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Integrating circular economy and sustainability assessment on the micro-level: An umbrella review

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ABSTRACT

The implementation of Circular Economy (CE) strategies in industry requires the adoption of effective assessment approaches to measure progresses in several dimensions, including the sustainability level. However, the lack of standardization of CE related concepts and assessment methods that also include sustainability assessment results in a fragmented landscape that does not help companies and organizations to effectively assess the circular and environmental performance of their business strategies. This work aims at summarizing the state of the art about CE assessment approaches on the micro level including sustainability considerations, with the objective to contribute to the systematization of circularity assessment approaches from a sustainability perspective. With this purpose, an umbrella review is performed, revealing trends and criticalities related to circularity and sustainability assessment, and suggesting some steps for future research on this topic. A classification of assessment approaches is provided as a basis for the analysis. Results confirm the heterogeneity of assessment methods, outlining that CE strategies are not well represented in current approaches, while sustainability dimensions are often neglected, especially the social one. Future research should address these gaps and focus on the integration of sustainability in CE assessment, proposing leading approaches and industry-specific methods.

1. Introduction

The interest of academia, institutions and companies towards Circular Economy (CE) has been increasing tremendously in the last decade, due to several drivers (Govindan and Hasanagic, 2018). On one side, the need to reduce environmental and social pressures related to anthropomorphic activities is generating policies oriented to seek more sustainable production and consumptions patterns, in line with the Sustainable Development Goals identified by the United Nations (UN, 2015). On the other side, some companies have detected in this trend a possible way to innovate their business, create new markets and increment profits. As a result, CE initiatives are spreading worldwide (Marino and Pariso, 2020; Tang et al., 2020), often supported by national normative frameworks and governmental interventions (such as the European CE Action Plan or the Chinese CE Promotion Law) (European Commission. Directorate General for Communication., 2020; The World Bank, 2020). This increase of public and private initiatives goes along with a growing interest of the academic community; a huge number of papers have been published in the last decade focusing on different points of view and topics, including a clear definition of the theoretical framework of CE and its measurement, which still represents a critical point.

Recently, some steps towards the standardization of the CE concept have been carried out: the British Standard Institution launched in 2017 the "BS 8001:2017 Framework for implementing the principles of the circular economy in organizations" (BSI, 2017), while the International Organization for Standardization (ISO) has released in May 2024 the standards ISO 59004, 59,010 and 59,020, dealing respectively with CE conceptualization, transition for business models and circularity assessment (ISO, 2023a, 2023b, 2023c). In addition, several CE definitions and classifications (Kalmykova et al., 2018; Kirchherr et al., 2017), as well as CE assessment methods (Kristensen and Mosgaard, 2020; Moraga et al., 2019; Vinante et al., 2020), have been proposed in the scientific literature for the three CE implementation levels, i.e. micro, macro and *meso* levels. In detail, the micro level refers to strategies applied in companies and products; the meso level includes multi-stakeholder ecosystems like supply chains, eco-clusters or eco-industrial parks; and the macro level regards specific geographic areas, like cities, regions or nations (de Oliveira et al., 2021; Ghisellini et al., 2016; Nikolaou and Tsagarakis, 2021). Recently, the introduction of the nano level has been proposed, referring to products, components

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Nomenclature

CE	Circular Economy
DEA	Data Envelopment Analysis
LCA	Life Cycle Assessment
MCDM	Multi Criteria Decision Methods
MFA	Material Flow Analysis
OECD	Organization for Economic Co-operation and Development
SDG	Sustainable Development Goals
SFA	Substance Flow Analysis
TBL	Triple Bottom Line

and materials (de Oliveira and Oliveira, 2023; Saidani et al., 2017), with the aim of focusing more specifically on the product dimension, while the micro level is usually associated to a broader company's perspective.

The definition of appropriate CE assessment methods represents a challenge for companies as well as researchers engaging in applying effectively CE strategies. Many efforts have been oriented to define new approaches, or to adapt traditional ones, for measuring circularity on different levels previously introduced. However, literature highlights some criticalities of currently available assessment methods, including the inability to effectively cover sustainability aspects, mostly focusing on the environmental dimension (Bastianoni et al., 2023; Samani, 2023). Research on CE assessment approaches should include the environmental outcomes of CE strategies, since the relation between circularity and environmental sustainability cannot be taken for granted (Helander et al., 2019; Millar et al., 2019). In fact, recent studies have outlined that some CE activities can generate rebound effects that need to be considered when accounting for the overall environmental impacts (Harris et al., 2021; Zink and Geyer, 2017). CE strategies do not necessarily always result in more environmentally sound solutions, and the relation between CE and sustainable development requires more investigation (Schöggl et al., 2020), also focusing on methods to measure both circularity levels and environmental performances (Helander et al., 2019).

Although studies focusing on CE assessment have been increasing in the last years, few studies looked specifically into the relationship between CE and sustainability, especially on the micro level (Lamba et al., 2023). This represents a research gap: organizations need guidelines and tools to effectively develop actions for supporting their transition to a more circular economic model which is also in line with environmental sustainability targets (Valls-Val et al., 2022), as a huge gap remains between CE theory, sustainability and their application in industry (Kristensen and Mosgaard, 2020; Saidani et al., 2019). One source of uncertainty derives firstly from the terms adopted for the several CE assessment approaches (such as indicators, methodologies, tools, etc.), often without consistency among the different studies: one example is that the terms metric, indicator and index are often used interchangeably as well as the terms methodology, method and tool (Saidani et al., 2019; Vinante et al., 2020). This fosters a lack of clarity that increases the difficulty of consistently identifying and adopting proper assessment methods to measure the performance of CE strategies according to an environmental sustainability point of view. This is also reflected in different approaches and methods proposed in the literature, contributing to increase uncertainty about this critical topic.

This work aims at addressing this need, trying to provide a clear picture of the state of the art on the assessment of CE strategies on the micro level, focusing on how sustainability assessment is included, with the aim of identifying the main trends and challenges characterizing this topic and suggesting directions for future research. The following research questions have been introduced to focus the analysis:

- RQ1: what is the state of the art on CE assessment approaches with focus on the micro level proposed in literature?
- RQ2: How is sustainability included in current CE assessment approaches on the micro level?

An umbrella review (which is a systematic review of reviews) is proposed to address these questions, identifying the main trends, criticalities and research gaps regarding a CE assessment integrated with sustainability issues applied at micro level.

The remaining part of the paper is structured as follows: Section 2 presents a literature review detailing the problem in analysis, describing the background on the relationship between CE and environmental sustainability. The methodology is explained in Section 3, while results of the review are presented in Section 4. Discussion and conclusions are provided in Sections 5 and 6.

