sustainability

MDPI

Review

A Critical Review of Academic Approaches, Methods and Tools to Assess Circular Economy at the Micro Level

Erik Roos Lindgreen [1,*], Roberta Salomone [1] and Tatiana Reyes [2]

[1] Department of Economics, University of Messina, Piazza Pugliatti 1, 98122 Messina, Italy; salomoner@unime.it

[2] ICD, CREIDD, University of Technology of Troyes, Rue Marie Curie 12, 10004 Troyes, France; tatiana.reyes@utt.fr

* Correspondence: erooslindgreen@unime.it

Received: 11 May 2020; Accepted: 12 June 2020; Published: 18 June 2020

Abstract: Transitioning from the current linear economic development model to a circular economy (CE) is a hot topic in academic literature, public governance, and the corporate domain. Actors have implemented CE strategies to reduce their resource use and its associated impacts, while boosting economic competitiveness and generating positive social impact. Companies are identified as key actors in transitioning to a CE, and many academics have proposed tools to assess CE and guide them in this process. This paper critically reviews such academic 'assessment approaches' at the micro level in order to reflect on their key properties. Seventy-four approaches are inventoried through a systematic literature review of academic literature. A critical review framework is constructed and applied, containing four perspectives: A general perspective, a descriptive perspective (methodological aspects), a normative perspective (connections to Sustainable Development), and a prescriptive perspective (implementation-focused). Methodologically, the 74 approaches are highly diverse, having various connections to previously established methodologies. Eighteen of the reviewed assessment approaches include all three dimensions of Sustainable Development (SD), in addition to a 'circular' dimension. Roughly one quarter of the approaches apply a participatory design approach. Suggested key desired properties of CE assessment approaches include making use of existing assessment methodologies such as Life Cycle Assessment (LCA), and a closer collaboration between science and practitioners to consider end-user needs in the design of CE assessment approaches.

Keywords: circular economy; sustainable development; circularity metrics; sustainability assessment; micro level; corporate sustainability

1. Introduction

Our current global economic development model revolves mostly around linear flows of materials and energy [1]. This model generates waste, depletes natural resources, leads to emissions, and transforms natural landscapes, resulting in a complex web of pressing interlinked environmental, social, and economic problems [2]. The interest in replacing our current linear economic model with a circular economy (CE) model to facilitate moving towards a more sustainable society, has grown rapidly in the past 5–10 years [3].

Many definitions of CE are available [4]. One of the primary goals of establishing a CE has been described as decoupling global economic development from finite resource consumption by introducing closed resource loops, leading to reduced environmental degradation and positive social impacts while stimulating economic growth [5,6]. While the various roles of actors in moving towards a CE have not been formalized in literature, companies are expected to drive this transition [7], since firms are the entities that transform resources such as raw materials (natural capital) into goods and services (man-made capital) [8,9].

A new field of research focuses on understanding how to assess CE at micro (products, firms), meso (industrial symbiosis networks), and macro (city, country, and beyond) level [10]. Among other reasons, CE assessment tools are said to contribute to the advancement of the concept by facilitating information exchange, monitoring progress, inform decision-making, and improve circular business investment decisions [11,12]. Reference [13] summarizes these reasons by referring to the idiom "what gets measured gets managed" (p. 545). At the same time, the absence of broadly accepted metrics has been described as a barrier to transitioning to a CE. [14], for example, notes that "the absence of adequate metrics and standards has been a key barrier to the inclusion of resource efficiency requirements" (p. 1533). [15] finds that companies in the fast-moving consumer goods sector make limited use of performance indicators or quantitative CE assessments in their implementation of CE-related policies. Only a small fraction of investigated organizations presents a dedicated set of key performance indicators (KPIs) to their approach to CE. Similarly, some studies point towards low consciousness of the CE potential across various industries, and even lower levels of "alleged CE maturity" [16] (p. 107). Among others, [17] touches upon the importance of CE measurement tools by stating that to "(...) enable and accelerate CE transition driven by industry, integrative decision support tools to identify and tap potentials of CE transition scenarios on company and inter-company level are necessary" (p. 48).

In summary, the field of CE assessment has a low level of maturity, and the level of implementation of CE assessment approaches by organizations appears to be limited. This forms a barrier to transitioning to a more circular—and sustainable—society. To be able to explain the current lack of uptake and stimulate progress, this paper has two research objectives: (1) To categorize the characteristics of available academic approaches, methods, and tools to assess CE at the micro level; and (2) after applying the categorization, to suggest key desired properties of CE assessment at the micro level that guide future research. Both objectives aim to support the conceptual development and accelerate the uptake of CE assessment on the micro level.

The first research objective is realized by carrying out a systematic academic literature review, providing a complete overview of such 'micro level assessment approaches' from academic literature, and then applying a newly proposed critical review framework. This framework contains four perspectives: (i) A general perspective, (ii) a descriptive perspective (methodological foundations), (iii) a normative perspective (addressing sustainable development as the end goal of CE), and (iv) a prescriptive perspective (participatory construction methods and questions of implementation). For the second objective, the present research reflects on the coherence within the group of inventoried approaches after applying the review framework and, where possible, formulates key desired properties addressing the potential lack of consensus. Where this is not possible, directions for future research are indicated. The desired properties are formulated to satisfy two criteria: To promote the ability of CE assessment approaches to accurately assess the sustainability of CE processes, and to inform the design of future CE assessment approaches with a higher uptake by organizations.

The structure of this paper is as follows. In the second section, the interpretation of CE is presented and complemented with an overview of previous reviews of available CE assessment approaches. Hereby, the current state of the CE measurement research field is described, and the added value of the research here proposed is highlighted. In Section 3, the material and methods are described, and the core concepts relevant to conducting the systematic literature are addressed: i.e., the use of the term 'assessment approaches' and the interpretation of the term 'micro level'. In addition, Section 3 contains the systematic literature review methodology and a newly proposed critical review framework. Next, the last two sections describe and contextualize the results of the critical review, reflecting on key characteristics. Additionally, to aid the development of future approaches, suggested key desired properties are presented where possible. They are based on critically reflecting on the coherence within the presented results while adhering to the previously mentioned criteria. The final section summarizes the results and identifies directions for future research.

2. Overview of the Research Context

There is no clear evidence of a single origin or originator of the CE, and there are many definitions and interpretations of the concept available in literature [4,18]. The definition of [19] describes CE as a conceptual framing of earlier resource management strategies and interdisciplinary fields. The ideas of exploring resource loops and biomimicry in the field of Industrial Ecology (IE) are notably present in CE [20].

CE is sometimes interpreted as a vehicle to facilitate moving towards Sustainable Development (SD). Some authors specifically zoom in on the relationships between the two unbounded concepts [2]. Reference [21] challenges the proposition that implementing CE is facilitating a move towards SD, while [22] critically evaluates some epistemological problems of both concepts. In [4], reviewing available CE definitions, it is found that only a few studies link CE to all three dimensions of SD (society, economy, and environment). Overall, the relation between the two multifaceted concepts is undecided and strongly depends on the interpretation of CE. However, recent literature focusing on CE indicators often considers SD to be the desired end goal of circular strategies [23], and states that, for CE to successfully support SD, all three dimensions of sustainability must be included [24]. The authors of the study presented here have adopted this view as well.

Another principal component of CE is the presence of a hierarchy in 'circularity strategies' that are part of CE as a resource management model [5,25,26]. Resource management options that appear 'higher' in the hierarchy are presumed to be more beneficial in terms of environmental, economic and, although to less-formalized extend, social impacts. In literature on CE, such hierarchical resource management options are often referred to as 'R-strategies' or simply 'Rs': Resource value retention options [3].

In the study here presented, the concept of CE is interpreted as an umbrella concept: "A broad concept or idea used loosely to encompass and account for a set of diverse phenomena" [19,27] (p. 604). Three fundamental principles can be identified (Figure 1): (1) CE focuses on value retention of resources, aiming at a decoupling of raw material extraction and growth, (2) the framework of CE options is hierarchical and guides preferred priorities in resource management options, and (3) CE is aimed at generating multi-dimensional impact with the overall end goal to facilitate reaching SD.

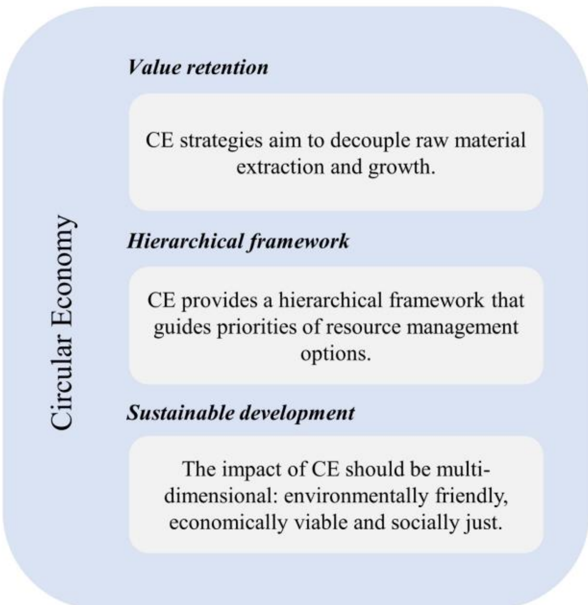

Figure 1. Interpretation of Circular Economy (CE) concept.

Research interest in the field of assessing CE at the micro level is expanding rapidly, and various authors have recently inventoried CE assessment approaches. Inventories and reviews that include the micro level perspective and are thus relevant to this study are summarized in Table 1.

Particularly relevant is the recent review by [24], in which the authors collected, categorized, and assessed micro level indicators for a CE. The analysis presented in the present study carries some similarities, albeit with a slightly different scope (i.e., addition of CE- or resource-centered dimension) and different results.

Reference [23] recently carried out a critical assessment of current circularity metrics, reviewing them on the basis of their validity: The degree to which a "metric measures what it intends to measure". The authors offer an extensive reflection on connections between the metrics and various methodologies and find that none of them fulfil their previously formulated validity requirements.

Worth mentioning is the previously mentioned taxonomy of 55 sets of C-indicators on various levels by [12]. The authors categorize the indicators based on, among other criteria, their 'transversality' (being generically applicable or sector-specific), level of CE implementation, and performance (intrinsic or consequential). Another publication applies a Multiple Correspondence Analysis (MCA) to assess 63 CE metrics and 24 features relevant to CE [28]. No distinction between micro-, meso- or macro-levels is made by the authors.

Reference [29] published a classification framework for CE indicators that zooms in on the differences in CE strategies and applied measurement scopes. To illustrate their framework, the authors apply it to quantitative micro level indicators from academic literature and macro scale indicators from the European Commission's 'CE monitoring framework'. The micro level indicators are particularly relevant to the study presented in this paper. The same holds for the work of [30], in which the authors also conducted a systematic literature review to find and describe 'CE performance assessment methods'. While the scale is not necessarily identical, the inventory's approach and findings are in line with this research and have been used to reflect on the collected approaches here.

The research proposed here presents an updated inventory of micro level assessment approaches. To the authors' knowledge, no previous work has applied the methodological, normative, and implementation-oriented review perspectives here presented (see Section 3.3). Additionally, previous publications do not consider the critical outlook of suggesting desired properties of the micro level assessment approaches.

Table 1. Previous reviews of available CE assessment approaches.

References	Number of Inventoried Approaches	Summary and Differences/Common Aspects with the Review here Proposed
[23]	72	Zooms in on 'validity', 'reliability', and 'utility' of metrics, and connection to existing methodologies (Life Cycle Assessment (LCA)/Material Flow Analysis (MFA), no focus on micro level.
[24]	30	Focus on micro level, zooming in on 'CE categories' and connection to Sustainable Development (SD) dimensions. Less attention for implementation perspective. Also includes grey literature.
[29]	20	Introduces classification framework for CE indicators, both on macro- as well as micro level. Addresses different CE strategies captured by indicators.
[28]	63	Applies Multiple Correspondence Analysis (MCA) to assess metrics. No distinction between different levels of assessment.
[12]	55	Proposes intricate taxonomy of indicators, applying 10 differentiation categories.
[30]	45	Collects and reviews CE performance assessment methods. Primary focus on methodological foundation. No specification of level of assessment.

