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Research paper

A Typology for Circular Economy Data

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Abstract

The circular economy (CE) is a key pillar of sustainability policies, notably the European Green Deal, requiring extensive data across the value chain. However, the lack of a clear definition of CE data creates ambiguity in its understanding and application. This study addresses this gap by investigating the fundamental research questions: What are the dimensions that define CE data? and How is CE data currently being utilized according to these dimensions? To answer these questions, this research proposes a novel typology for CE data, examining its various dimensions and subdimensions across different levels, from product-specific to macroeconomic scales. Through a literature review and an analysis of 26 CE performance measurement frameworks, 334 distinct CE data points were identified and collected, serving as the foundation for defining eight CE data dimensions within the proposed typology. This approach has provided a clear definition of what constitutes CE data, contributing positively to business applications, particularly in performance measurement. Additionally, it streamlines data collection and analysis, offering a structured approach to prioritizing and interpreting CE data for effective implementation.

Keywords: Circular Economy · Circular Economy Data · Typology · Circular Economy Metrics · Circular Economy Indicators · Circular Economy Assessment

1. INTRODUCTION AND BACKGROUND

The vision of a Circular Economy (CE), which emerged in the 1970s, has attracted significant interest from business and government. The goal of CE is to achieve sustainable development by decoupling resource use and environmental impact from economic prosperity and well-being. By extending the use and longevity of products and components, and by keeping materials circulating within industrial systems rather than discarding them after initial use, materials can be used repeatedly and more intensively, thereby contributing to higher value added per unit. Consequently, the need for newly extracted natural resources is reduced, and less waste material is released into the natural environment (Kirchherr et al., 2017; United Nations Economic Commission for Europe, 2023). Furthermore, given that approximately 55% of greenhouse gas emissions are attributable to the area of materials and production sector, CE plays a pivotal role in climate protection (United Nations Environment Programme, 2024). On top, studies have demonstrated that CE possesses the potential to generate significant business and employment opportunities (see, for example, Circle Economy; International Labour Organization; Solutions for Youth Employment (S4YE), 2023; European Parliament, 2023; Lacy & Rutqvist, 2015).

The concept of CE has evolved into a critical component of numerous sustainability-oriented policies. This is particularly evident in the ongoing initiatives of the European Union (EU) under the European Green Deal

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and the so-called twin transition, i.e., digital and green transition. Initiatives such as the Circular Economy Action Plan (CEAP), the Ecodesign for Sustainable Products Regulation (ESPR), the Battery Regulation and numerous others underscore the pivotal role of CE in contemporary industrial policy and related measures (European Commission, 2020). At the national level, governments are committed to implementing CE, from countries like China to transnational initiatives led by the EU (Velenturf & Purnell, 2021). Additionally, many industries are increasingly engaging in these efforts (Acerbi & Taisch, 2020). A significant development in the realm of industrial measures is the introduction of the Digital Product Passport, which aims to facilitate CE under various regulations, including the ESPR in the EU.

CE is a systemic approach that requires a holistic view of products lifecycles and material systems. The implementation of CE throughout the value chain is supported by three fundamental strategies: narrowing, slowing and closing, which are further differentiated into "R-strategies" such as the well-known 9-R framework by Potting et al. (2017). Figure 1 illustrates the various CE strategies, and the actors involved in the value chain, from producers to consumers, including the recycling stage. The implementation of CE strategies enables the optimization of each stage of the value chain. For instance, in the production phase, the emphasis is placed on enhancing resource efficiency and designing products that align with CE principles. Conversely, in the use or consumption phase, the focus shifts towards promoting product reuse, sharing, and facilitating spare parts provision. In essence, these strategies involve technical, managerial and societal solutions.