2. Literature review: the link between circularity and sustainability

The concept of CE has been derived from other well-known concepts, such as industrial ecology, closed-loop systems, eco-design, etc. Over the years, CE has gained its own relevance, with increasing attention in the last two decades, often presented as a way to decouple economic growth and environmental impacts, as opposed to the linear "take, make and dispose" model (Ellen MacArthur Foundation, 2013). Several authors present the CE paradigm as a promising path towards environmental sustainability, a new perspective that can help leading our consumption-based society to become more sustainable (Ghisellini et al., 2016). Some researchers state that CE can contribute to accomplish sustainable development (SD) (Kirchherr et al., 2017; Ma et al., 2014; Park et al., 2010; Xue et al., 2010; Korhonen et al., 2018). However, other researchers have been arguing that circularity does not necessarily imply sustainability. Some CE actions (such as eco-design, use of innovative materials, etc.) aiming at improving the environmental sustainability of a system, can present rebound effects that can reduce or even eliminate the environmental benefits (Helander et al., 2019; Salvador et al., 2020; Zink and Geyer, 2017). Similarly, recycling, whose target is usually to avoid material losses and new materials extraction, could be, in specific conditions, more energy-intensive than the primary process. These strategies should be analyzed in their complexity, especially when focused on a single life-cycle stage (Cullen, 2017). Thus, a deeper analysis is essential to evaluate if CE strategies generate environmental sustainability benefits (Geissdoerfer et al., 2017; Momete, 2020; Harris et al., 2021; Lamba et al., 2023).

Several recent studies have pointed out some criticalities related to the evaluation of the actual impact of CE to foster sustainable development. Adami and Schiavon (2021) acknowledged the need to strengthen the connection between CE and environmental sustainability, introducing the concept of "Circular Ecology" as a revised CE, explicitly focused on decreasing the environmental burden of human activities. Schöggl et al. (2020) proposed a review on CE and its connections with sustainability, drawing a map of the evolution of CE research, underlining a lower attention to the social impacts of CE as well as a focus on only few environmental aspects, confirming that the relation between CE and SD still represents a research gap, as well as integrated circularity and sustainability assessment methods. Similarly, de Pádua Pieroni et al. (2018) underlined that even if different approaches for the design of circular business models and sustainable business models have been developed, there was a lack of integration between the two concepts. Literature highlights several gaps regarding the link between CE and sustainability, such as the lack of a shared definition of CE that explicitly involve sustainable development, and a lack of clarity about how circularity promotes sustainability (Millar et al., 2019).

Furthermore, concerns about the effective contribution of CE strategies to increase the sustainability of our economic system are diffused

among academics. Hobson (2021) argued that current CE practices and policies might result in an increase of resource use. Millar et al. (2019) stated that in its current form, the CE might delay environmental degradation compared to a linear economy, but it cannot be considered an alternative path to promote sustainability. This is also related to the rebound effects that can generate from CE practices, occurring when a higher resource efficiency results in higher consumption and exploitation of resources (Horvath et al., 2019; Zink and Geyer, 2017). The influence of the rebound effect on sustainability is considered as a critical point and potential weakness of CE strategies by many researchers, and the lack of assessment approaches that are able to capture this effect is also highlighted (Calzolari et al., 2022; Corona et al., 2019; Harris et al., 2021; van Loon et al., 2021).

However, the introduction of Sustainable Development Goals (SDG), defined by the United Nations in 2015 (Nikolaou and Tsagarakis, 2021) has recently provided a support for effectively integrating CE and sustainability issues, especially from an environmental point of view. Schroeder et al. (2019) highlighted how CE practices can contribute to different extents to several SDG, while Rodriguez-Anton et al. (2019) observed that there is a correlation between a subset of CE indicators and some SDGs. Similarly, a recent study by Garcia-Saravia Ortiz-de-Montellano et al. (2023) analyzed the correlation between CE strategies and SDGs, concluding that CE can support goals related to economic growth, responsible production and consumption, and climate action.

Overall, providing integrated assessment approaches to evaluate the relationship between CE and environmental sustainability is essential in order to point out the effective benefits of CE actions and strategies at all the implementation levels, and avoid the risk of incurring in "circular washing" or pursuing "circularity for circularity's sake" (Harris et al., 2021). Through the RQs previously defined, this study focuses on the micro level, aiming to provide a state of the art of CE assessment approaches including their link with sustainability.

3. Methodology

3.1. Assessment approaches for Circular Economy strategies: a taxonomy

Before starting the umbrella review, a taxonomy about CE assessment methods has been introduced, with the aim of providing a clear reference framework to classify and analyze literature. However, the taxonomy can also benefit both practitioners and academics by proposing a clear and consistent classification of approaches.

Different assessment approaches are presented both in scientific and grey literature, according to the width of their scope and the specific objective. However, the nomenclature used in the studies analyzed is not always uniform and consistent, creating some uncertainties in the application. Vinante et al. (2020) classify the assessment approaches in four categories: *metrics, indicators, methods and methodologies*. According to the authors, a metric has the "finest level of granularity" for assessing purposes, while an indicator has a broader scope; a method is a set of indicators, while a methodology represents a collection of methods. On the contrary, Corona et al. (2019) defined a metric as any approach used to assess the effectiveness of a CE strategy. Two main groups were also proposed: *circularity measurement indices*, expressing the level of circularity of a system, and *circularity assessment tools*, more focused on assessing the environmental and economic impacts of CE strategies on society, which are further divided in indicators and frameworks. A further classification is provided by Chrispim et al. (2023), who consider an indicator as a single value assessing a goal, a metric as the normalized measure of an indicator, an index as the weighted average of corresponding metrics, and a tool as an instrument to enable the use of indicators and metrics. Saidani et al. (2019) and Roos Lindgreen et al. (2020) underline the lack of consensus around the definition of "indicator" in scientific literature, where often other terms are used as synonyms, such as "metrics", "measures", "indices" or "index". Saidani et al. (2019) proposed to adopt the approach of OECD (Organization for Economic Co-operation and Development), defining indicators as "*quantitative or qualitative factors or variables that provide a simple and reliable means to measure achievement, to reflect changes connected to an intervention, or to help assess the performance of a development actor*".

Overall, a lack of consistency on these concepts can be outlined, especially regarding the terms "metric" and "indicator", which sometimes are used as synonyms. Therefore, for the scope of this work, it is necessary to clarify the meaning of these terms proposing a systematization of the various approaches available, considering that they can have very different scopes and respond to different objectives and needs. The Oxford dictionary defines metrics as "*a set of numbers or statistics used for measuring something*", which aligns with the definition given by Vinante et al. (2020), while it gives a broader description of indicator, as "*a sign that shows you what something is like or how a situation is changing*". Starting from all the interpretations presented, highlighting a lack of consensus in literature on some of the terms used, a classification of the assessment approaches is proposed as follows:

- **Metric**: a single value measuring one dimension of a system (e.g., recycled material content, electricity consumption, etc.).
- **Indicator**: a combination of two or more metrics, providing information on a specific aspect of a system (e.g., Material Circularity Indicator, CO2-equivalent emissions, etc.).
- **Methodology**: a structured and formalized procedure based on defined methods, which includes the use of metrics and/or indicators (e.g., Life Cycle Assessment, Material Flow Analysis, etc.)
- **Tool**: an instrument allowing the assessment of different metrics and/or indicators for a system, which can be also based on methodologies (e.g., Circulytics by Ellen MacArthur Foundation, etc.).

