a matrix based on WOMEN elements for defining the exclusion motivation: e.g., paper X does not conduct the LCT method (M), the paper focuses on the different objects from (O) and so on.

3.3. Sample preparation

The sample preparation stage includes the main steps to select eligible documents and if any, the number of scenarios (studies) under evaluation. This stage, together with the data collection one, is very challenging, being resource-intensive and sensitive to personal judgement that may affect the review's effectiveness, quality, and reliability. For this reason, many guides on systematic review suggest that at least two reviewers in parallel should judge the relevance of the references to establish which include in the final sample, applying the declared selection criteria [16,20,23].

The sample of documents is generally prepared following three main screening steps that consist of: 1) identifying documents running the search strategies (searching) and elimination of duplicates (screening I), 2) reading titles and abstracts to select only manuscripts that respect both bibliometric and eligibility criteria (screening II) and finally, 3) retrieving and investigating the full-text of manuscripts for verifying their eligibility and selection of final documents sample (screening III).

Advices for preparing the sample are reported in Table 4.

3.3.1. Identification of documents (searching) and elimination of duplicates (screening I)

The first step for preparing the sample is to run the search strategy to identify the available literature studies that respect the preliminary criteria. Search queries may produce thousands or tens of thousands of references requiring modification and filter application (bibliometric criteria). The last step represents the first sample screening which allows the selection of all that documents that have or do not have a particular criterion. This step is strongly affected by filter functions available in selected databases. In addition, retrieving relevant studies generally leads to articles being identified multiple times, especially when various databases or search queries are used. Although removing duplicate documents could reduce the time linked to the other screening steps, this process can be cumbersome and time-consuming due to the heterogeneous nature of studies in databases [20].

Thus, once searching is complete, relevant studies must be efficiently selected, and irrelevant articles detected and discarded. To do this, a double screening should be carried out (as described in the following). It is vital to ensure that search results are organised to be further screened for eligibility, giving evidence synthesis in one file.

3.3.2. Skimming the identified documents (screening II)

After removing duplicates, the sample should be resized by a second-round screening of the documents based on the document's title and abstract through eligibility criteria. If a document lacks an abstract and has only the title, the manuscript should be included in the next step. At this phase, keeping track of the exclusion's reason is unnecessary [20]. However, describing which items are searched in the abstract and titles help readers evaluate the review's quality. This step could be performed before or after the elimination of duplicates.

3.3.3. Selection of the final sample of documents (screening III)

After the titles and abstracts are analysed and the preliminary sample is identified, the full texts of the screened references should be retrieved. Once all full texts are retrieved, the sample should be resized by a third round-screening of the documents using the eligibility criteria to select those to be included in the systematic review. At this phase, it is essential to keep track of: i) reasons for

Table 5
Examples and advice for collecting and analysing data.