3. Materials and Methods

This critical review focuses on academic publications that propose approaches, methods, and tools to assess CE at micro level. It has been carried out in order to provide an overview of CE 'assessment approaches' at the micro level and to enable the categorization of their characteristics. As a second objective, a critical reflection on the methodological coherence within the group of inventoried approaches is used to formulate key desired properties. As mentioned, these properties aim to satisfy two criteria: To promote their ability to accurately represent sustainability outcomes and to increase the uptake of future approaches. The literature review method is structured in three main steps: (i) Identification and clarification of the core concepts relevant to conducting the inventory process; (ii) implementation of a systematic literature review of the current state-of-the-art of the academic literature; (iii) developing and applying the review framework.

3.1. Clarification of Core Concepts

The terminology applied in the process of collecting the 'CE assessment approaches' at 'micro level' is based on the following theoretical foundation:

'Assessment approaches'—In previous research on the measurement of sustainability and CE at the micro level, the term 'indicators' has previously been used widely [12,31]. However, some authors signal that a general understanding or definition of this term appears to be lacking [24]. Academic literature also interchangeably uses other terms for approaches to compress quantitative or qualitative information into manageable units; examples are: Variable, parameter, measure, metric, measurement, dashboard, index, framework, etc. [12,32]. Most of them extend their scope beyond the traditional indicator as being a singular point of concentrated information. To capture the wide range of applied terms, in the present study, the term 'assessment approaches' has been used.

'Micro level'—This study focuses on approaches that assess CE on the micro level. Similar to the meso and macro levels, various interpretations of the meaning of this level exist between different assessment disciplines [23]. In [33], the authors describe the micro level as the "(...) complex structures of rules that constitute systems such as firms" (p. 267). This firm-perspective of the micro level will still include many different levels of scale, such as manufacturing plants [34], products [24] or suppliers, producers, consumers, and designers [12,20]. For the sake of creating a complete overview of available assessment approaches, the micro level is here considered to contain CE elements relevant to the decision-making context within firms. This wide-ranging interpretation includes products, business models, companies, and supply chains. Excluded from the scope are approaches focusing on eco-industrial parks (meso level) and cities, nations, and beyond (macro level).

3.2. Systematic Literature Review

In the systematic literature review of academic publications focused on CE assessment approaches at micro level, both peer-reviewed journals articles as well as conferences papers are included. The search was limited to publications in English, and was focused on key words. Grey literature and web-based assessment approaches, although potentially useful to organizations, have been omitted since they do not fall within the scope of the research objectives and do often not include documentation on how the proposed approach has been constructed (While some grey literature CE assessment approaches such as the Ellen MacArthur Foundation's (EMF) Material Circularity Indicator (MCI) contain enough documentation and appear to be applied in practice relatively frequently, they have been excluded since they do not originate from the academic community. The same holds for relevant CE standards such as the BS 8001 or Afnor's XP X30-901 standard [35,36]. For a review that includes grey literature, even if with a different scope, see e.g., [24]). Another reason for exclusion is the absence of a searchable grey literature database enabling a systemic search process.

Academic publications have been collected from Scopus and ScienceDirect by using three categories of search themes: Circular economy, evaluation, and micro level. The search period is defined as from 2007 until 2019. The start date 2007 has been selected since it is generally considered the start of the launch of the development of CE literature, especially in the Chinese context [37]. The resulting inventory is complemented by applying the snowballing method to previously conducted CE measurement reviews [38].

The first search category is CE, using key words 'circular economy' or 'circularity'. The second category is assessment, using key words 'assessment' or 'evaluation' or 'measurement' or 'quantification' or 'quantify' or 'tool' or 'metric' or 'indicator'. The third category refers to the micro level: 'Micro', 'company', 'business', 'product', 'supply chain'.

After each search, a selection routine was applied in which irrelevant papers were filtered out. For this, the inclusion and exclusion criteria in Table 2 were applied. The aim of this routine was to obtain a strict selection of papers that propose CE assessment methods on micro level. One example: The combination of the search terms "Circular economy", "Measurement", and "Product" resulted in 47 results in Scopus. After screening the title, abstract, and content of the publications, 16 of these publications were considered to be relevant to the topic of CE assessment approaches. Then, 11 of the publications were added to Mendeley, as five had already been found through search terms previously used. This process, using the same keywords, was then repeated in ScienceDirect.

Table 2. Inclusion and exclusion criteria used in the systematic review process.

Inclusion Criteria	Exclusion Criteria
Academic literature	Grey literature approaches
Micro level approaches	Meso or macro level approaches
Newly proposed CE assessment approaches (i.e., not based on conventional methodologies)	Conventional LCA, Life Cycle Costing (LCC), Social Life Cycle Assessment (S-LCA) studies, eco-design or eco-innovation studies
Approaches that combine or expand existing methodologies or indicators to propose new CE assessment approaches	Conventional eco-design, eco-innovation, and general sustainability assessment-oriented studies
	Applications of existing CE indicators such as Material Circularity Indicator (MCI)

This search process firstly resulted in 315 publications. After an in-depth selection process using the inclusion and exclusion criteria in Table 2, 63 publications remained. Key examples of research publications excluded from the analysis and removed from the search results in this evaluation round are conventional LCA, Life Cycle Costing (LCC), and Social Life Cycle Assessment (S-LCA) studies, eco-design or eco-innovation studies, meso and macro level CE assessments, and studies limited to applying existing CE indicators, such as the Material Circularity Indicator (MCI) [39]. The reason for their exclusion is that these merely apply existing methodologies in a CE context, instead of proposing new assessment approaches. LCAs, LCCs, SLCAs, eco-design, eco-innovation, and general sustainability assessment-focused publications are excluded when they are not primarily involved with proposing CE-focused assessment approaches. Other inventories of metrics were also excluded for this reason. However, CE assessment approaches that combine different existing methods (standardized methods, such as LCA, or those proposed by grey literature, such as the MCI by the EMF), use only part of existing methods or expand them, have been included only when CE-focused. Meso and macro level assessment were excluded because they are not within the scope of this research.

To avoid missing certain approaches, in the complementing step, 11 more academic publications from cross-checking previously conducted inventories were added later. The previous inventories that were checked are summarized in Table 1, and the inclusion and exclusion criteria from Table 2 were applied. The structured search process of literature is summarized in Figure 2.

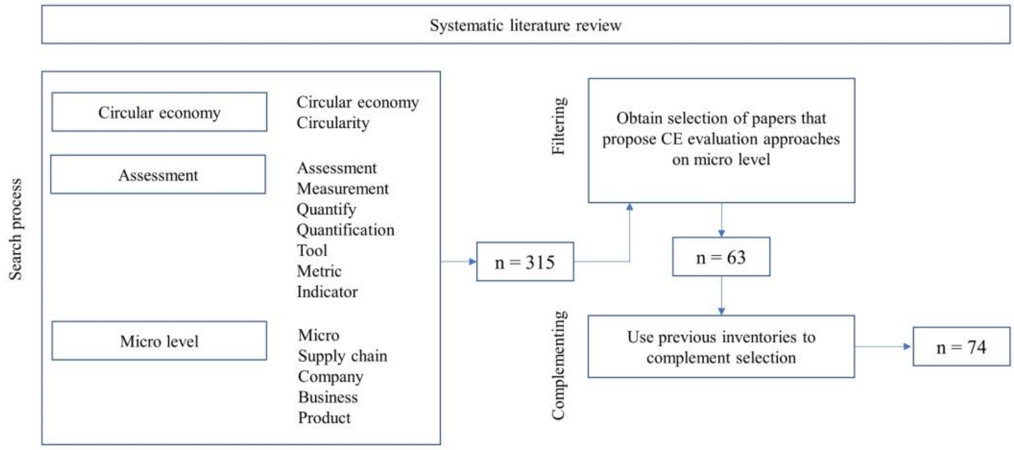

Figure 2. Summary of the structured search process of academic literature.

3.3. The Critical Review Framework

Next, a new review framework was constructed to categorize the characteristics of the inventoried approaches. The review framework consists of four perspectives: (i) A general perspective, (ii) a descriptive perspective (methodological foundation), (iii) a normative perspective (addressing SD as the end goal of CE), and (iv) a prescriptive perspective (participatory construction methods and questions of implementation). The perspectives, their complementary review attributes and analyzed characteristics are summarized in Table 3. The structure of the framework has been inspired by management literature on decision making in a corporate setting, primarily in [40]. Here, a typology of analysis perspectives in a decision-making context is put forward, and, more specifically, the term "prescriptive" as a complement to "normative" and "descriptive" analyses is introduced.

(i) **General perspective**—the first perspective contains the general characteristics of the inventoried approaches.

(ii) **Descriptive perspective: Methodological connections**—according to Reference [40], descriptive analysis engages with what has happened in the past to better understand current phenomena. The question becomes: 'How has research constructed previous approaches to assess CE?' This leads to evaluating the following methodological traits:

- Scale of assessment—the micro scale of evaluation still contains a variety of sub-scales, and no scientific consensus on its definition exists. The entire range of categories of different micro level scales of assessment has been included in the review.
- Sector specificity—since product- and firm heterogeneity appear not to have been addressed in detail in literature, sector specificity has been included as an element of interest in the descriptive dimension of the critical review framework. The type of sector was analyzed as well.
- Connection to existing methodologies (LCA/MFA/input-output analyses)—it will be valuable to explore how decades of knowledge on sustainability quantification, resulting in the development of widely used tools, are exhibited in newly introduced concepts such as CE. Therefore, the connections between CE assessment and LCA, S-LCA, LCC, MFA, and input–output analysis have been included. These methods were later completed by frequently occurring underlying methods that were used in combination with other methods (i.e., MCI).
- Case study and validation—to test the practical application of their proposed approaches, authors use case studies as a source for input data. The inventoried publications were screened for the application of a validation approach using case study data.

(iii) **Normative perspective: SD as the end goal of CE**—reference [40] describe a normative model as "(. . .) an abstract system that attempts to capture how ideal people behave" (p. 17). In stakeholder theory, the concept of a 'normative core' has been described as explicitly moral, and an effort to answer questions such as: 'What is the purpose of the firm?' [41]. In the context of CE assessment, this results in the question: 'What should the ideal outcome of applying CE be for the concept to be valuable?' The concept of CE is here interpreted to be valuable only when providing a pathway to SD (see Section 2). Hereby, this study intends to address (valid) criticisms of CE that state that resource-efficiency measures do not lead to sustainable outcomes per se (see e.g., [21]). The present research refers to the model of sustainable development cited in [8], proposing SD indicators in the environmental, economic, and social domain. When other dimensions are included, it is checked whether these belong to any of these categories or are more suited to the separate 'circular' dimension, which could be seen as a box containing any resource-efficiency related dimensions.

(iv) **Prescriptive perspective: Participatory design and questions of implementation**—lastly, reference [40] introduces the prescriptive decision-making model. This model addresses the question: "What should an individual do to make better choices? What modes of thought, decision aids, conceptual schemes are useful—useful not for idealized, mythical, de-psychologized automate—but for real people?" (p. 17). A very practical perspective that incorporates human—and organizational—limitations emerges. Three implementation-oriented prescriptive attributes are considered: The presence of providing operational guidance is assessed through using the search terms 'implementation', 'practitioner', 'operational', and 'application'. The application of a participatory approach was assessed in three steps: (1) By reviewing whether the intended end-user of the approach is mentioned, (2) if so, what the characteristics of these end-users are, and (3) whether end-users were involved in the design of the proposed approach. The authors' consideration of ease of communication is evaluated through searching for 'simplicity' and 'communication', 'user friendly', 'intuitive', and 'visualization'.

Table 3. The four perspectives of the critical review framework.