3.2. The review analysis

Given the growing number of publications dealing with CE assessment methods, and the presence of different reviews exploring this topic through different perspectives, we have chosen to perform a systematic review of literature reviews, defined as umbrella review. On one side, this methodology allows to ensure a higher thoroughness of the review, considering how a wide range of CE assessment methods have been analyzed so far, and the results that have already been reached by other reviews. On the other side, it can be useful to compare different points of view that have been currently analyzed, trying to provide a synthesis of the huge body of knowledge available in literature. Thus, analyzing reviews on this topic can allow to verify if and how CE assessment methods for the micro level have been classified, evaluating specifically the relationship with environmental sustainability, with the aim of answering to the proposed research questions.

The process of an umbrella review is analogous to that of a systematic literature review, with the essential difference that only review papers are selected for the analysis (Garousi and Mäntylä, 2016; Javaid et al., 2020). Finally, the procedure aims at: "(1) selecting a collection of appropriate studies that will address the review question from the vast and rapidly increasing knowledge base and (2) extracting trends, patterns, relationships, and the overall picture from the collected studies" (Borrego et al., 2014).

The review has been developed through three main steps as shown in Fig. 1 (Tranfield et al., 2003):

1. Planning;
2. Execution;
3. Result analysis.

The results of the first two steps are included in the description of the phases, detailed in the following subsections, while the result analysis is presented and discussed in Section 4.

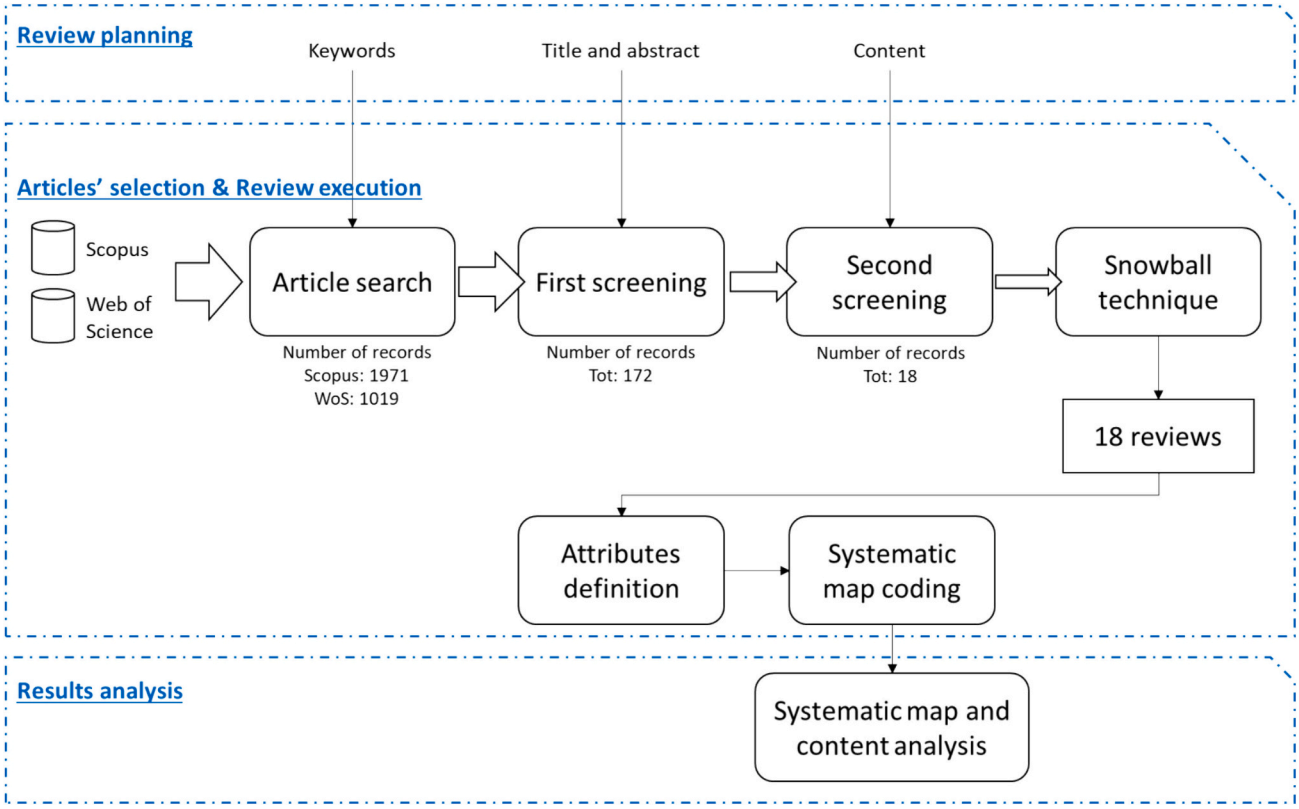

Fig. 1. Process followed to perform the umbrella review.

3.2.1. Review planning

Two databases were selected for the research, Scopus and Web Of Science (WoS), which are two of the most well-known multidisciplinary scientific databases, including articles from different publishers all over the world. Thus, the aim is to find the most relevant studies, regardless of the specific discipline in which they were published (Borrego et al., 2014). Starting from the purpose of our review, a few sets of keywords were defined, limiting the search to title, abstract and keywords: "Circular Economy" + "review" or "state of the art" + one of the following strings: "assessment methods", "assessment methodologies", "indicators", "index", "metrics", "assessment tools", "sustainability assessment", "environmental assessment", "environmental impact" (details are shown in Table 1). The term "micro level" was not included in the first preliminary search, aiming to conduct a wider search at the first stage and refining the results in the second step. The search was then refined to include only literature reviews in the results. Only papers written in English were included in the analysis, and only peer reviewed works (articles published in international peer reviewed journals and conference proceedings). White papers, book chapters, companies' reports and other kinds of publications were not considered. Other inclusion criteria regard the content of the review: starting from a wider sample of papers, only articles including the analysis of assessment approaches for the micro level have been considered; finally, articles focusing on a specific sector (e.g. construction) have been excluded from the review.

Table 1
Search strings used for the literature review.