How to collect and analyse data	
Data extraction form and coding scheme	
Example	Examples of built data forms and coding schemes for LCT were reported in different reviews such as [12,13,42]. An example of a coding scheme is also reported in supplementary materials (SM2 - FLAVIA-LCT_literature database.xlsx – Sheet Example of coding scheme)
Advice	Considering that the LCT studies could be characterised by high variability in life cycle stages accounted for products or organizations and that they generally present massive discrepancies in methodological assumptions and choices, creating a data form is challenging that could be reduced by creating a coding scheme that will guide who are collecting data. The complexity of the data collection form and coding scheme is amplified if more than one LCT approach is evaluated in the literature review. Therefore, it is advised to use standards such as ISO 14040 or guidelines developed by UNEP and SETAC to harmonise meta-data in a standardised way.
Data gathering and harmonisation	
Advice	It is recommended to extract data in both adjusted and non-adjusted forms to allow confounding factors to be used in the analysis by combining them later [27]. In the case of meta-analysis of quantitative impacts data and needed harmonisation of quantitative data, the methods developed by Refs. [43–45] could help reach the scope limiting the bias or misinterpretation of results. While the harmonisation of qualitative data is performed coherently with another review, it is necessary to mention it and describe and justify any deviation from that its method.
Examples	if no general consensus exists among the functional units (FU) used in the sample, they could be clustered as energy, time, unit, and mass-related, following the definition proposed by LCT standards and guidelines. In the case of system boundaries, the harmonisation procedures could be reported in the figure detailing the phase included (e.g., manufacturing, use) and types of approach evaluated (e.g., cradle to grave, cradle to cradle). An example of a flowchart detailing the varying system boundaries is provided by Ref. [42] to describe the building's whole life cycle. Therefore, an example of a literature database is reported in supplementary materials (SM2 - FLAVIA-LCT_literature database.xlsx – Sheet Database).
Data analysis and synthesis	
Advice	An example of clustered data based on existing literature reviews is reported in supplementary materials (file SM1 - Table S2). If the data form is developed in Excel, some functions, such as pivot tables, allow a quick quantification of main similarities among methodological choices or provide statistical calculation among the outcomes (meta-analysis). Various other software applications similarly will enable the organisation and management of the data extraction form, including Access, Google Forms, Google Sheets and Open Refine.

excluding references, ii) objects and methods accounted for the studies after a preliminary reading, and iii) descriptions of selection criteria respected. At this point, additional full-text documents or studies could be added to the sample. These documents could be generally identified using snowballing methods [40], evaluating cited articles in other reviews, or previous studies. The manuscripts should report how studies are determined and why they are included in the sample.

Then, the final sample is finally ready, and the included papers can be analysed to identify scenarios, indicators [41], or other parameters to answer the RQ(s). During the critical appraisal of the data collection stage, it is possible to exclude other studies that may not have the desired quality level and could affect the review results. Eventually, this process shall be described and justified in the text.

3.4. Data collection and analysis

The data collection and analysis stage consists of extracting and classifying relevant data from the selected LCT studies to identify and take note of knowledge, gaps and conclusion emerging from them. This stage includes: i) creating a data extraction form and coding scheme to organise relevant data; ii) identifying the way to gather data from studies and harmonise them; iii) identifying the type of analysis and synthesis methods and software used for managing data without bias.

Collecting the relevant data contained in the LCT studies in a form is essential for allowing data management and evaluation. Data to be collected include information on what kind of data and from where it is extracted (e.g. qualitative or quantitative data, methodological assumption, the geographic context of case studies from inventory data, goal and scope sections, supplementary materials and so on), how and where they are adequately collected and managed (e.g. the software used to collect data). Finally, qualitative data (such as type of allocation, system boundaries, etc.) must be harmonised by building a coding scheme coherent with LCT standards and guidelines. Then, the methods of analysis could be applied to highlight evidence.

Some examples and advice for collecting and analysing data are reported in Table 5.

3.4.1. Create a data extraction form and coding scheme

Extracting pertinent data requires developing a structured data extraction form (a matrix). Designing the data extraction form requires careful consideration of the research question(s) and the requirements identified to ensure data traceability, transparency, transferability, and replicability (generally referred to as data quality). The coding scheme should list what kind of data they represent and should be extracted for each item. Reaching the level of detail required for answering RQs is an iterative process based on analysing the first studies included in the sample to identify pertinent data. This data collection form could be pilot tested for extraction using random studies from the sample. A good data extraction form should minimise the need to return to the source documents. In addition, before developing a data form, it is necessary to understand what kind of analysis will be applied (e.g., content analysis, meta-analysis, and others). This choice will affect the type of data that will be extracted.