Perspective	Goal	Attribute	Analyzed Characteristic
(i) General	To describe published approaches' general characteristics	Age	Year of publication
		Peer-reviewed	Yes/No
		Source	Name of journal, book, or other sources
		Country	Country of home university of author
		Name and abbreviation	Name and abbreviation of the approach
(ii) Descriptive	To assess methodologies underlying the inventoried approaches	Scale of assessment	Determine scale of application within 'micro level', establish categories of scale of application
		Sector specificity	Determine whether the approaches are designed to be applied in a specific sector, and, if so, document which sector
		Connection to existing methodologies	Determine methodological connections by applying search terms 'LCA', 'MFA', 'input output', 'MCI'. Complement after in-depth review of approaches
		Application of case study validation	Screen publications for occurrence of application of proposed approaches in case study setting
(iii) Normative	To obtain a better understanding of connections to the three dimensions of SD	Inclusion of the three SD dimensions	Determine whether and how the environmental, economic, and social dimensions of SD are considered
		Inclusion of 'CE' dimensions	Determine whether and how 'CE' (resource-related) dimensions are considered

Table 3. *Cont.*

Perspective	Goal	Attribute	Analyzed Characteristic
(iv)Prescriptive	To evaluate the presence of implementation considerations and inclusion of end-user needs	Providing operational guidance	Does the publication mention 'implementation', 'practitioner', 'operational', or 'application'?
		Participatory approach	Is the end-user mentioned?
			If so, who is the intended end-user?
			Are the end-user or other stakeholders involved in the design of the evaluation approach?
		Ease of communication	Does the publication mention 'simplicity' or 'communication'?

In addition to describing the results for each of the attributes of the perspectives above, the connections between the attributes of the descriptive, normative, and prescriptive perspective have also been analyzed to discover underlying patterns. The goal of this analysis was to discover the extent to which each attribute is linked to the others (i.e., do product-level assessment approaches more often employ the LCA methodology?). All combinations between attributes have been checked and the most relevant discovered patterns are described in the results section.

4. Results

In the following sections, the findings from the analysis of the inventoried 74 CE evaluation approaches at micro level are discussed according to the four dimensions of the proposed review framework. The general results can be retrieved in Appendix A, whereas more specific results for each perspective are presented below.

4.1. General Attributes

Most of the inventoried approaches originate from peer-reviewed academic publications (60), while the remaining 14 are published in conference papers. Some journals that appear often are the Journal of Cleaner Production (17 times), Resources, Conservation, and Recycling (8 times), and Procedia CIRP for conference papers (7 times). As presented in Figure 3, the field is very young: Only 6 publications from before 2016 are included in the inventory. Presented on the right side of the graph, European countries such as Italy (9), the Netherlands (9), the United Kingdom (8), and Denmark (6) are well-represented. Only 15 publications are from outside of the EU. Research attention appears to have decreased slightly after its peak in 2018, but at the moment it is not possible to interpret this as a decline of interest or a simple oscillatory trend.

4.2. Descriptive Perspective: Methodological Attributes

The inventoried approaches use a large variety of scales. As displayed in Table 4, most approaches focus on product (22) or company level (12). For the product level, some approaches are, to a varying extent, tailored to specific product categories. Within these, again, the products are very heterogeneous in size, composition, and use; for instance, compare the indicator for pharmaceuticals by [42] and the tool for evaluating the end-of-life performance of a hybrid scooter by [43]. 'Business model' is technically not a scale of assessment, thus it was not among the search terms; it has nevertheless been included as a separate category because of its frequent occurrence, especially in relation with Product-Service Systems (PSS). Similarly, although 'material' was not explicitly included in the search terms, 4 of the approaches focus on the level of materials.

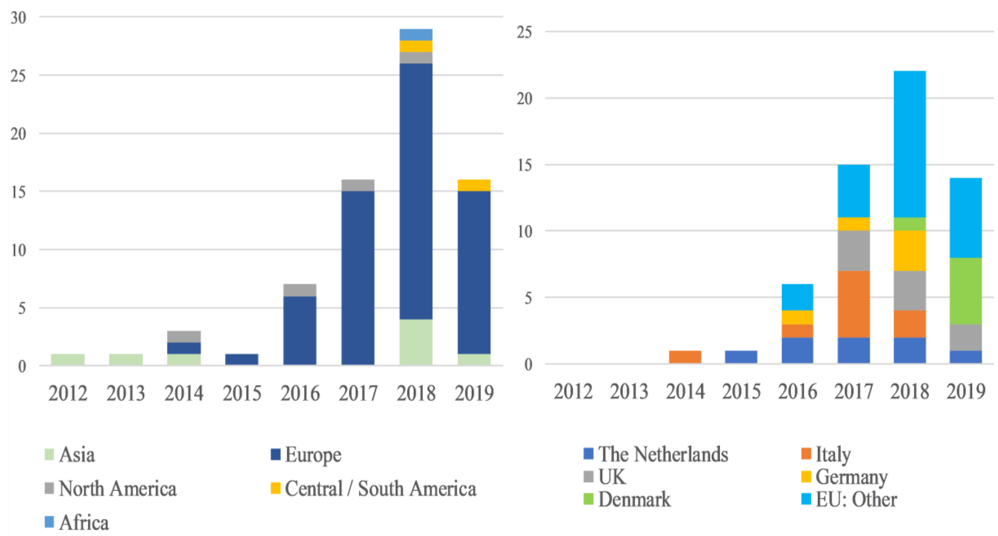

Figure 3. Publication dates of the inventoried approaches (globally and in Europe).

Table 4. Scales of assessment.

Scale	Approaches (N.)	General (N.)	Detailed (N.)
Product	22	Product (16)	Chemicals (1), energy-related product (1), gypsum product (1), automotive vehicle (1), product family (1), end-of-life product (1)
Company	12	Company (9)	Small and Medium-sized Enterprise (SME) (2), Circular Economy initiative (1)
Business model	11	Business model (6)	Product-Service System (5)
Other	9	-	Building (2), component (1), technology (1), sector/industry (1), farm (1), event (1), strategy (1), innovation (1)
Supply chain	6	Supply chain (6)	-
Material	4	Material (2)	Biobased polymers (1), waste (1)
Packaging	4	Product packaging (3)	Packaging chain (1)
Plant/installation	3	-	Treatment plant (1), installation (1), Wastewater Treatment (WWT) plant (1)
Various scales	3	-	Materials and products (1), products, services, or processes (1), company or strategy (1)
Total	74	42	32

Concerning sector specificity, 30% of the inventoried approaches are developed with the intention to be applied to a specific sector, while 69% are designed to be applied across sectors. This is supported by earlier findings by, e.g., [12]. One publication proposes both a sector-specific as well as general approach [44].

An example of a widely cited non-sector specific approach in the inventory is the hybrid-LCA approach by [45], in which a traditional LCA approach is complemented with a number of 'CE indicators': Carbon emissions, kg's virgin resources used, kg's waste recovered. The level of assessment is product supply chain, and the proposed approach is applied in two explicitly different sectors:

A chemical supply chain and a food supply chain. An example of a well-cited publication that involves a sector-specific approach is [42], in which the case is made that mass-based indicators for green chemistry and CE should be combined with LCA indicators.

From comparing the attributes 'scale of assessment' and 'sector specificity', it is found that approaches designed to assess business model-, company level- or supply chain CE are almost never sector specific (4 out of 29). For the product level, this increases very slightly, but is still low: 7 out of 22 product level approaches are sector specific. As expected, the 7 approaches designed for more specific scales 'packaging' and 'plant/installation' (7 in total) are all sector-specific.

Regarding the connection to existing methodologies, the LCA methodology is used in 32 approaches (see Table 5). In 14 of those cases, LCA is used in combination with other existing methods. These combined methods are very diverse and include methods such as Material Flow Cost Accounting [46] or a Material Reutilization Score [15]. They are summarized in Table 6. Besides LCA, other methods appear to be used on the micro level: MFA is used in 5 cases, while the previously introduced MCI indicator is used three times. Interestingly, 3 publications apply fuzzy set theory in their works. One example is the case of [47], in which Fuzzy Cognitive Mapping is applied to quantify direct and indirect effects of CE strategies on social, economic, and environmental dimensions. The category 'other methods' includes the Cumulative Energy Demand (CED) [48], the ISO 22,628 [49] standard and UNIFE Energy- and Material Recycling Factors (MRF and ERF) [43], and the Material Security Index [50]. Deeper methodological connections between LCA and CE have been researched by [23].

Table 5. Connections to existing methodologies.

Connection with ...	Number of Approaches
LCA	32
LCA	18
LCA + other methods	14
MFA	5
Fuzzy set theory	3
MCI	3
Other methods	15
No connection to other methods	31

Almost half (31) of the inventoried approaches do not refer explicitly to existing assessment methods, but propose novel methods. The novel methods are highly heterogenous, primarily in terms of output, complicating the task to categorize their methodological development steps: 13 approaches develop a 'CE evaluation framework', the output of 9 consist of a set of indicators, 7 present single indicators, and 2 are classified as 'other form of output' (a computer model and a set of calculations).

In these 31 novel approaches, two forms of alternative methodological development emerged. First, it was found that many approaches made use of external (expert) input to construct and revise the proposed approach: 7 publications used expert input, 3 publications used interviews, 2 studies applied the Delphi method, and 4 publications revised an initial version of the approach after its application in practice. In other cases, the inputs come from students (1), stakeholders (1), users (1), or peers at a conference presentation (1). One publication bases its proposed framework on a previous framework proposed in the literature [51]. Eighteen approaches do not use any form of external consultation. Second, the 31 novel approaches often use a literature review approach: 15 papers first review the available existing methods or tools, highlighting and exploiting a gap in research, or building on lessons from the review. The other 16 do not provide such a review. In summary, most publications that do not explicitly refer to existing methodologies use either external expert input, a literature review or a combination of both.

The attributes 'sector specificity' and 'connection to existing methodologies' were analyzed jointly to identify patterns. Almost half (19) of the 43 inventoried approaches that are based on existing methods are designed to be applied to a specific sector. Interestingly, the 31 approaches that are not based on existing methods are much less often designed to be applied specifically: This occurs in only 3 cases.

A large majority of inventoried publications uses case study data to test and apply their proposed approaches. In almost all the 48 approaches that use a case study approach, the case study sector is different.

Observing the links between the attributes 'scale of assessment' and 'case study validation', it is found that the company level approaches are not always validated by applying a case study approach (6 out of 12 approaches). On the contrary, for the product level, this ratio is much higher with 20 out of 22 approaches.

Table 6. Combinations of LCA and other methods.

Reference	Method
[52]	LCA, LCC, S-LCA
[53]	LCA, MFA, multi-objective optimization
[54]	LCA, LCC
[55]	LCA, LCC, S-LCA
[45]	LCA, Environmental Input-Output (EIO)
[56]	LCA, Recyclability Benefit Rate (RBR), Recycled Content Benefit Rate (RCBR)
[57]	LCA, MFA
[58]	LCA, MFA, Constructive Technology Assessment (CTA), input-output analysis, LCC, Cost-Benefit Analysis (CBA)
[15]	LCA, Material Reutilization Score (MRS), MCI
[59]	LCA, MFA, LCC, S-LCA
[46]	LCA, Material Flow Cost Accounting (MFCA)
[42]	LCA, E-factor
[60]	LCA, Net Present Value, Internal Rate of Return, questionnaire on stakeholder perception
[61]	LCA, Environmental Product Declaration

4.3. Normative Perspective: SD as the End Goal of CE

The results for the application of the normative perspective to the inventoried approaches are described in Table 7. Eighteen of the approaches consider the three environmental, economic, and social domains of SD while also including a 'circular' dimension. On the other side of the spectrum, 20 approaches only include the circular dimension, which is interpreted differently by almost every author. Without the space to zoom in on all of them, some examples are: kg's of waste produced over lifecycle [62], ease of disassembly of products [63], materials quality and energy quality [64], and material efficiency [65].

Table 7. Sustainable Development as goal of Circular Economy.

References	Environment	Economic	Social	Circular	Number of Approaches
[47,52,58,59,66–79]	X	X	X	X	18
[55,60]	X	X	X		2
[61,80–82]	X	X		X	4
[46,54,83]	X	X			3
[15,42,44,45,48,84–89]	X			X	11
[50]		X		X	1
[56,90–95]	X				7
[13,96,97]		X			3
[43,51,53,57,62–65,98–114]				X	25
	45	31	20	59	74

Seven approaches only include the environmental dimension in their assessment process, while 3 consider only the economic domain. Other groups of approaches combine information on the environmental and circular dimension (11 approaches), economic and circular dimension (1), or economic and environmental dimensions (3).