Search string	N. articles (Scopus)	N. articles (Web of Science)
CE + assessment methods + review	165	79
CE + assessment methods + state of the art	20	8
CE + assessment methodology + review	81	35
CE + assessment methodology + state of the art	13	8
CE + index + review	20	17
CE + index + state of the art	2	1
CE + indicators + review	123	70
CE + indicators + state of the art	15	8
CE + sustainability assessment + review	250	98
CE + sustainability assessment + state of the art	32	13
CE + environmental assessment + review	363	145
CE + environmental assessment + state of the art	42	20
CE + environmental impact + review	766	466
CE + environmental impact + state of the art	79	51
Total	**1971**	**1019**

3.2.2. Review execution

As reported in Table 1, the initial search gave 1971 records on Scopus and 1019 on WoS. A first screening was done on the base of their title and abstract, excluding those that were clearly out of scope and duplicates, reducing the sample to 172 papers. A second screening was then based on their content, narrowing considerably the sample to 18 papers. Finally, the snowball technique was applied, which consists in checking the list of references of the selected articles, aiming to identify potential papers that did not appear in the first search (Sayers, 2007). However, this step did not increase the number of articles identified. Hence, the process ended with the final identification of 18 review papers published until May 2023 and relevant to the scope of the research.

The classification and analysis of the papers selected have been carried out based on the systematic mapping approach (Garousi and Mäntylä, 2016; James et al., 2016). Systematic mapping allows categorizing the studies analyzed through a list of attributes, with the aim of

describing available evidence regarding a specific topic. The process of describing each study through a set of attributes is defined "coding", and it generates meta-data related to the studies analyzed (James et al., 2016). Attributes (or coding variables) are defined starting from some key questions related to the main research goal. For this study, the questions considered and the resulting attributes are summarized in Table 2. Questions and attributes were defined aiming at including information that could be relevant to understand the different perspectives adopted by the authors (ex. Q1 and Q4) and help answering the RQs defined. In particular, the aim was to understand which and how many assessment approaches were included in previous reviews (Q2 and 3), if sustainability dimensions were explicitly analyzed (Q5) and which other factors were used to classify these approaches.

3.2.3. Result analysis

First, a descriptive analysis of the reviews based on attributes from the systematic map was performed. The following content analysis focuses on the link between CE metrics and sustainability assessment of CE strategies.

4. Results

This section outlines the main results of the umbrella review performed, summarizing the systematic map and the following content analysis. The results reported are referred to the 18 reviews analyzed, which are representative of the current body of literature on the topic, since they analyze and discuss primary studies in the field.

4.1. Systematic map results

4.1.1. Q1 – aim of the review

The first attribute of the systematic map is the aim of the review analyzed (Table 3). Although each study has a particular focus, the reviews have been classified in three clusters according to their main objectives (highlighted in Fig. 2). The biggest cluster includes 12 studies that identify and classify the existing CE assessment approaches on the micro level: the common aim is to clarify and systematize approaches in literature, but usually each study adopts different points of view for the analysis (e.g. focusing on different implementation levels or including different classification factors). This confirms the need for a thorough classification of methods and tools that are currently used for assessing circularity. A second cluster collects 4 reviews aiming at evaluating the effectiveness of CE assessment approaches for measuring the impact of CE strategies on sustainability: these studies specifically address the capacity of existing CE assessment approaches to capture one or more sustainability dimensions. Finally, the third cluster is the smaller one, with 2 studies analyzing if and how existing environmental assessment

Table 2
Key questions and attributes for the development of the systematic map.

Key questions	Attributes	Values
Q1: What are the aims of the reviews published so far?	Aim of review	(free field)
Q2: What kind of assessment approaches are reviewed?	Assessment approaches	Metrics, indicators, methodologies, tools
Q3: How many assessment approaches are reviewed?	Number of assessment approaches	(free field)
Q4: Which are the Circular Economy implementation levels considered in the review?	Circular Economy implementation level	Nano, micro, meso, macro
Q5: Which are the sustainability dimensions considered in the review?	Sustainability dimensions	Environmental, social, economic
Q6: What are other classification factors adopted to review the assessment approaches?	Other classification factors	(free field)

Table 3
Reviews included in the study and their aims.

Authors	Title	Aim of the review
Elia et al. (2016)	Measuring circular economy strategies through index methods: A critical analysis	Analyzing the effectiveness of environmental assessment methodologies to measure the impact of CE
Corona et al. (2019)	Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics	Assessing the validity of current CE metrics considering the sustainability concept
Sassanelli et al. (2019)	Circular economy performance assessment methods: A systematic literature review	Detecting and classifying current CE assessment methods
Kravchenko et al. (2019)	Towards the ex-ante sustainability screening of circular economy initiatives in manufacturing companies: Consolidation of leading sustainability-related performance indicators	Developing a consolidated database of leading performance indicators for ex-ante sustainability screening of CE strategies in manufacturing context
Helander et al. (2019)	How to monitor environmental pressures of a circular economy. An assessment of indicators	Evaluating the effectiveness of current CE assessment approaches to monitor progress towards environmental sustainability
Saidani et al. (2019)	A taxonomy of circular economy indicators	Clarifying the utility and scope of current CE indicators through a taxonomy
Moraga et al. (2019)	Circular economy indicators: What do they measure?	Clarifying the utility and scope of current CE indicators through a taxonomy
Parchomenko et al. (2019)	Measuring the circular economy - A Multiple Correspondence Analysis of 63 metrics	Providing a structured picture of the current stock of CE metrics, identifying methodology clusters
Kristensen and Mosgaard (2020)	A review of micro level indicators for a circular economy - moving away from the three dimensions of sustainability?	Clarifying the scope of current CE indicators for the micro level, considering the sustainability concept
Roos Lindgreen et al. (2020)	A Critical Review of Academic Approaches, Methods and Tools to Assess Circular Economy at the Micro Level	Categorizing CE assessment approaches for the micro level
Harris et al. (2021)	Circularity for circularity's sake? Scoping review of assessment methods for environmental performance in the circular economy.	Reviewing environmental assessments of CE across system levels and how they can be linked
De Pascale et al. (2020)	A systematic review for measuring circular economy: The 61 indicators	Providing an overview of CE indicators
de Oliveira et al. (2021)	Nano and micro level circular economy indicators: Assisting decision-makers in circularity assessments	Providing an overview of CE indicators for the micro and nano levels
Vinante et al. (2020)	Circular economy metrics: Literature review and company-level classification framework	Classifying CE metrics for the micro level
Valls-Val et al. (2022)	How can organizations measure their level of circularity? A review of available tools	Analyzing the existing tools for measuring the circularity level of organizations (micro level)
Jerome et al. (2022)	Mapping and testing circular economy product-level indicators: A critical review	Clarifying what resource-related effects from implementing CE strategies are captured by existing product-level indicators
de Oliveira and Oliveira (2023)	What Circular economy indicators really measure? An overview of circular economy	Analyzing CE indicators that can assess the three pillars of

(continued on next page)

Table 3 (*continued*)

Authors	Title	Aim of the review
	principles and sustainable development goals	sustainability at the nano and micro levels
Chrispim et al. (2023)	The underrepresented key elements of Circular Economy: A critical review of assessment tools and a guide for action	Assessing the contributions and limitations of CE assessment tools regarding the key elements: social dimension, stakeholder engagement, R-imperatives and industrial symbiosis

methodologies can be used to assess the sustainability of CE strategies.