3.4.2. Data gathering and harmonisation

Data gathering is the stage by which authors obtain the necessary information about study features and findings from the included studies, and requirements will vary from review to review. Extracting reliable qualitative and quantitative data from studies is a challenge of a systematic literature review because misinterpreting data or missing data could strongly affect the review conclusions and recommendations. Therefore, it is essential to describe and justify how data are treated in these cases and if relevant effects could be on results. Then, the qualitative and quantitative data shall be clustered and cleaned to identify sample evidence quickly. This step represents the essential part besides sample design in a systematic review. Unfortunately, data gathering and harmonisation are strongly affected by personal judgement. Since a systematic review is characterised by transparency, transferability, and replicability, the method or parameters used to organise and harmonise data must be reported clearly in the text.

3.4.3. Data analysis and synthesis

After the data are cleaned, reviewers can proceed with their analysis and synthesis. This step is crucial in any research. It summarises collected data and interprets data gathered using analytical or logical reasoning to determine models, relationships, or trends. Any bias during this step could affect all outcomes.

Further, the manuscript shall state the type of synthesis conducted as part of the systematic map (narrative only) or systematic review (narrative and quantitative, narrative, qualitative and quantitative, narrative and mixed-methods and bibliometric and network analysis). As mentioned before, these choices will affect the data gathering type and form. To be transparent, any calculations performed, or software used to synthesise data must be reported in the manuscript, and any different settings from defaults should be described.

3.5. Results reporting

This stage focuses on how data could be reported in the manuscript or critically discussed and presented correctly. Assisting the reader in understanding the critical data, flaws, and strengths of the individual studies is key to a robust and valuable review and provides context for the reader that facilitates the appropriate application of the review study results. For that reason, the SLR protocols should report this stage to anticipate the presentation and discussion of results by presenting: i) the types of synthesis analysis conducted to present the results, ii) which characteristics are presented and how they are organised in the results and discussions section, iii) how quality, limits or risk of bias of sample is evaluated, and iv) finally all protocol stages could be synthesised through a flowchart.

Examples and advice for reporting the results are available in Table 6.

3.5.1. Summary of synthesis analysis conducted

After the sample is identified and data extracted, it is essential to state the type of synthesis conducted as part of the systematic review and how and which data will be used for each. During this step, a description of any calculation performed for manipulating data and presented in tables and graphs should be anticipated to support readers in understanding how RQs have been answered.

3.5.2. Summary of key characteristics in outcomes

Assembling key characteristics of the individual studies can be complex; thus, presenting the features or results in a visual format (e.g., table format or plots) can be helpful [19,36]. Considering that a systematic review should synthesise and discuss the magnitude of one choice or impact, the data might be presented accounting for the four phases presented in ISO 14040:2006 or, if a different approach is used, it should be described. Key characteristics must be identified coherently with the RQs and sub-questions. Summarising the review's insights regarding the strengths and weaknesses of individual studies, including elements such as confidence intervals, distributions, and individual study limitations, also assists the reader in evaluating and understanding the steps from individual studies to systematic review conclusions.

3.5.3. Evaluation of the sample quality

To allow for critical interpretation and a clear understanding of the review, essential information about the individual studies or sources of data included in the review should be provided. The quality of any review or meta-analysis depends on the individual studies upon which it is built [27]. Describing how the quality of studies has been evaluated and how they differ from the standards series ISO 14040 and guidelines is essential. This step should include coherence and limitation description, as well as the risk of bias across or in studies. This sample evaluation could be an excellent opportunity to highlight essential recommendations and important questions for further research [16] and guide future applications of LCT methods.

3.5.4. Draw a summary flowchart

A well-designed flowchart contains information on: i) the number of relevant citations identified through database searches, experts, and reference lists; ii) the number of studies excluded based on title and abstract search; iii) the number of complete texts screened; iv) the number of studies excluded after full-text assessment with the reasons for exclusion citing the number of studies excluded for each sense; and v) the number of the studies included in the systematic review.

Instead of PRISMA flowcharts, this study proposes to develop a flowchart that considers the screening process and the other search strategies steps from research question to system boundaries until types of collected data and results reporting (see supplementary material SM3 - FLAVIA-LCT flow diagram. ppt).