Some insights above have been previously described in literature. For example, the social dimension of CE is generally considered underrepresented [4]. In this study, it is found to be included in only 20 of the 74 proposed assessment approaches; these are the approaches that consider all three dimensions of sustainability. Additionally, the high amount of assessment approaches that focus on explicit CE characteristics is remarkable. Such approaches can be interpreted to fall under the umbrella of 'intrinsic' indicators [12]. They deliberately focus on 'CE' as a dimension of evaluation, instead of also including environmental, economic, and social impacts; an example is product-level circularity [13]. Other studies, such as [52] or [44] combine CE-dimensions with impacts on the three sustainability domains; essentially, they hereby interpret CE as a resource-efficiency based means to achieve SD. These approaches can perhaps also be said to be more in line with the characteristic of 'consequential' circularity [12].

When comparing the results to the outcomes in [24], some interesting differences can be noted. In [24], the economic dimension is included most frequently: 17 out of the 30 indicators directly include economic parameters, and two indirectly. At the same time, the environmental dimension is included 12 times. In the present study, the environmental dimension (45) is included more often than the economic dimension (31). The difference is most likely caused by small differences in search terms and the selection process afterwards. The results of both studies for the social dimension are however quite similar, with an even more visible underrepresentation discovered in [24]: Only 4 out of 30 indicators include the social dimension, predominantly focusing on job creation.

Subsequently, links between the descriptive and normative attributes were analyzed. When comparing 'scale of assessment' and the included dimensions, it was found that company-level approaches relatively often (7 out of 12) include the three SD dimensions as well as an additional resource efficiency-related parameter. For the business model scale, this ratio is 4 out of 11, while for the product level, it is much lower: Only 3 out of 22. This indicates that researchers more often use a holistic perspective when considering company level assessment than product level assessment. The other dimensions follow this general pattern as well. Zooming in on the product level, half of the approaches only include the single 'resource efficiency' dimension. The environmental- and economic dimension is included in 8 out of 22 approaches, while the social dimension only occurs in three out of 22 product level CE assessment approaches.

In addition, patterns between the attributes 'presence of existing methods' and the SD dimensions were analyzed. As expected, the connection between the underlying methods, and particularly with LCA, is strongly visible in the approaches that include the environmental dimension. Out these 45 approaches, 32 are based on LCA, or LCA in combination with other existing methods. For the approaches that include the economic dimension, this is slightly less obvious: Out of 31, only 18 use existing underlying methods, consisting of LCC. When focusing on the social dimension, which is included in 20 of the underlying methods, only 6 use S-LCA. Interestingly, with respect to the 18 approaches that offer a holistic view on CE and SD, 8 of these approaches are not based on existing methods. An example is [66], proposing a qualitative sustainable value proposition framework based on narrowing, slowing, and closing resource loops.

Lastly, when considering the presence of case studies and the included dimensions, a potentially interesting finding is that the inventoried 'holistic' approaches are more likely to lack a case study approach (7 out of 18 approaches do not apply this) than the 'non-holistic' approaches, in which 9 out of 56 approaches do not apply a case study. Again, although the numbers are small, this could point towards the practical limitations that occur when researching CE assessment: Company level data in all three sustainability domains might not always be readily available, especially when considering the social and economic domains.

4.4. Prescriptive Perspective: Participatory Construction and Questions of Implementation

Lastly, the inventoried approaches are reviewed using the prescriptive perspective. They are screened for any form of operational guidance, mention of ease of communication, and application of participatory construction method in the design of the approaches.

The findings show that 18 out of 74 approaches provide suggestions or guidance for the implementation of the proposed approaches. The operational guidance provided is often very brief. For example, [88] provides a paragraph called 'managerial implications' that briefly describes how managers and supplier organizations can use their proposed approach for evaluating green supplier's performance. Another example is found in [94], albeit in a different form; the paper mentions: "(. . .) an organization that evaluates a new PSS must either have employees whom are LCA practitioners or must outsource these skills" (p. 722), providing a suggestion on the starting point of carrying out an environmental assessment of product-service systems (PSS). Reference [46] presents an extended table containing integrated LCA and MFCA implementation steps; interestingly, many of these steps also provide insights to companies on how to organize CE data collection, suitability, and quality control. [92] makes valuable remarks on the existence of top-down and bottom-up CE indicators, whereas the last are based also on appreciation of the preoccupations expressed by stakeholders.

Regarding the intended end-users of the proposed approaches, it emerges that in 27% of the inventoried approaches, the indented end-user, i.e., person or entity responsible for eventual application, is not mentioned. The remaining 54 approaches are intended to be used by a highly heterogeneous collection of users, as visualized in Figure 4.

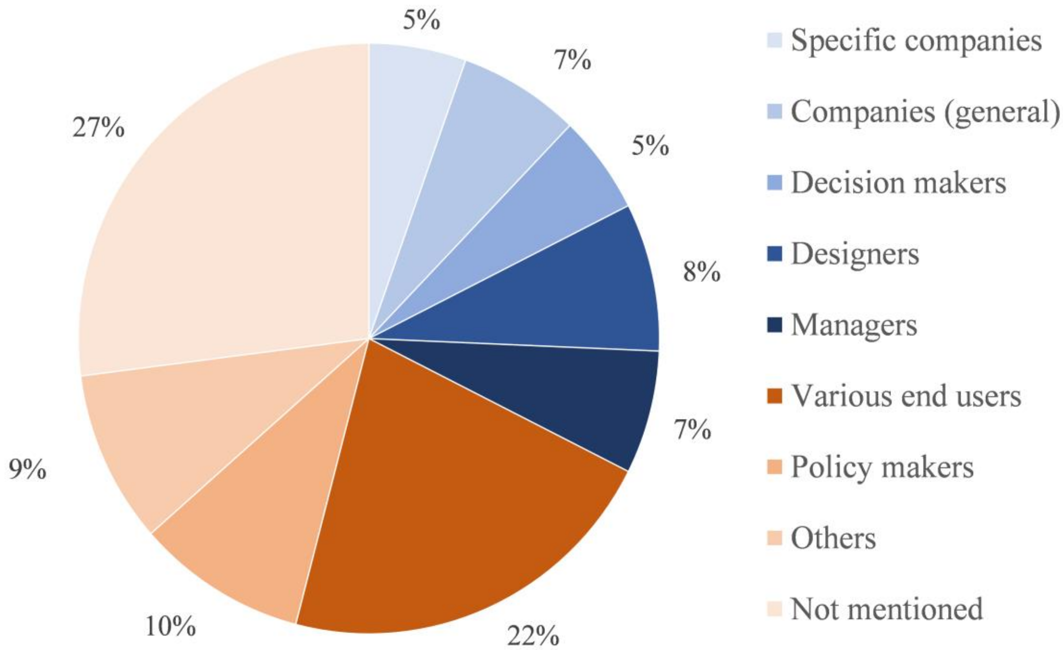

Figure 4. Intended end-users mentioned in CE assessment approaches.

As can be seen in the figure, authors sometimes mention 'companies', either specific or general, as end-users, while not specifying the position or function of the person(s) that will eventually apply the approach. Examples of specific companies are 'manufacturing enterprises' [65], 'initiatives relating to the CE' [91], and 'small- and medium sized companies' [113]. A detailed description of the intended company is provided in [98], listing both the necessary skills of the end-users as well as the characteristics of the company ("manufacturing and/or retail companies of tangible goods with access to bill of materials") (p. 3).

The roles and positions of the end-users that are more specific are often still multi-interpretable or very broad; examples are 'decision-maker' or 'manager'. The relatively frequent occurrence of policy makers as end-users is somewhat unexpected at micro level scale. In the category 'other', the following end-users are included: 'Academia', 'CEOs and production managers of manufacturing companies', 'consumers', 'industrial practitioners', 'non-experts', 'R&D managers and investors', and 'stakeholders'.

Sixteen approaches address their intended audience by listing multiple potential end-users, sometimes depending on the intended goal of analyzing an organization's degree of circularity. For example, [111] describe how "the use of a particular set of sustainability indicators depends on the stakeholders involved in the case study analyzed. Therefore, the modifications during early design phases are strongly related to the interest and addressing efforts established by the designer, manufacturer or the company" (p. 1441). Some other authors, such as [50] more straightforwardly list various end-users, in this case 'other researchers, companies, countries, and stakeholders'. Similarly, [73] mentions both 'process owners' as well as 'industrial practitioners' as intended end-users. A more specific example is provided in [94], stating that the organization that evaluates a Product-Service System (PSS) must "either have employees whom are LCA practitioners or must outsource these skills" (p. 721).

With regards to involving these end-users in the design of the proposed approaches, it is found that 20 out of the 74 inventoried approaches are designed in a participatory manner. Some examples are listed hereafter. The Delphi method, a process for structuring communication processes in order to obtain consensus on complex issues, is used sometimes. [113] use this process in their participatory identification process of crucial CE elements in implementation in SMEs. Still, their participants are not necessarily involved in the application of a CE measurement tool as they consist of academia and consultants. Other studies focus on including stakeholder perceptions of CE. In a study by [60], stakeholder perception is investigated to understand what drives stakeholders to utilize biofertilizer. It is not necessarily participatory in the sense that it does not involve end-user feedback for constructing an assessment approach, but it does involve the end-users of the system under assessment in the decision-making process. A study that clearly involves end-users is [103], where surveys are used to link CE principles to business actions, specifically focusing on Romanian SMEs operating in the PVC joinery industry. The paper's approach is aimed at aiding entrepreneurs in "assessing and choosing the most suitable circular business model or set of business actions for their business" (p. 321). Reference [73] explicitly includes participatory elements in their PSS assessment process, describing how, for example, "processes and tools for PSS assessment shall then be designed to facilitate participation in the definition of the evaluation criteria, mixing value- and sustainability-related considerations" (p. 2). Last, yet another participatory approach is found in [82]: In this case, the authors' approach to constructing a framework for end-of-life evaluation is guided by the preferences of designers, who are the end-users of the proposed tool.

It is found that in 17 out of the 74 approaches, the ease of communication is considered as a criterium for a well-functioning approach. For example, in [109], CE indicators are described to fulfill purposes of monitoring, reporting, and "communicating progress towards the CE". Similarly, in describing the desired characteristics of a disassembly standard, [63] mentions the ability to "facilitate communication of product information to consumers to encourage comparison of ecodesign performances of products" (p. 326). More detail to the communication process is provided in [82], in which an information management framework is presented that shows how designers and end-of-life managers should communicate. Ease of communication is in some cases incorporated through the visual presentation of the end result of a proposed CE assessment approach, see, e.g., in [68,114].

While many combinations did not result in any emerging patterns, some findings emerge when prescriptive attributes are analyzed in combination with the previous descriptive and normative attributes. Firstly, when comparing the presence of operational guidance with the attribute 'sector specificity', it emerges that of the 18 approaches that provide operational guidance, only 1 is sector-specific, while the others are designed to be applicable to various sectors. Contrarily, for the 56 approaches that do not offer guidance, 21 are sector-specific. This is unexpected: More focused approaches might be expected to offer more in terms of operational assistance. A similar pattern appears when zooming in on sector specificity and 'ease of communication': Of the 17 approaches that acknowledge that 'ease of communication' is important to a well-functioning approach, only 2 are sector specific.

The various attributes within the prescriptive perspective have also been analyzed comparatively. It is found that, for example, the 20 participatory approaches do not necessarily offer operational guidance; they do so in only 7 out of 20 cases. Vice versa, the 18 studies that offer operational guidance are not participatory in 11 cases. When studying the participatory approaches' end-users, most of these approaches are spread out relatively equally over the various intended end-users, and an interesting observation is that the 4 end-users' (specific) companies include 3 participatory approaches. The 20 approaches for which the end-user is not mentioned are much less likely to be participatory: Only 2 cases are designed in a participatory way.