In general, the reviews differ for the implementation level considered: as a reminder, we only included reviews covering the micro level, according to the scope of this work, but some of them cover also other levels. The objectives are also different considering the focus on sustainability: some studies openly investigate the relationship between circularity and sustainability assessment (like (Corona et al., 2019)), while others do not include this dimension in their scope.

4.1.2. Q2 and Q3 – type and number of assessment approaches included

Another observation regards the type of assessment approaches involved in the reviews. The classification of the analyzed approaches proposed in each review has been carried out by the authors, based on the taxonomy proposed in Section 3.1, checking what kind of approaches were covered in each study. Results show that *indicators* are the most analyzed approaches, included in 15 of the 18 reviews. This reflects the increase of specific CE indicators in literature, driven by the need to assess the impacts of circular strategies through immediate and simple approaches: indicators are usually less time-consuming and easier to communicate compared to structured methodologies (such as Life Cycle Assessment - LCA - or Material Flow Analysis - MFA), which makes them fit for companies both for internal analysis and external communication (Jerome et al., 2022).

Less than half of the studies (8) include available *tools*. Specifically, only 1 article focuses solely on tools: Valls-Val et al. (2022) outline a gap in literature, observing that despite CE tools can facilitate the choice and calculation of indicators for companies, no reviews of CE tools were available yet. The other 7 studies include tools in a wider perspective on assessment approaches.

Only one third of the reviews include *methodologies*: these studies consider existing methodologies, not specifically conceived for circular contexts, for assessing CE outcomes. To name a few, Input-output analysis, LCA, MFA and derived methods (Corona et al., 2019; Parchomenko et al., 2019; Roos Lindgreen et al., 2020), simulation, Multi Criteria Decision Methods (MCDM), Data Envelopment Analysis (DEA) (Sassanelli et al., 2019), etc. Two studies (Elia et al., 2016; Harris et al., 2021) openly focus on how environmental methodologies are used to assess the sustainability of CE strategies.

Finally, 2 reviews include *metrics* in their analysis, along with indicators (Vinante et al., 2020; Kravchenko et al., 2020). These studies are also the ones analyzing a higher number of approaches (365 and 279 respectively, while the other studies range from a minimum of 8 to a maximum of 74 approaches reviewed). This is related to the nature of the approaches: since metrics have been defined as single values measuring at the finest level of granularity, it is reasonable that the number of possible metrics to assess the impacts in a system can be high.

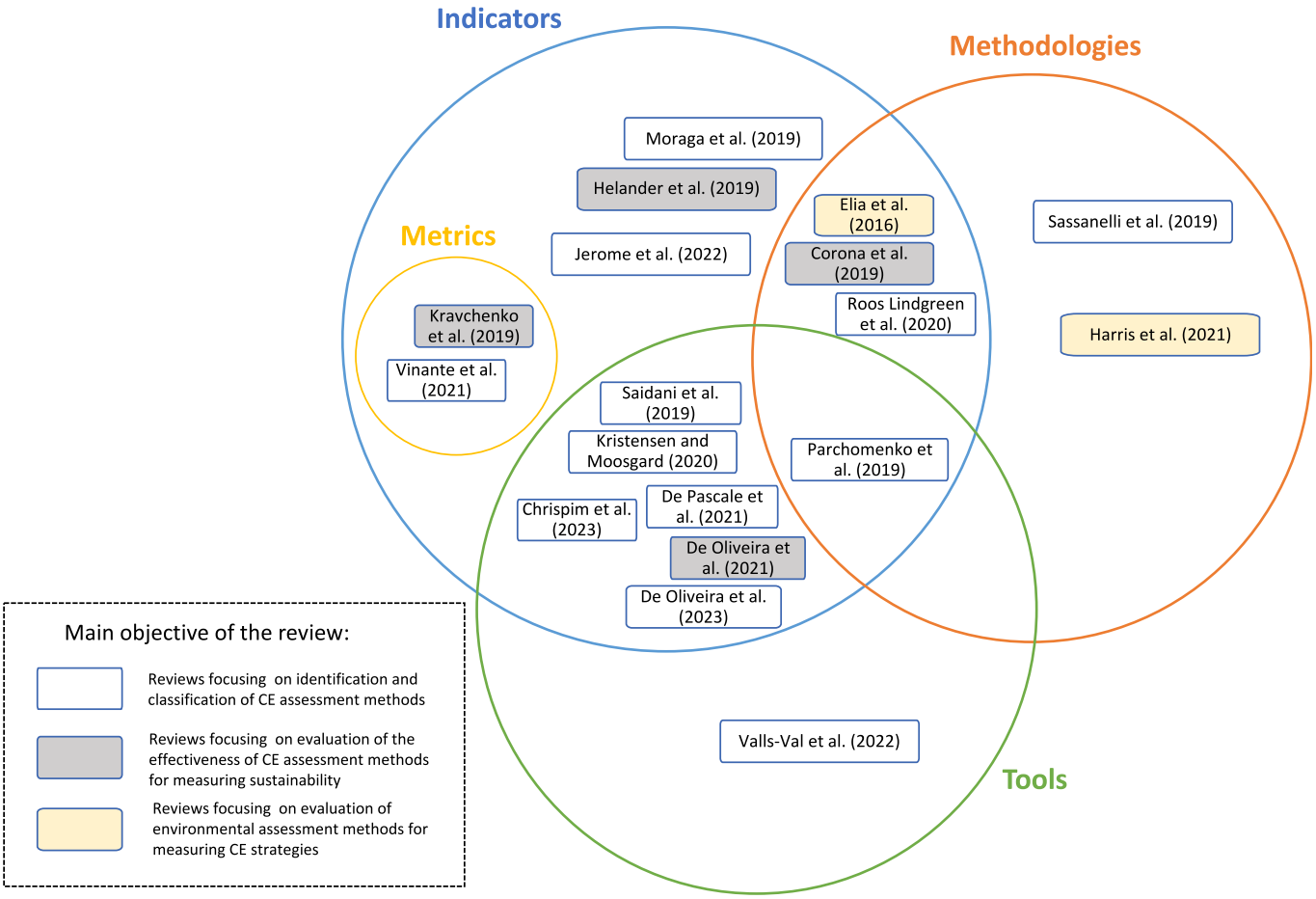

Fig. 2. Clusterization of the reviews according to the type of approaches included and main objective.