4. Conclusions

A systematic literature review (SLR) constitutes a fundamental approach for evidence-based LCT assessments and policymaking in a time of proliferating scientific publications and journals. LCT practitioners and researchers should be aware of the principles of preparing such reviews and follow strict protocols to use them effectively. The FLAVIA-LCT five-step framework can simplify the process of carrying out a systematic review, providing LCT reviewers with the tools to conduct methodologically sound systematic reviews and meta-analyses and enhance the quality of synthesis efforts already underway. The FLAVIA-LCT aims to increase and maintain high standards in conducting systematic reviews of LCT studies through increased transparency and reaching high-quality SLR. The key attributes of such a framework are to: (i) ensure all necessary content required by the current and future updates of ISO 14040:2006 and UNEP guidelines; (ii) prevent manuscript bounces that consume time and resource before peer-review; (iii) increase readers' understanding of the complexity of the process and the quality of published systematic reviews; (iv) raise and maintain high standards in conducting systematic reviews through greater transparency, and (v) improve the incorporation of knowledge synthesis into sustainable decisions and policymaking.

As done in the health and ecology sector and with PRISMA and RoSes, there is a need to refine reporting standards as methods and terminology evolve continually. Therefore, FLAVIA-LCT will be continuously updated to consider the last reviews performed and the advice from LCT communities on improving the methodologies. To allow this, researchers must identify their SLR with the term "systematic review" and use appropriate words to indicate the type of LCT approaches evaluated.

FLAVIA-LCT focuses on the earlier and intermediate stages of the review process, such as research problem definition, search strategy design, sample preparation, data collection and analysis and result reporting. At the same time, there is little information on the terms used in LCT studies. This is a necessary framework aspect for being applied to various LCT methods and objects of a systematic literature review. One of FLAVIA LCT's advantages is its adaptability and flexibility. A universally valid reporting standard for all conceivable types of critical elements available in LCT studies (e.g., from functional units to inventory data used, to impacts assessment methods to system boundaries) would be cumbersome and unworkable because the critical appraisal is a highly complex and context-specific process in any systematic review.

Another limit of this framework is linked to the knowledge of researchers that wants to apply it. Indeed, it is necessary to have a good understanding of LCT standards, modeling, and impacts categories to avoid generating bias and misinterpretation during article screening and data collection. The FLAVIA-LCT aims to reduce that bias, involving researchers in using LCT standards and guidelines to improve the quality and reliability of their works.

Table 6
Example and advice for reporting the results.

How to report results	
Sample Quality	
Advice	The definition of bias for LCA studies is reported in Ref. [16]. Muka et al. [20] provide how to calculate them that could be modified following the definition of data quality [10]. For example, the reviewer could evaluate if the gathered data characteristics can satisfy the review's stated requirements. Generally, the risk of bias is not presented in LCT reviews, but it is essential for enhancing the possibly highest quality of the review.
Flowchart	
Example	An example of a flowchart is written in an edible version in supplementary materials (SM3 - FLAVIA-LCT flow diagram.ppt).

Although authors tested the frameworks in previous works, as highlighted in Section 3, the framework's effectiveness could not be evaluated through statistical analysis due to the high variability of parameters and terms generally used in LCT studies that could change from case to case, making the results insignificant. A solution to the high heterogeneity of initial data and results must be found. Future studies could evaluate the effects of using techniques typical of multivariate statistics (factorial-based or clustering techniques) by proposing the definition of a code to make the data (or metadata) more homogeneous. In addition, to support the systematic literature review in the LCT fields, future studies should account for developing a publicly accessible archive where reviewers could register the study aims, search strategy methods and analysis used for synthesising data (if possible) of literature review that they would like to perform. Ideally, the registration of the preliminary search could be useful for receiving advice from an expert on terms and search strategies.

Production notes

Author contribution statement

Teresa Maria Gulotta; Roberta Salomone; Giovanni Mondello: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Bruno Ricca: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interest's statement

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e15547.

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