Other observed patterns can be said to be more in line with expectations. For example, almost all (18 out of 20) participatory approaches use a case study to validate their proposed approach.

5. Critical Reflection and Suggested Key Desired Properties

Inventorying available approaches and applying the review framework provided insights into the first research objective of the present study: To enable a categorization of the characteristics of available academic approaches to assess CE at the micro level. Next, the second research objective of providing key desired properties of CE assessment at the micro level to guide future research is addressed. For this, the coherence of the results (i.e., how previous research addresses CE assessment) is reviewed and where possible, key desired properties addressing the potential lack of consensus are proposed. These key desired properties are connected to two criteria, emerging from the review framework: To promote the ability of CE assessment approaches to accurately assess the sustainability of CE processes, and to inform the design of future CE assessment approaches with a higher chance of uptake by organizations. The first criterium is connected to the interpretation of CE as an umbrella concept, generating multi-dimensional impact with the overall end goal to facilitate reaching SD (see Section 2 and the description of the normative perspective). The second criterium is selected to highlight that CE assessment approaches carry real-world value only when they are implemented (prescriptive perspective). Where formulating desired properties is not possible, directions for future research are indicated. An overview of the key desired properties is presented in Figure 5.

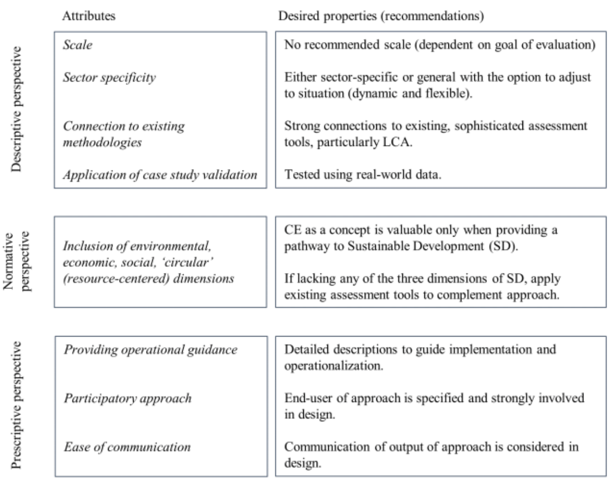

Figure 5. Summary of desired properties micro level CE assessment.

Descriptive perspective—for this perspective, assessment scale, sector specificity, connection to existing methodologies, and application of case study validation are relevant. The inventoried approaches apply a variety of scales, as shown in Table 4. This is directly linked to the broad interpretation of micro level and the keywords used. It could also be interpreted to reflect the lack of consensus on the question of what constitutes a 'circular' organization. Large multinational companies with complex supply chains might need different tools to assess their circularity than small companies that produce only a single product, for example. These issues have been acknowledged in earlier research on corporate sustainability measurement [31]. Interestingly, in literature on CE evaluation, the connection to this earlier body of sustainability assessment approaches and theory does not seem to be made. Therefore, for this attribute, no suggested desired properties can be highlighted. On the contrary, it can be noted that the different scales likely all have a degree of relevance, depending on the end-user's characteristics and end goal. This can be said to be in line with applying different scales in methodologies such as LCA, in which product-, service-, and organizational level studies can all be relevant in different contexts.

Sector-specific approaches (30%) occur less frequently than approaches designed to be applied across sectors (69%). While the results show no consistent pattern, only future practical application will indicate which is more appropriate in which situation. Nevertheless, it is expected that generally applicable approaches might be more challenging to implement due to the high complexity and heterogeneity of organizations and their activities. Examples are differences in material use (bio-based or fossil-based), supply chain complexity, or simply differences in whether an organization is inherently linear and needs transformative change or already operates in line with CE principles. When sketching such differences, approaches that are adequately tailored to the specifics of a sector might appear to offer more potential for change [78]. Another option could be to design frameworks that offer flexibility and can be adjusted accordingly to the situation at hand. Nevertheless, again, this preliminary finding will need to be tested in practice before any definite statements can be made.

It has emerged that 32 of the inventoried approaches are partly- or completely based on the LCA methodology, while 31 are not based on any previous methodology. In other words, no coherent message on which existing methodology to apply—or whether to apply one—is found in academic literature. Using LCA for evaluating the environmental impact of CE solutions still carries some methodological issues [23], and there are some doubts around its complexity and costs [92,96]. Still, it is currently the most sophisticated environmental assessment methodology available, and less sophisticated tools and methods might not capture the full range of environmental impacts, potentially missing important trade-offs [91]. In the light of the current climate- and ecological crisis, missing such trade-offs is undesirable. For the economic- and social dimensions, the less-developed state of the field of measurement is reflected in the low occurrence of S-LCA and LCC methods. Similar to the environmental dimension, it is however recommended to reflect on these impacts using the most sophisticated assessment tools available. Still, further research could elaborate on the usefulness of both tools in a more practical setting.

From the 74 inventoried approaches, 48 use a case study approach for validation. This process, using real-world data, allows for signaling potential risks: e.g., in term of data collection, time consumption, and costs, but also an approach's ability to accurately reflect a real-world scenario.

Normative perspective—the inventoried approaches show low coherence with respect to which dimensions are included in CE assessment (see Table 7). Eighteen publications include both the 3 domains of SD as well as a 'circular' dimension. As presented in Section 2 and considered in the description of the normative perspective of the review framework, the present study considers the concept of CE to be valuable only when providing a pathway to SD, generating positive impacts in the environmental, economic, and social domains. A note should be made that the many approaches that adopt a less holistic view could be combined with existing LCA, LCC (see, e.g., [115]) or S-LCA methodologies. The same holds for the approaches that, for instance, only include the environmental- and CE dimensions: By complementing them with other available tools such as LCC and S-LCA, or even with available qualitative impact assessment approaches, a comprehensive picture of a decision's impact can still be established.

A lingering issue of the dimension of 'circularity', and perhaps of the concept of CE altogether, is that solutions that perform best in terms of environmental, economic, and social impacts might not be based on resource-efficiency oriented CE principles. This interpretation informs the previously mentioned first criterium for selecting desired properties. Naturally, CE could be interpreted merely as a pathway towards lowering impacts on these dimensions, instead of being a goal in itself. This raises the key question of whether it is worthwhile to, as an organization, evaluate your degree of circularity. Indeed, as many other authors point out, the relation between CE and SD is an assumed one, and should not be considered to be self-evident. The popularity and rapid adaptation of the concept could lead to the risk that decision makers shift their focus from reaching SD to reaching resource-efficiency goals, which might consequently not necessarily have positive overall effects on all the three sustainability dimensions.

Prescriptive perspective—The implementation-oriented attributes appear to have received relatively little attention in the inventoried approaches: Roughly a quarter of the inventoried approaches offers operational guidance, applies a participatory design method, or mentions the ease of communication as an important factor in the design and use of the proposed approaches. As described in Section 3.2., literature on the success factors of implementation of CE or sustainability assessment approaches is scarce. Still, the key factors that prevent implementation by companies are both internal shortcomings, i.e., shortcomings of the implementing organization, and external deficiencies, i.e., shortcomings of the approaches themselves [116]. From this, it could be argued that a CE assessment approach could be designed by establishing the optimal mix of these two factors; understanding the end-user's desires and limitations in the use of such an approach and making sure the proposed approach matches this appropriately. Incorporating human—and organizational—limitations, potentially leading to higher rates of implementation, can be realized in close collaboration with the end-users of the approach. Remarkably, such a participatory approach has only been observed in 20 out of 74 publications. Returning to the notion of consensus within the inventoried approaches, in around three-quarters of the publications, the needs of the end-user are not considered in the design, potentially making them less likely to be implemented in the future. Perhaps, from this finding, it can be suggested that stimulating closer connections between science and practice might lead to higher uptake of assessment approaches and the concept of CE altogether. Referring to the second criterium for formulating desired priorities, the desired properties of designing future CE assessment approaches at micro level entail closely collaborating with the end-user of the approach, incorporating human and organizational limitations.

6. Conclusions

In this study, approaches to assess CE at the micro level have been inventoried using a systematic literature review. A newly constructed review framework allowed for the application of four review perspectives: A general, descriptive (methodological), normative (inclusion of SD/CE dimensions), and prescriptive (implementation-focused) perspective. Results for each of these perspectives provide insights into academic authors' different interpretations of assessing CE, ultimately arriving at suggestions for desired properties of to-be-designed approaches. Little methodological coherence within the available inventoried approaches was found, while the normative perspective (i.e., the perceived outcome of a CE) also showed a broad variety of interpretations. These two primary findings might, in combination with little attention for the eventual implementation of an approach, be fundamental to the low uptake of CE assessment approaches by organizations. The formulated desired properties aim to guide the design of future CE assessment approaches with a higher eventual uptake by organizations, while promoting the ability of an CE assessment approach to accurately assess the sustainability of CE processes.

This work is limited to approaches that were extracted from academic literature; it could be expanded by reflecting on approaches from grey literature. In particular works by the EMF and various private sector organizations could be added to better understand different interpretations of micro level CE assessment. Additionally, CE assessment approaches that have been developed and implemented by organizations could be collected and studied in a similar manner. For some of the review perspectives, especially the normative and prescriptive perspectives, a clear limitation is that only some elements have been explored. For example, more types of participation could be investigated (see [40], p. 297). Lastly, a similar review, perhaps expanding the review perspectives, could be undertaken for approaches that are designed for the meso- and macro levels.

After conducting the inventory and review, various gaps in current literature on CE assessment approaches on micro level can be identified. First, the review shows that most approaches are very different in terms of methodology, both when reflecting on their scale of assessment as well as use of existing methodologies. Previous reviews have signaled this as well, and point towards the different understandings of the concept of CE [23] or the various interpretations of the micro level [24] as some of the underlying reasons. With respect to the latter, a gap in understanding what constitutes a 'circular' company becomes apparent. How to deal with supply chain complexity in CE assessment, and how to understand an organization's responsibility in achieving supply chain sustainability is currently investigated by many organizations and academics, and provides much room for further work. Additional transdisciplinary research projects will provide insights into the question whether sector-specific or more generic CE assessment is preferred. The goal of the assessment will be a large determinant in this choice.

Another gap present in the inventoried approaches, and currently receiving much attention in CE literature, is that of the links between CE and SD. The position taken in this article is that CE is considered to be valuable only when providing a pathway towards SD; otherwise, it carries the risk of diverting the attention of solving some of our global climate- and ecological crises by focusing on incremental instead of systemic change, driven by the promises of economic gains through resource efficiency. However, the relation between the two concepts is still fuzzy, in terms of the environmental and economic impacts of CE, and especially in the context of integrating social equity—and related—impacts into CE.

Furthermore, applying the prescriptive perspective of the critical review framework indicated that the connections between academic research and practical implementation of CE assessment approaches are in an early stage. As indicated in the framework of suggested desired properties, this area of research offers many opportunities for further work. Relatively little is known about company needs, operational-, mid-management-, or strategic must-haves and skillsets, decision-making contexts, internal- as well as external barriers to implementation, and other real-world attributes that appear to be relevant to CE assessment. Further research on the assessment of CE could potentially employ a more transdisciplinary research strategy to establish valuable insights into these questions.

Finally, a better understanding of needs, goals, and implementation of CE assessment approaches might also lead to a better understanding of the concept of CE and its role in shaping a sustainable future. As assessments and measurements are part of any adaptive learning system, the rapidly developing field will expose deeper links between the evaluated concepts and their relation to finding practical-, real-world solutions to global challenges [32].

Author Contributions: Conceptualization, E.R.L., R.S., T.R.; methodology, E.R.L., R.S., T.R.; formal analysis, E.R.L.; writing—original draft preparation, E.R.L., writing—review and editing, R.S., T.R.; visualization, E.R.L., R.S.; supervision, R.S., T.R.; funding acquisition, R.S., T.R. All authors have read and agreed to the published version of the manuscript.

Funding: This article is part of the outcomes of the research project CRESTING (Circular Economy: Sustainability implications and guiding progress), funded by the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement number 765198.