4.1.3. Q4 and Q5 – CE implementation level and sustainability dimensions analyzed

Considering the additional CE application levels included for the analysis of assessment methods, Fig. 3(a) shows the different perspectives adopted in the reviews: less than half of the studies focus exclusively on the micro level. Three reviews openly differentiate between micro and nano level, two of them including assessment methods for both levels (de Oliveira et al., 2021; de Oliveira and Oliveira, 2023), one focusing specifically on product-level indicators (Jerome et al., 2022). 6 works perform a wider analysis, including all the three main implementation levels, while the remaining two focus on the macro or *meso* level in addition to the micro one.

Fig. 3(b) shows how the sustainability dimensions were included in the works analyzed. More than half of the reviews considered all three dimensions of sustainability in their analysis and classification of the assessment approaches considered. Three of them only included environmental considerations, and one focused solely on the social dimension. The remaining 4 did not explicitly classified the assessment approaches considering the impact on sustainability.

4.1.4. Q6 – other classification factors considered in the reviews

Finally, the systematic map classifies the studies by pointing out other factors adopted in the review to analyze assessment approaches (beyond CE implementation level and sustainability dimensions already evaluated). 11 of the 18 reviews classify the approaches according to the CE strategy to assess. However, there is no consensus on how to define CE strategies: different references are used, like the definition provided by the Ellen MacArthur Foundation (Elia et al., 2016), the 10R framework (de Oliveira and Oliveira, 2023; Kravchenko et al., 2019), the 3R framework (De Pascale et al., 2020), or other ones. This reflects a wider lack of consensus on the CE concept and terminology that is frequently outlined in literature (Homrich et al., 2018), which is extended to assessment methods.

5 studies include the product life-cycle phase as a classification factor, distinguishing among methods that can be applied for assessing impacts in different phases (de Oliveira et al., 2021; Helander et al., 2019; Jerome et al., 2022; Sassanelli et al., 2019; Valls-Val et al., 2022).

A few other classification factors can be found in some of the reviews (such as the material flow involved, the type of data required, etc.), but they are usually connected to the specific scope of the study.

4.2. Content analysis

The content analysis is presented starting from the classification of the different methods previously introduced: metrics, indicators, methodologies and tools.

4.2.1. Metrics and indicators

Since the category defined as "metrics" is included only in two reviews, which also focus on indicators, and given the affinity of these two concepts as defined in Section 3.1, results on these two assessment methods are contextually presented.

The high number of metrics found in literature has been related to the fragmentation of literature around the concept and pillars of CE, causing a lack of uniformity in circular evaluation for companies (Elia et al., 2016; Vinante et al., 2020; De Pascale et al., 2020). This is also reflected in the inability of current CE assessment methods to capture the systemic nature of CE, encompassing all CE elements (Chrispim et al., 2023). In particular, most available indicators focus on material preservation and resource recovery strategies (de Oliveira et al., 2021; De Pascale et al., 2020; Moraga et al., 2019), while few focus on product functions (e.g. product sharing) or value maintenance through life extension, which still represents a huge gap for CE assessment (Elia et al., 2016; Parchomenko et al., 2019; Jerome et al., 2022). Moreover, literature underlines a lack of indicators for supporting decision making in the product design and business model development phases, two key processes in which companies might engage requiring efficient measurement methods (Kravchenko et al., 2019; de Oliveira and Oliveira, 2023). Another criticality highlighted regards the high effort required to evaluate all consequences related to multiple cycles applied in CE strategies (e.g. downcycling) (Corona et al., 2019).

Additionally, the majority of the indicators and metrics currently proposed for measuring circularity are lagging indicators, used to assess the impacts of realized actions and strategies only after their implementation. Kravchenko et al. (2019) underline a lack of leading assessment approaches for circularity, which could provide companies with information about the potential outcomes on different levels of planned actions ex-ante, supporting decision-making considering circular and sustainability implications.

Concerning the capability of current methods for the micro level to assess sustainability, several studies focusing on metrics and indicators underline that the relationship between CE and sustainable development is still fuzzy, indicating this as a major research gap (Helander et al., 2019). These studies outline that only a subset of methods includes a triple bottom line (TBL) perspective, while the environmental dimension is currently the most covered dimension, compared to the social one, which is worryingly underrepresented (Kravchenko et al., 2019; Vinante et al., 2020; de Oliveira et al., 2021; Kristensen and Mosgaard, 2020; De Pascale et al., 2020; Roos Lindgreen et al., 2020; Saidani et al., 2019; Chrispim et al., 2023; Corona et al., 2019). The need

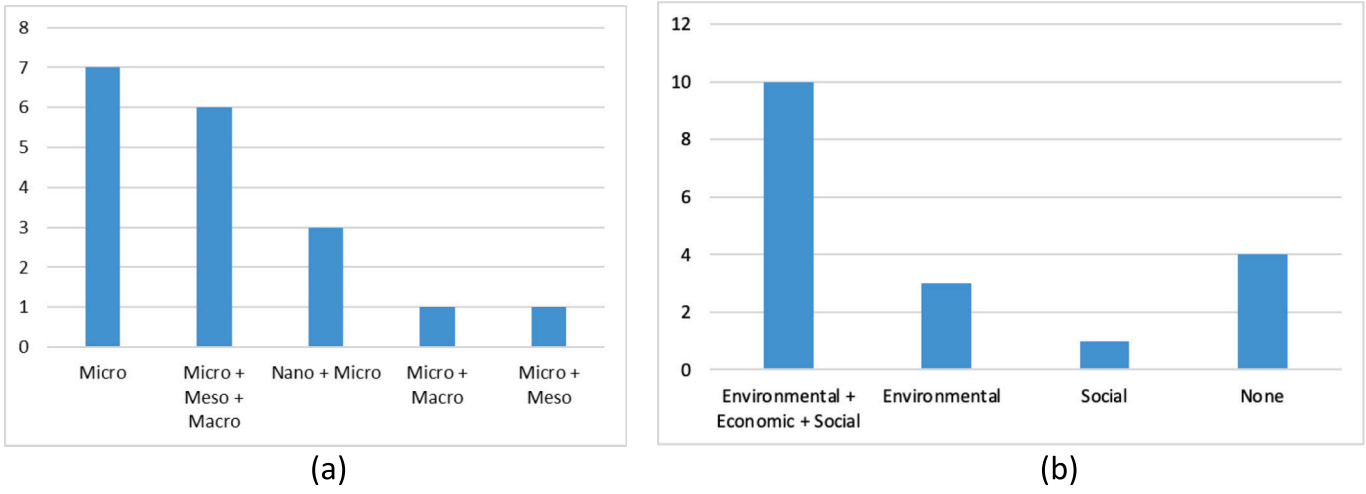

Fig. 3. Distribution of the reviews according to the application level (a) and the sustainability dimensions considered (b).

for the development and inclusions of indicators that include all sustainability dimension is one of the most shared findings among the studies reviewed.