Acknowledgments: The authors would like to thank the CRESTING project partners, members of the department of Economics of the University of Messina, and the CREIDD team members of the University of Technology of Troyes, for their inputs and discussions on the topic of CE assessment. The authors also thank the anonymous reviewers and Anna Walker and Walter Vermeulen who reviewed earlier versions of this paper.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Overview of all inventoried approaches.

Reference	Name Approach	Scale	Sector Specific	Connection to Methods	Case Study	Number of SD Dimensions/CE Dimension Included	Provides Operational Guidance	Intended End-User	Ease of Communication	Participatory
[101]	N/A	Various	No	No	No	0/Yes	No	N/A	No	No
[71]	PR-MCDT	Product	No	No	Yes	3/Yes	Yes	Managers	No	Yes
[102]	CPA (and CPI)	Product	No	No	Yes	0/Yes	No	N/A	No	No
[89]	REAPro	Product	No	Yes, LCA	Yes	1/Yes	Yes	Various	No	No
[72]	SCI	Company	No	Yes, MCI	No	3/Yes	Yes	Managers	Yes	No
[94]	e-BEP	Business model	No	Yes, LCA	Yes	1/No	Yes	Other	Yes	Yes
[73]	N/A	Business model	No	No	Yes	3/Yes	Yes	Various	Yes	Yes
[43]	N/A	Product	Yes	Yes, ISO 22628, UNIFE (MRF/ERF)	Yes	0/Yes	No	Various	No	No
[52]	N/A	Other	No	Yes, LCA, LCC, S-LCA	Yes	3/Yes	No	Designers	No	No
[65]	N/A	Supply chain	No	No	Yes	0/Yes	No	(Specific) companies	No	No
[74]	N/A	Company	No	Yes, LCA	Yes	3/Yes	No	Managers	No	Yes
[98]	CEIP	Product	No	No	Yes	0/Yes	No	(Specific) companies	Yes	Yes
[103]	N/A	Business model	No	No	No	0/Yes	No	N/A	No	Yes
[53]	CI	Plant/installation	Yes	Yes, LCA, MFA, multi-objective optimization	Yes	0/Yes	No	Policy makers	No	Yes
[84]	N/A	Product	Yes	Yes, LCA	No	1/Yes	No	N/A	No	No
[104]	CEV	Other	No	Yes, MCI and the Korse model	Yes	0/Yes	No	N/A	No	No
[75]	N/A	Business model	No	No	No	3/Yes	No	N/A	No	No
[96]	CEI/KRI	Product	Yes	No	Yes	1/Yes	No	Policy makers	No	No
[97]	VRE	Other	No	No	Yes	1/No	No	Policy makers	Yes	No
[92]	Various	Various scales	No	Yes, LCA	No	1/No	No	N/A	No	No
[83]	Environmental-economic assessment	Other	No	Yes, LCA	Yes	2/No	No	N/A	No	No
[68]	RSI	Company	Yes	Yes, LCA	No	3/Yes	No	N/A	Yes	No
[81]	N/A	Product	No	No	Yes	2/Yes	No	Designers	No	No
[105]	N/A	Company	No	No	Yes	0/Yes	No	Various	No	No
[100]	Repairability Indicator	Product	Yes	No	Yes	0/Yes	No	Other	No	Yes
[106]	CEV	Other	No	No	Yes	0/Yes	No	N/A	No	No
[107]	N/A	Product	No	No	No	0/Yes	No	Various	No	No
[108]	Longevity indicator	Product	No	Yes, MFA	Yes	0/Yes	No	Managers	No	No
[54]	N/A	Other	Yes	Yes, LCA, LCC	Yes	2/No	No	Designers	No	No

Table A1. *Cont.*

Reference	Name Approach	Scale	Sector Specific	Connection to Methods	Case Study	Number of SD Dimensions/CE Dimension Included	Provides Operational Guidance	Intended End-User	Ease of Communication	Participatory
[55]	LCA, SLCA, LCC and CBM	Business model	No	Yes, LCA, LCC, S-LCA	Yes	3/No	Yes	Managers	Yes	No
[76]	CMT	Company	No	No	Yes	3/Yes	Yes	N/A	No	No
[45]	Hybrid LCA	Supply chain	No	Yes, LCA, EIO	Yes	1/Yes	No	Policy makers	No	No
[47]	N/A	Product	Yes	Yes, 'Streamlined' LCA	Yes	1/Yes	No	N/A	No	No
[44]	N/A	Supply chain	Yes and No	Yes, Fuzzy Cognitive Mapping	Yes	3/Yes	No	Policy makers	No	No
[48]	N/A	Material	Yes	Yes, CED	No	1/Yes	Yes	Designers	No	No
[109]	N/A	Company	No	No	No	0/Yes	Yes	Companies	No	No
[56]	RBR	Material	Yes	Yes, LCA, RBR, RCBR	Yes	1/No	No	N/A	No	No
[69]	N/A	Business model	Yes	Yes, LCA	Yes	3/Yes	No	Companies	No	No
[70]	N/A	Product	Yes	No	Yes	3/Yes	No	Other	No	No
[77]	N/A	Supply chain	No	Yes, LCA	No	3/Yes	Yes	Various	No	No
[57]	N/A	Plant/installation	Yes	Yes, LCA, MFA	Yes	0/Yes	No	Various	No	No
[110]	N/A	Business model	No	No	Yes	0/Yes	No	Other	No	No
[58]	N/A	Other	No	Yes, LCA, MFA, CTA, I/O analysis, LCC, CBA	Yes	3/Yes	No	Other	No	No
[78]	N/A	Company	No	No	No	3/Yes	No	Decision makers	No	No
[66]	N/A	Business model	No	No	Yes	3/Yes	No	Companies	No	No
[62]	PWF	Product	No	Yes, LCA	Yes	0/Yes	No	Other	Yes	No
[82]	N/A	Product	No	No	Yes	2/Yes	No	Designers	Yes	Yes
[85]	CE Evaluation Index System	Company	Yes	Yes, QUALIFLEX & VIKOR	Yes	1/Yes	No	Decision makers	No	No
[93]	EnvPack	Packaging	Yes	Yes, LCA	Yes	1/No	No	Various	No	No
[13]	Product-level circularity	Product	No	No	Yes	1/No	No	N/A	No	No
[95]	EVPT (Environmental Value Propositions Table) + step-by-step evaluation.	Business model	No	Yes, LCA	Yes	1/No	Yes	Companies	No	No
[51]	N/A	Business model	No	No	Yes	0/Yes	No	Various	No	No
[111]	N/A	Product	No	Yes, LFI by EMF	Yes	0/Yes	Yes	Various	No	Yes
[15]	MRS, MCI, LCA, MDCDA	Packaging	Yes	Yes, LCA, MRS and MCI	Yes	1/Yes	No	N/A	No	No

Table A1. *Cont.*

Reference	Name Approach	Scale	Sector Specific	Connection to Methods	Case Study	Number of SD Dimensions/CE Dimension Included	Provides Operational Guidance	Intended End-User	Ease of Communication	Participatory
[80]	N/A	Supply chain	Yes	Yes, Fuzzy set theory	Yes	2/Yes	No	Decision makers	Yes	Yes
[112]	Reuse potential	Material	No	No	Yes	0/Yes	No	Various	Yes	No
[86]	N/A	Packaging	Yes	Yes, LCA	No	1/Yes	No	Designers	No	No
[59]	Dashboard of quantitative system indicators	Company	No	Yes, LCA, MFA, LCC, S-LCA	No	3/Yes	Yes	N/A	No	No
[113]	N/A	Company	No	No	No	0/No	Yes	(Specific) companies	Yes	Yes
[46]	LCA and MFCA	Company	No	Yes, LCA, MFCA	Yes	2/No	Yes	Various	Yes	Yes
[67]	N/A	Company	No	No	Yes	3/Yes	No	Companies	Yes	Yes
[99]	Hybrid top-down and bottom-up framework	Product	No	No	Yes	0/No	Yes	Other	Yes	Yes
[90]	EVR & CTF	Business model	No	Yes, LCA	Yes	1/Yes	No	N/A	No	No
[87]	N/A	Packaging	Yes	Yes, LCA	Yes	1/Yes	No	Various	No	Yes
[42]	E-factor, PMI, RME, LCA	Product	Yes	Yes, LCA, E-factor	Yes	1/Yes	No	N/A	No	No
[88]	N/A	Supply chain	No	Yes, Fuzzy set theory	Yes	1/Yes	Yes	Decision makers	No	No
[64]	QC	Material	No	No	Yes	0/Yes	No	Various	No	No
[50]	RDI	Product	No	Yes, MSI, TRL	Yes	1/Yes	No	Various	No	Yes
[114]	RI	Product	No	No	Yes	0/Yes	No	Various	Yes	No
[60]	N/A	Plant/installation	Yes	Yes, LCA, NPV, IRR, questionnaire on stakeholder perception	Yes	3/No	No	Policy makers	No	Yes
[63]	eDIM	Product	No	No	Yes	0/Yes	Yes	Policy makers	Yes	No
[79]	'Expanded Zero Waste'	Various scales	No	Yes, LCA	No	3/Yes	No	N/A	No	No
[61]	Building Circularity Indicator	Other	Yes	Yes, LCA, EPD	Yes	2/Yes	No	N/A	No	Yes
[91]	N/A	Other	No	Yes, LCA	Yes	1/No	No	(Specific) Companies	No	Yes

References

1. Korhonen, J.; Honkasalo, A.; Seppälä, J. Circular Economy: The Concept and its Limitations. *Ecol. Econ.* **2018**, *143*, 37–46. [CrossRef]
2. Geissdoerfer, M.; Savaget, P.; Bocken, N.M.P.; Hultink, E.J. The Circular Economy—A new sustainability paradigm. *J. Clean. Prod.* **2017**. [CrossRef]
3. Reike, D.; Vermeulen, W.J.V.; Witjes, S. The circular economy: New or Refurbished as CE 3.0?—Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. *Resour. Conserv. Recycl.* **2018**, *135*, 246–264. [CrossRef]
4. Kirchherr, J.; Reike, D.; Hekkert, M. Conceptualizing the circular economy: An analysis of 114 definitions. *Resour. Conserv. Recycl.* **2017**, *127*, 221–232. [CrossRef]
5. Ellen MacArthur Foundation (EMF). *Circular Economy—Towards the Economic and Business Rationale for an Accelerated Transition*; Ellen MacArthur Foundation: Cowes, UK, 2013.
6. Cullen, J.M. Circular Economy: Theoretical Benchmark or Perpetual Motion Machine? *J. Ind. Eco.* **2017**, *21*, 483–486. [CrossRef]
7. Urbinati, A.; Chiaroni, D.; Chiesa, V. Towards a new taxonomy of circular economy business models. *J. Clean. Prod.* **2017**, *168*, 487–498. [CrossRef]
8. Azapagic, A.; Perdan, S. Indicators of sustainable development for industry: A general framework. *Process Saf. Environ. Prot.* **2000**, *78*, 243–261. [CrossRef]
9. Malovics, G.; Nagypal Csigene, N.; Kraus, S. The role of corporate social responsibility in strong sustainability. *J. Behav. and Exp. Econ.* **2008**, *37*, 907–918. [CrossRef]
10. Geng, Y.; Fu, J.; Sarkis, J.; Xue, B. Towards a national circular economy indicator system in China: An evaluation and critical analysis. *J. Clean. Prod.* **2012**, *23*, 216–224. [CrossRef]
11. EEA. Circular economy in Europe. Developing the knowledge base. *Eur. Environ. Agency* **2016**. [CrossRef]
12. Saidani, M.; Yannou, B.; Leroy, Y.; Cluzel, F.; Kendall, A. A taxonomy of circular economy indicators. *J. Clean. Prod.* **2019**, *207*, 542–559. [CrossRef]
13. Linder, M.; Sarasini, S.; van Loon, P. A Metric for Quantifying Product-Level Circularity. *J. Ind. Eco.* **2017**, *21*, 545–558. [CrossRef]
14. Tecchio, P.; McAlister, C.; Mathieux, F.; Ardente, F. In search of standards to support circularity in product policies: A systematic approach. *J. Clean. Prod.* **2017**, *168*, 1533–1546. [CrossRef] [PubMed]
15. Niero, M.; Kalbar, P.P. Coupling material circularity indicators and life cycle based indicators: A proposal to advance the assessment of circular economy strategies at the product level. *Resour. Conserv. Recycl.* **2019**, *140*, 305–312. [CrossRef]
16. Cristoni, N.; Tonelli, M. Perceptions of Firms Participating in a Circular Economy. *Eur. J. Sust. Dev.* **2018**, *7*, 105–118. [CrossRef]
17. Lieder, M.; Rashid, A. Towards circular economy implementation: A comprehensive review in context of manufacturing industry. *J. Clean. Prod.* **2016**. [CrossRef]
18. Winans, K.; Kendall, A.; Deng, H. The history and current applications of the circular economy concept. *Renew. Sust. En. Rev.* **2017**, *68*, 825–833. [CrossRef]
19. Blomsma, F.; Brennan, G. The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity. *J. Ind. Ecol.* **2017**, *21*, 603–614. [CrossRef]
20. Bruel, A.; Kronenberg, J.; Troussier, N.; Guillaume, B. Linking Industrial Ecology and Ecological Economics: A Theoretical and Empirical Foundation for the Circular Economy. *J. Ind. Ecol.* **2018**, *23*, 12–21. [CrossRef]
21. Millar, N.; McLaughlin, E.; Börger, T. The Circular Economy: Swings and Roundabouts? *Eco. Econ.* **2019**, *158*, 11–19. [CrossRef]
22. Sauvé, S.; Bernard, S.; Sloan, P. Environmental sciences, sustainable development and circular economy: Alternative concepts for trans-disciplinary research. *Environ. Dev.* **2016**, *17*, 48–56. [CrossRef]
23. Corona, B.; Shen, L.; Reike, D.; Carreón, J.R.; Worrell, E. Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics. *Resour. Conserv. Recycl.* **2019**, *151*, 104498. [CrossRef]
24. Kristensen, H.S.; Mosgaard, M.A. A review of micro level indicators for a circular economy—moving away from the three dimensions of sustainability. *J. Clean. Prod.* **2020**, *243*, 118531. [CrossRef]