Consequently, some authors propose the integration of CE indicators with sustainability ones to help improving the sustainability assessment of CE strategies (de Oliveira et al., 2021), suggesting that existing methodologies - such as MFA, LCA and footprint-based approaches - can be successfully used to assess the environmental dimension of sustainability (Corona et al., 2019; Moraga et al., 2019; Jerome et al., 2022; Helander et al., 2019).

Moreover, some authors suggest that specific indicators should be chosen each time according to the scope and objective of the analysis (Jerome et al., 2022), enhancing the development of industry-specific indicators, which could improve the efficiency of the assessment, supporting the concretization of CE in specific sectors (Kristensen and Mosgaard, 2020).

4.2.2. Methodologies

As underlined in Section 4.2.2, only 6 of the studies reviewed include methodologies for the micro level in their analysis. More specifically, two of them focus solely on methodologies, while the other four analyze different types of assessment methods (as summarized in Fig. 2). In general, all these studies included in the analysis existing methodologies to evaluate how they are applied to assess CE strategies, and in particular their sustainability. Most authors included well-known and established methodologies, namely: approaches based on LCA and footprints, MFA, Substance Flow Analysis (SFA), Input/Output analysis, Emergy/exergy analysis (Elia et al., 2016; Corona et al., 2019; Parchomenko et al., 2019; Roos Lindgreen et al., 2020; Harris et al., 2021), and broader approaches such as multi-criteria decision methods, simulation and design4X (Sassanelli et al., 2019). The first consideration is that, so far, the methodologies applied to assess CE strategies are not designed expressly for the CE context, but are pre-existing methodologies widely applied in several fields. So, while an interesting number of metrics and indicators for the micro level specifically designed for CE have been proposed in literature in the last decade, this is not happening for methodologies.

A further point of discussion is related to the type of methodologies analyzed: most of them are usually applied for the assessment of environmental aspects, and these studies confirm that such approaches remain fundamental for measuring the sustainability of CE strategies, given the lack of indicators and methods integrating circularity and sustainability performance (Corona et al., 2019; Sassanelli et al., 2019; Harris et al., 2021).

4.2.3. Tools

So far, only one of the reviews focused solely on this type of assessment approach: Valls-Val et al. (2022) analyzed various tools to assess the circularity of organizations, studying their main scopes, characteristics and differences, with the aim of clarifying weather different tools provide comparable results and which of them appear to be most complete and effective. Results underline that not all tools include sustainability aspects, and that when they do, the environmental dimension is more represented than the economic and social ones. The authors conclude that the tools analyzed are not comparable, because they cover different areas and aspects and adopt different approaches (qualitative or quantitative), underlining once again the lack of standardization for CE assessment.

The remaining reviews including this assessment approach adopted a wider perspective, analyzing tools together with indicators. It has to be outlined that these studies analyze tools specifically designed to assess CE practices on the micro level, as opposed to what has been said about methodologies in the previous section. While this might represent an advantage in terms of coherence with the objectives of CE strategies, it is no guarantee of success in providing a holistic assessment of CE, as literature confirms a lack of tools incorporating all the key aspects of CE (Chrispim et al., 2023). In fact, the main criticalities and challenges described for indicators (Section 4.2.1) are confirmed for tools as well. One is the lack of methods able to assess all kinds of CE strategies, since most approaches focus on material preservation and recovery, while design and life-extension strategies are underrepresented (Parchomenko et al., 2019; De Pascale et al., 2020; de Oliveira and Oliveira, 2023). Moreover, the need to find methods able to catch all the three dimensions of sustainability, together with circularity, is frequently outlined (de Oliveira et al., 2021; Kristensen and Mosgaard, 2020; Valls-Val et al., 2022), and in particular the lack of methods considering the social dimension (Saidani et al., 2019; De Pascale et al., 2020; de Oliveira et al., 2021; Valls-Val et al., 2022; Chrispim et al., 2023).

5. Discussion

The umbrella review performed allowed to identify some key points regarding the state of the art about CE assessment on the micro level, which have been detailed in the previous section. The results presented can be considered as representative of the body of literature on the topic, and offer different discussion points, which will be addressed in the following sections aiming to answer the research questions defined (Table 4).

5.1. RQ1: state of the art on Circular Economy assessment approaches with focus on the micro level

The analysis has outlined that there is heterogeneity in the assessment approaches analyzed in the studies reviewed. As pointed out in Section 3.1, so far there is no consensus on the definitions of metrics, indicators, methodologies and tools in CE literature, and although their scope can be very different, these approaches are often referred to in an interchangeable manner. A classification has been proposed in this study

Table 4
Connection of the main findings of this review with the research questions defined.

Research questions	Findings of the review
RQ1 - what is the state of the art on Circular Economy assessment approaches with focus on the micro level proposed in literature?	• Heterogeneity of Circular Economy assessment approaches, lack of uniform nomenclature • Heterogeneity of categorizations of the approaches, lack of standardization, consequent classification proposal (metrics, indicators, methodologies and tools) • Lack of leading assessment approaches compared to lagging ones • Circular Economy strategies are not well represented in Circular Economy assessment approaches
RQ2 - How is sustainability included in current Circular Economy assessment approaches on the micro level?	• Growing importance of sustainability dimensions in Circular Economy assessment research • Sustainability dimensions are not always included in Circular Economy assessment • The social dimension of sustainability is currently the most neglected in Circular Economy assessment • Lack of standardization for sustainability assessment of Circular Economy actions • Industry-specific methods might increase the effectiveness of sustainability assessment of Circular Economy actions • Complementary approaches are suggested to cover both circularity and sustainability assessment (e.g., Life Cycle Assessment-based + Circular Economy based approaches)

defining metrics, indicators, methodologies and tools for assessing CE strategies. Metrics and indicators can be more immediate to calculate, but their scope is narrow and they are used to measure very specific aspects of a system (Vinante et al., 2020). Methodologies are usually more complex and time consuming, giving elaborated results that can provide more significative information on a system. However, they may require specific competences for their application (e.g., LCA) and be less effective than indicators on the communicative level (Elia et al., 2016). Tools can enable the measurement of different indicators, providing a wider scope than metrics and indicators, while keeping an easier applicability compared to methodologies (Chrispim et al., 2023). Hence, a first step that a company should take for assessing CE strategies should be the definition of the aim and scope of the analysis, clarifying the objective (e.g., what needs to be measured and why) and the target (e.g., internal versus external communication), in order to define if the most fitting approach can rely on metrics, indicators, a methodology or a tool (or eventually a combination of them).

The content analysis highlighted another difference among the approaches considered: while several metrics, indicators and tools that have been specifically designed to assess CE strategies on the micro level, the main methodologies proposed in literature for circularity assessment are already existing and well-established methods that are often used to measure the environmental performance of CE strategies.

Another interesting hint is provided by Kravchenko et al. (2019), the only review that specifies the difference between leading and lagging assessment approaches, underlining that current CE assessment practices mostly rely on lagging indicators, and the absence of this topic from all the other reviews confirms that this still represents a gap in CE assessment research.

Another observation regards the classification of approaches made in the previous reviews. Most studies categorize them according to the CE strategy to assess and/or the life-cycle stage of the product involved. However, results show that a shared codification of the main CE strategies is still lacking, different frameworks are adopted as reference and there is no standardization on definitions and basic concepts. This can make the choice of the right assessment approach even harder to make for a company that does not have the proper guidance in the process. Overall, many authors claim a lack of standardization in this field and an abundance of methods that increase the difficulty of orientation for actors wishing to adopt assessment approaches fitting their needs.

Finally, results outline that even CE strategies are not well represented in the available CE assessment approaches for companies. In particular, while strategies like material recovery and recycling are well covered, there is a lack of approaches to measure the value durability of products, which is one of the pillars of CE (Elia et al., 2016), and from a life-cycle perspective, more approaches are needed to support the design phase.

In general, reviews of CE assessment approaches for the micro level have been focusing on two main research areas so far: the first is the attempt to respond to the high fragmentation and abundance of non-structured approaches in this field, by proposing taxonomies, frameworks and classifications to help companies and researchers orient in the choice of assessment methods. The second regards the investigation of the relationship between circularity and sustainability in assessment approaches, by analyzing how circular approaches can measure sustainability, or by evaluating the capacity of environmental assessment methodologies to capture the impacts of circular strategies. This finding confirms the growing importance that sustainability assessment is having in CE research, since the impacts of circular strategies is sometimes given for granted, but recent CE literature shows an increasing awareness of the criticalities related to sustainability (Castro et al., 2022).

Based on these findings, some feedbacks for companies who are working towards improving their CE assessment strategies based on a more sustainable way can be briefly introduced by analyzing the results. Firstly, companies should clearly identify the objectives of their assessment analysis as well as the communication target: a first essential step is to select the most fitting assessment approach according to company specific conditions (metrics, indicators, methodologies or tools). Once the type of approach has been defined, it has to be noted that evaluating the assessment method will be influenced by the specific CE strategy applied or to be applied by the company; the life-cycle phase involved is also an important issue to evaluate, as literature shows that the different approaches are often classified according to these parameters. Finally, the definition of the CE and sustainability dimensions to be monitored can guide the evolution of the most effective method to be adopted in a wide pool of available approaches able to satisfy the fixed requirements.

5.2. *RQ2: the inclusion of sustainability in current Circular Economy assessment approaches on the micro level*

Looking specifically into the relationship between sustainability and circularity and how current CE assessment approaches for the micro level integrate sustainability dimensions, most of the studies analyzed agree that sustainability aspects are not always well represented. Moreover, when sustainability is considered, usually it is not through a TBL approach: environmental aspects are discretely represented in all approaches, so are economic aspects for metrics and indicators, while the social dimension is mostly neglected by current available approaches, and the relationship between circularity and sustainable development needs to be investigated more deeply in all dimensions. A shared observation is that well-established and standardized methodologies such as LCA-based approaches and footprints can effectively capture the environmental impacts of systems at the micro level, hence the integration between CE assessment approaches and LCA-based approaches can represent a valid answer to the need for assessing environmental pressures and benefits generated by circular actions. However, a huge gap in sustainability assessment of CE strategies is still represented by social sustainability, indicating that future research should focus more on the triple bottom line integration of sustainability in CE assessment. Some authors also suggest the adoption of industry-specific methods, which is a research area that could be explored further. Another frequent suggestion is to evaluate the adoption of set of indicators/methods that can be employed in a complementary manner, to cover both the circularity and sustainability dimensions.

In conclusions, the relationship between circularity and sustainability should be object of further research, focusing in particular on the proposal of assessment methods for companies and organizations that can effectively capture the advantages of CE strategies with a TBL approach.

6. Conclusion

Despite the increasing literature on CE strategies in the last decade, researchers agree that several open questions are still present. In particular, the relationship between CE and sustainability has to be unraveled, both on the theoretical side and on the practical one. Several reviews on CE assessment approaches were published lately, in which researchers try to make order in the numerous attempts to provide effective methods to measure progresses towards circularity, including considerations on the impacts on sustainability that circular actions can have.

Unlike previous reviews on this topic, this work aims at depicting the state of the art about CE assessment approaches on the micro level including sustainability considerations, outlining the main trends and challenges, with the objective to contribute to the systematization of circularity assessment approaches from a sustainability perspective. The umbrella review performed on 18 studies outlined several trends and criticalities related to circularity and sustainability assessment, allowing to answer the research questions defined in the introduction.

In particular, a taxonomy of CE assessment approaches has been introduced, classifying the existing methods in four main categories:

metrics, indicators, methodologies and tools. This preliminary step was necessary not only to conduct the review, but also to respond to the heterogeneity of terms used in literature, providing a comprehensive and clear classification. The following review allowed to highlight several challenges in the state of the art of CE assessment on the micro level. Among these, the lack of homogeneity and standardization, together with the underrepresentation of some CE strategies in most available approaches are underlined. Moreover, the relationship between circularity and sustainability remains a critical issue, since most circularity approaches overlook sustainability dimensions, especially the social one, while some efforts to cover the environmental and economic objectives are observed.

One limitation of this study is related to the methodology adopted. Being a literature review of reviews, this study does not present a list of CE assessment approaches, as the articles analyzed did, but adopt a higher perspective consenting a lower level of detail. However, this perspective allowed to compare the different analyses that have been performed so far, giving a broader view of methods, approaches and findings currently present.

Future research should focus on different aspects of CE assessment to address the various gaps identified. First, a consolidation of the CE concept and characteristics is essential to allow more effective assessment processes on all implementation levels. This should involve the vast panorama of CE assessment approaches that is continuously evolving. The publication of the ISO standards on CE will probably give a burst of speed to the process. Another relevant gap regards the social assessment of circular strategies, aspect included only in 11 of the 18 reviews analyzed, most of them confirming its underrepresentation, requiring more methods able to capture the social impact of circularity in order to improve their sustainability. Finally, the proposal and validation of effective multi-method approaches for a joint circularity and sustainability assessment, as well as sector-specific approaches, can contribute to overcome the gap between theory and practice in the implementation of CE actions.

CRediT authorship contribution statement

Valerio Elia: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Maria Grazia Gnoni:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Fabiana Tornese:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

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

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