25. Bocken, N.M.P.; De Pauw, I.; Bakker, C.; Van Der Grinten, B.; Bocken, N.M.P.; De Pauw, I.; Van Der Grinten, B. Product design and business model strategies for a circular economy. *J. Ind. Prod. Eng.* **2016**, *1015*, 1–12. [CrossRef]
26. Zielińska, A. Comparative Analysis of Circular Economy Implementation in Poland and other European Union Countries. *J. Int. Studies* **2019**, *12*, 337–347. [CrossRef]
27. Hirsch, P.M.; Levin, D.Z. Umbrella Advocates Versus Validity Police: A Life-Cycle Model. *Org. Sci.* **1999**, *10*, 199–212. [CrossRef]
28. Parchomenko, A.; Nelen, D.; Gillabel, J.; Rechberger, H. Measuring the circular economy—A Multiple Correspondence Analysis of 63 metrics. *J. Clean. Prod.* **2019**, *210*, 200–216. [CrossRef]
29. Moraga, G.; Huysveld, S.; Mathieux, F.; Blengini, G.A.; Alaerts, L.; Van Acker, K.; Dewulf, J. Circular economy indicators: What do they measure? *Resour. Conserv. Recycl.* **2019**, *146*, 452–461. [CrossRef]
30. Sassanelli, C.; Rosa, P.; Rocca, R.; Terzi, S. Circular economy performance assessment methods: A systematic literature review. *J. Clean. Prod.* **2019**, *229*, 440–453. [CrossRef]
31. Keeble, J.J.; Berkeley, S. Using indicators to measure sustainability. *J. Business Ethics* **2003**, *44*, 149–158. [CrossRef]
32. Veleva, V.; Ellenbecker, M. Indicators of sustainable production: Framework and methodology. *J. Clean. Prod.* **2001**, *9*, 519–549. [CrossRef]
33. Dopfer, K.; Foster, J.; Potts, J. Micro-meso-macro. *J. Evol. Econ.* **2004**, *14*, 263–279. [CrossRef]
34. Geng, Y.; Doberstein, B. Developing the circular economy in China: Challenges and opportunities for achieving 'leapfrog development'. *Int. J. Sust. Dev. World Ecol.* **2008**, *15*, 231–239. [CrossRef]
35. British Standardisation Institute. *Framework for Implementing the Principles of the Circular Economy in Organizations* (BSI No. 8001:2017); 2017. Available online: https://www.bsigroup.com/en-GB/standards/benefits-of-using-standards/becoming-more-sustainable-with-standards/BS8001-Circular-Economy/ (accessed on 10 April 2020).
36. AFNOR. Circular Economy Project Management System—Requirements and Guidelines (XP X30-901). 2018. Available online: https://www.boutique.afnor.org (accessed on 20 February 2020).
37. Kalmykova, Y.; Sadagopan, M.; Rosado, L. Circular economy—From review of theories and practices to development of implementation tools. *Resour. Conserv. Recyc.* **2018**, *135*, 190–201. [CrossRef]
38. Wohlin, C. Guidelines for Snowballing in Systematic Literature Studies and a Replication in Software Engineering. *Ease '14 Proc. 18th Int. Conf. Environ. Assess. Softw. Eng.* **2014**, *38*, 1–10. [CrossRef]
39. Ellen MacArthur Foundation and Granta Design. Circularity Indicators: An Approach to Measuring Circularity—product overview. *Ellen Macarthur Found.* **2015**, 1–10. [CrossRef]
40. Bell, S.; Morse, S. Breaking through the glass ceiling: Who really cares about sustainability indicators? *Local Environ.* **2001**, *6*, 291–309. [CrossRef]
41. Parmar, B.L.; Freeman, R.E.; Harrison, J.S.; Wicks, A.C.; Parmar, B.; de Colle, S. Stakeholder theory: The state of the art. *Stakehold. Theory State Art* **2010**, *4*, 1–343. [CrossRef]
42. Sheldon, R.A. Metrics of Green Chemistry and Sustainability: Past, Present, and Future. *ACS Sust. Chem. Eng.* **2018**, *6*, 32–48. [CrossRef]
43. Berzi, L.; Delogu, M.; Pierini, M.; Romoli, F. Evaluation of the end-of-life performance of a hybrid scooter with the application of recyclability and recoverability assessment methods. *Resour. Conserv. Recyc.* **2016**, *108*, 140–155. [CrossRef]
44. Gnoni, M.G.; Tornese, F.; Thorn, B.; LCarrano, A.; Pazour, J. A Measurement Tool for Circular Economy Practices: A Case Study in Pallet Supply Chains. 15th IMHRC Proceedings—Progress in Material Handling Research. 2018. Available online: https://digitalcommons.georgiasouthern.edu/pmhr_2018 (accessed on 4 December 2019).
45. Genovese, A.; Acquaye, A.A.; Figueroa, A.; Koh, S.C.L. Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. *Omega* **2017**, *66*, 344–357. [CrossRef]
46. Rieckhof, R.; Guenther, E. Integrating life cycle assessment and material flow cost accounting to account for resource productivity and economic-environmental performance. *Int. J. LCA* **2018**, *23*, 1491–1506. [CrossRef]
47. Gnoni, M.G.; Mossa, G.; Mummolo, G.; Tornese, F.; Verriello, R. Circular economy strategies for electric and electronic equipment: A fuzzy cognitive map. *Environ. Eng. Mgmt. J.* **2017**, *16*, 1807–1818.
48. Hildebrandt, J.; Bezama, A.; Thrän, D. Cascade use indicators for selected biopolymers: Are we aiming for the right solutions in the design for recycling of bio-based polymers? *Waste Mgmt. Res.* **2017**, *35*, 367–378. [CrossRef]

49. International Organization for Standardization (ISO). *Road Vehicles—Recyclability and Recoverability—Calculation Method*; (ISO No. 22628:2002); 2018; Available online: https://www.iso.org/standard/35061.html (accessed on 2 February 2020).
50. Sultan, A.A.M.; Lou, E.; Mativenga, P.T. What should be recycled: An integrated model for product recycling desirability. *J. Clean. Prod.* **2017**, *154*, 51–60. [CrossRef]
51. Matschewsky, J. Unintended circularity? Assessing a product-service system for its potential contribution to a circular economy. *Sustainability* **2019**, *11*, 2725. [CrossRef]
52. Bradley, R.; Jawahir, I.S.; Badurdeen, F.; Rouch, K. A Framework for Material Selection in Multi-Generational Components: Sustainable Value Creation for a Circular Economy. *Procedia Cirp* **2016**, *48*, 370–375. [CrossRef]
53. Cobo, S.; Dominguez-Ramos, A.; Irabien, A. Trade-Offs between Nutrient Circularity and Environmental Impacts in the Management of Organic Waste. *Environ. Sci. Technol.* **2018**, *52*, 10923–10933. [CrossRef]
54. Fregonara, E.; Giordano, R.; Ferrando, D.G.; Pattono, S. Economic-Environmental Indicators to Support Investment Decisions: A Focus on the Buildings' End-of-Life Stage. *Buildings* **2017**, *7*, 65. [CrossRef]
55. Garcia-Muiña, F.; González-Sánchez, R.; Ferrari, A.; Settembre-Blundo, D. The Paradigms of Industry 4.0 and Circular Economy as Enabling Drivers for the Competitiveness of Businesses and Territories: The Case of an Italian Ceramic Tiles Manufacturing Company. *Soc. Sci.* **2018**, *7*, 255. [CrossRef]
56. Huysveld, S.; Hubo, S.; Ragaert, K.; Dewulf, J. Advancing circular economy benefit indicators and application on open-loop recycling of mixed and contaminated plastic waste fractions. *J. Clean. Prod.* **2019**, *211*, 1–13. [CrossRef]
57. Kiselev, A.V.; Magaril, E.R.; Rada, E.C. Energy and Sustainability Assessment of Municipal Wastewater Treatment Under Circular Economy Paradigm. *Energy Sust. VIII* **2019**, *1*, 109–120. [CrossRef]
58. Koch, R.; Kuindersma, P.; van Harmelen, T.; Keijzer, E.; Kootstra, L.; Verstraeten-Jochemsen, J. IMPACT: A Tool for R&D Management of Circular Economy Innovations. *Procedia Cirp* **2018**, *69*, 769–774. [CrossRef]
59. Pauliuk, S. Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations. *Resours Conserv. Recyc.* **2018**, *129*, 81–92. [CrossRef]
60. Vaneeckhaute, C.; Styles, D.; Prade, T.; Gunnarsson, I.; Thelin, G.; D'Hertefeldt, T.; Rodhe, L. Closing nutrient loops through decentralized anaerobic digestion of organic residues in agricultural regions: A multi-dimensional sustainability assessment. *Resour. Conserv. Recyc.* **2018**, *136*, 110–117. [CrossRef]
61. Verberne, J.J.H. Building Circularity Indicators—An Approach for Measuring Circularity of a Building. 2016. Available online: https://pure.tue.nl/ws/files/46934924/846733-1.pdf (accessed on 23 November 2019).
62. Laurenti, R.; Martin, M.; Stenmarck, Å. Developing Adequate Communication of Waste Footprints of Products for a Circular Economy—A Stakeholder Consultation. *Resources* **2018**, *7*, 78. [CrossRef]
63. Vanegas, P.; Peeters, J.R.; Cattrysse, D.; Tecchio, P.; Ardente, F.; Mathieux, F.; Duflou, J.R. Ease of disassembly of products to support circular economy strategies. *Resour. Conserv. Recyc.* **2018**, *135*, 323–334. [CrossRef] [PubMed]
64. Steinmann, Z.J.N.; Huijbregts, M.A.J.; Reijnders, L. How to define the quality of materials in a circular economy. *Resour. Conserv. Recyc.* **2019**, *141*, 362–363. [CrossRef]
65. Braun, A.T.; Kleine-Moellhoff, P.; Reichenberger, V.; Seiter, S. Case study analysing potentials to improve material efficiency in manufacturing supply chains, considering circular economy aspects. *Sustainability* **2018**, *10*, 880. [CrossRef]
66. Kristensen, H.S.; Remmen, A. A framework for sustainable value propositions in product-service systems. *J. Clean. Prod.* **2019**, *223*, 25–35. [CrossRef]
67. Rossi, M.; Germani, M.; Zamagni, A. Review of ecodesign methods and tools. Barriers and strategies for an effective implementation in industrial companies. *J. Clean. Prod.* **2016**, *129*, 361–373. [CrossRef]
68. Fatimah, Y.A.; Aman, M. Remanufacturing sustainability indicators: An Indonesian small and medium enterprise case study. *IOP Conf. Ser. Mat. Sci. Eng.* **2018**, *403*. [CrossRef]
69. Jensen, J.P.; Prendeville, S.M.; Bocken NM, P.; Peck, D. Creating Sustainable Value through Remanufacturing: Three Industry Cases. *J. Clean. Prod.* **2019**, *218*, 304–314. [CrossRef]
70. Jiménez-Rivero, A.; García-Navarro, J. Indicators to Measure the Management Performance of End-of-Life Gypsum: From Deconstruction to Production of Recycled Gypsum. *Waste Biomass Valor.* **2016**, *7*, 913–927. [CrossRef]
71. Alamerew, Y.A.; Brissaud, D. Circular economy assessment tool for end of life product recovery strategies. *J. Remanufact.* **2019**, *9*, 169–185. [CrossRef]

72. Azevedo, S.; Godina, R.; Matias, J. Proposal of a Sustainable Circular Index for Manufacturing Companies. *Resources* **2017**, *6*, 63. [CrossRef]
73. Bertoni, M. Multi-criteria decision making for sustainability and value assessment in early PSS design. *Sustainability* **2019**, *11*, 1952. [CrossRef]
74. Bressanelli, G.; Perona, M.; Saccani, N. Assessing the impacts of Circular Economy: A framework and an application to the washing machine industry. *Int. J. Mgmt. Decis. Mak.* **2018**, *18*, 1. [CrossRef]
75. De Pádua Pieroni, M.; Pigosso, D.C.A.; McAloone, T.C. Sustainable Qualifying Criteria for Designing Circular Business Models. *Procedia Cirp* **2018**, *69*, 799–804. [CrossRef]
76. Garza-Reyes, J.A.; Salomé Valls, A.; Peter Nadeem, S.; Anosike, A.; Kumar, V. A circularity measurement toolkit for manufacturing SMEs. *Int. J. Prod. Res.* **2018**, *7543*. [CrossRef]
77. Kazancoglu, Y.; Kazancoglu, I.; Sagnak, M. A new holistic conceptual framework for green supply chain management performance assessment based on circular economy. *J. Clean. Prod.* **2018**, *195*, 1282–1299. [CrossRef]
78. Kravchenko, M.; McAloone, T.C.; Pigosso, D.C.A. Implications of developing a tool for sustainability screening of circular economy initiatives. *Procedia Cirp* **2019**, *80*, 625–630. [CrossRef]
79. Veleva, V.; Bodkin, G.; Todorova, S. The need for better measurement and employee engagement to advance a circular economy: Lessons from Biogen's "zero waste" journey. *J. Clean. Prod.* **2017**, *154*, 517–529. [CrossRef]
80. Olugu, E.U.; Wong, K.Y. An expert fuzzy rule-based system for closed-loop supply chain performance assessment in the automotive industry. *Expert Syst. Appl.* **2012**, *39*, 375–384. [CrossRef]
81. Favi, C.; Germani, M.; Luzi, A.; Mandolini, M.; Marconi, M. A design for EoL approach and metrics to favour closed-loop scenarios for products. *Int. J. Sust. Eng.* **2017**, *10*, 136–146. [CrossRef]
82. Lee, H.M.; Lu, W.F.; Song, B. A framework for assessing product End-Of-Life performance: Reviewing the state of the art and proposing an innovative approach using an End-of-Life Index. *J. Clean. Prod.* **2014**, *66*, 355–371. [CrossRef]
83. Fan, W.; Zhang, P.; Xu, Z.; Wei, H.; Lu, N.; Wang, X.; Weng, B.; Chen, Z.; Wu, F.; Dong, X. Life cycle environmental impact assessment of circular agriculture: A case study in Fuqing, China. *Sustainability* **2018**, *10*, 1810. [CrossRef]
84. Cordella, M.; Sanfelix, J.; Alfieri, F. Development of an Approach for Assessing the Reparability and Upgradability of Energy-related Products. *Procedia Cirp* **2018**, *69*, 888–892. [CrossRef]
85. Liang, W.; Zhao, G.; Hong, C. Performance assessment of circular economy for phosphorus chemical firms based on VIKOR-QUALIFLEX method. *J. Clean. Prod.* **2018**, *196*, 1365–1378. [CrossRef]
86. Pauer, E.; Wohner, B.; Heinrich, V.; Tacker, M. Assessing the environmental sustainability of food packaging: An extended life cycle assessment including packaging-related food losses and waste and circularity assessment. *Sustainability* **2019**, *11*, 925. [CrossRef]
87. Schmidt Rivera, X.C.; Leadley, C.; Potter, L.; Azapagic, A. Aiding the design of innovative and sustainable food packaging: Integrating techno-environmental and circular economy criteria. *Energy Procedia* **2019**, *161*, 190–197. [CrossRef]
88. Shen, L.; Olfat, L.; Govindan, K.; Khodaverdi, R.; Diabat, A. A fuzzy multi criteria approach for evaluating green supplier's performance in green supply chain with linguistic preferences. *Resour. Conserv. Recycl.* **2013**, *74*, 170–179. [CrossRef]
89. Ardente, F.; Mathieux, F. Identification and assessment of product's measures to improve resource efficiency: The case-study of an Energy using Product. *J. Clean. Prod.* **2014**, *83*, 126–141. [CrossRef]
90. Scheepens, A.E.; Vogtländer, J.G.; Brezet, J.C. Two life cycle assessment (LCA) based methods to analyse and design complex (regional) circular economy systems. Case: Making water tourism more sustainable. *J. Clean. Prod.* **2016**, *114*, 257–268. [CrossRef]
91. Walker, S.; Coleman, N.; Hodgson, P.; Collins, N.; Brimacombe, L. Evaluating the environmental dimension of material efficiency strategies relating to the circular economy. *Sustainability* **2018**, *10*, 666. [CrossRef]
92. Elia, V.; Gnoni, M.G.; Tornese, F. Measuring circular economy strategies through index methods: A critical analysis. *J. Clean. Prod.* **2017**, *142*, 2741–2751. [CrossRef]
93. Ligthart, T.N.; Thoden van Velzen, E.U.; Brouwer, M. EnvPack an LCA-based tool for environmental assessment of packaging chains. Part 1: Scope, methods and inventory of tool. *Int. J. LCA* **2018**, *24*, 900–914. [CrossRef]
94. Barletta, I.; Despeisse, M.; Johansson, B. The Proposal of an Environmental Break-Even Point as Assessment Method of Product-Service Systems for Circular Economy. *Procedia Cirp* **2018**, *72*, 720–725. [CrossRef]

95. Manninen, K.; Koskela, S.; Antikainen, R.; Bocken, N.; Dahlbo, H.; Aminoff, A. Do circular economy business models capture intended environmental value propositions. *J. Clean. Prod.* **2018**, *171*, 413–422. [CrossRef]
96. Di Maio, F.; Rem, P.C. A Robust Indicator for Promoting Circular Economy through Recycling. *J. Environ. Prot.* **2015**, *6*, 1095–1104. [CrossRef]
97. Di Maio, F.; Rem, P.C.; Baldé, K.; Polder, M. Measuring resource efficiency and circular economy: A market value approach. *Resour. Conserv. Recyc.* **2017**, *122*, 163–171. [CrossRef]
98. Cayzer, S.; Griffiths, P.; Beghetto, V. Design of indicators for measuring product performance in the circular economy. *Int. J. Sust. Eng.* **2017**, *10*, 289–298. [CrossRef]
99. Saidani, M.; Yannou, B.; Leroy, Y.; Cluzel, F. How to Assess Product Performance in the Circular Economy? Proposed Requirements for the Design of a Circularity Measurement Framework. *Recycling* **2017**, *2*, 6. [CrossRef]
100. Flipsen, B.; Bakker, C.; Van Bohemen, G. Developing a reparability indicator for electronic products. *2016 Electronics Goes Green 2016+ EGG 2016* **2017**, 1–9. [CrossRef]
101. Akrivos, V.; Haines-Gadd, M.; Mativenga, P.; Charnley, F. Improved metrics for assessment of immortal materials and products. *Procedia CIRP* **2019**, *80*, 596–601. [CrossRef]
102. Angioletti, C.M.; Despeisse, M.; Roca, R. Product Circularity Assessment Methodology. *IFIP Adv. Inf. Com. Technol.* **2017**. [CrossRef]
103. Ceptureanu, S.I.; Ceptureanu, E.G.; Murswieck, R.G.D. Perceptions of circular business models in SMEs. *Amfiteatru Econ.* **2018**, *20*, 310–324. [CrossRef]
104. Czikkely, M.; Olah, J.; Lakner, Z.; Fogarassy, C.; Popp, J. Waste water treatment with adsorptions by mushroom compost The circular economic valuation concept for material cycles. *Int. J. Eng. Bus. Mgmt.* **2018**, *10*, 1–12. [CrossRef]
105. Figge, F.; Stevenson Thorpe, A.; Givry, P.; Canning, L.; Franklin-Johnson, E. Longevity and Circularity as Indicators of Eco-Efficient Resource Use in the Circular Economy. *Eco. Econ.* **2018**, *150*, 297–306. [CrossRef]
106. Fogarassy, C.; Horvath, B.; Kovacs, A.; Szoke, L.; Takacs-Gyorgy, K. A circular evaluation tool for sustainable event management—An olympic case study. *Acta Polytech. Hung.* **2017**, *14*, 161–177. [CrossRef]
107. Franco, M.A. A system dynamics approach to product design and business model strategies for the circular economy. *J. Clean. Prod.* **2019**, *241*, 118327. [CrossRef]
108. Franklin-Johnson, E.; Figge, F.; Canning, L. Resource duration as a managerial indicator for Circular Economy performance. *J. Clean. Prod.* **2016**, *133*, 589–598. [CrossRef]
109. Howard, M.; Hopkinson, P.; Miemczyk, J. The regenerative supply chain: A framework for developing circular economy indicators. *Int. J. Prod. Res.* **2018**, *0*, 1–19. [CrossRef]
110. Kjaer, L.L.; Pigosso DC, A.; Niero, M.; Bech, N.M.; McAloone, T.C. Product/Service-Systems for a Circular Economy: The Route to Decoupling Economic Growth from Resource Consumption. *J. Ind. Eco.* **2019**, *23*, 22–35. [CrossRef]
111. Mesa, J.; Esparragoza, I.; Maury, H. Developing a set of sustainability indicators for product families based on the circular economy model. *J. Clean. Prod.* **2018**, *196*, 1429–1442. [CrossRef]
112. Park, J.Y.; Chertow, M.R. Establishing and testing the "reuse potential" indicator for managing wastes as resources. *J. Environ. Mgmt.* **2014**, *137*, 45–53. [CrossRef]
113. Prieto-Sandoval, V.; Ormazabal, M.; Jaca, C.; Viles, E. Key elements in assessing circular economy implementation in small and medium-sized enterprises. *Bus. Strat. Environ.* **2018**, *27*, 1525–1534. [CrossRef]
114. Van Schaik, A.; Reuter, M.A. Recycling Indices Visualizing the Performance of the Circular Economy. *World Metall. Erzmetall* **2016**, *69*, 4.
115. Clement, S.; Tepper, P.; Acker, H.; Seebach, D.; Adell, A. Driving energy efficient innovation through procurement: A practical guide for public authorities. *Smart SPP* **2011**. Available online: https://smart-spp.eu/ (accessed on 23 May 2020).
116. Johnson, M.P.; Schaltegger, S. Two Decades of Sustainability Management Tools for SMEs: How Far Have We Come. *J. Small Bus. Mgmt.* **2016**, *54*, 481–505. [CrossRef]