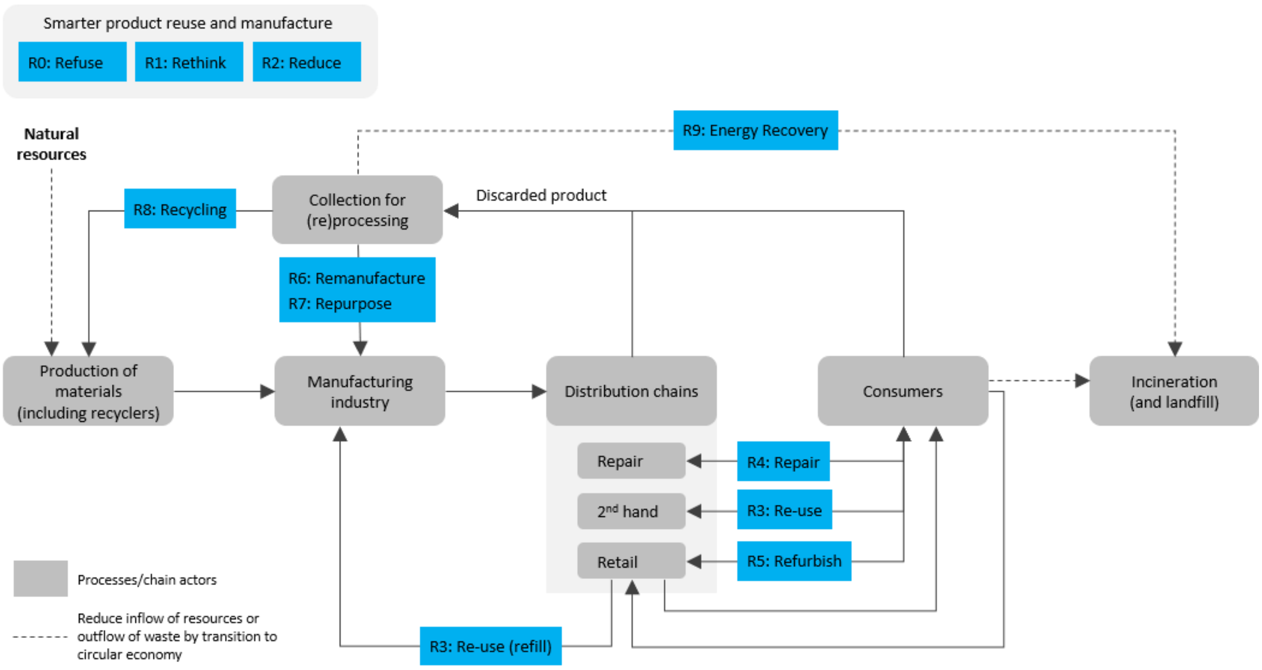

Figure 1. Circular Economy Strategies and the Role of Actors Within the Product Chain (adapted from Potting et al., 2017)

However, CE and its development must be understood and monitored. Therefore, multiple facets of CE development require consideration of multiple lifecycle-related indicators and appropriate tools for aggregation (Ūsas et al., 2021). The scope of CE metrics extends beyond mere physical and material aspects, incorporating additional dimensions such as policies, regulations, customer contributions, and technological advancements (Ahmed et al., 2022; Luoma et al., 2021). For instance, indicators have been developed for the specific purpose of assessing and monitoring the evolution and implementation of circular business models (Rossi et al., 2020). In another context, indicators are focused on the implementation, monitoring, and control of symbiotic resource networks in multi-tier supply chains (World Bank, 2021). In further cases, multiple indicators exist within the scope of ecodesign for CE (EMF, 2019). Saidani et al. (2019) provide a systematic overview of this broad range of CE indicators.

As a consequence, the extensive diversity of indicators for CE requires the generation of a substantial amount of data as inputs for their calculation, referred to as CE data. Matos et al. (2023) acknowledge a significant demand for CE data due to the wide range of CE performance metrics, represented in diverse scopes, goals, and characteristics. In this context, "data means a physical collection of qualitative or quantitative values about certain properties of objects or individuals that can be altered, processed, communicated, or interpreted by automatic means or humans" (Organisation for Economic Co-operation and Development, 2008). In essence, data represent the raw facts and figures collected to measure performance indicators (Neely et al., 2000).

Despite the pivotal role of CE data in facilitating the transition to CE, a prevailing challenge is the absence of a universally accepted definition in literature, giving rise to a diffuse understanding of the subject. As emphasized by Piétron et al. (2023) and Ducuing & Reich (2023), the absence of further investigation into CE data is a current challenge to the transition towards CE. Similarly, Berg & Wilts (2019) affirm that CE's implementation is primarily a problem of data and argue that current deficits have hindered its widespread adoption.

Ultimately, the absence of a comprehensive definition of CE data hinders its progress by creating challenges, such as, information gaps that obstruct the assessment of high-level circularity strategies, insufficient data on secondary materials and used products that increase costs, the absence of temporal information essential for tracking transition dynamics, and the lack of a standardized methodology for consistently measuring circularity. This issue is particularly critical for assessing value preservation and the dynamic interactions of products and systems (Baratsas et al., 2022; Franco et al., 2021; Piétron et al., 2023).

The increasing importance of CE across diverse sectors underscore the need for a deeper understanding of CE data, to better understand how it is currently used and how it can be potentially applied to better support circular practices, business models, and governmental policies. Specifically, the following research questions are further investigated: "What are the dimensions that define CE data?"; "How is CE data currently being utilized according to these dimensions?". Hence, this paper aims to propose a typology for CE data and examine its various dimensions and subdimensions across all levels, from the nano scale (product) to the macro scale (economies).. While previous research has primarily focused on developing taxonomies for circularity indicators (Fraccascia & Giannoccaro, 2020; Saidani et al., 2019), the present paper introduces a novel typology centered on CE data.

2. METHODS

This research is conceptual in nature, as it elaborates on and proposes new relationships among well-known constructs (Gilson & Goldberg, 2015). More specifically, it develops a typology, which represents a particular type of non-empirical or conceptual research (Jaakkola, 2020). The typology categorizes CE data by identifying and reconciling critical dimensions of CE from previous research. Figure 2 summarizes the methods applied successively to derive the CE data typology.

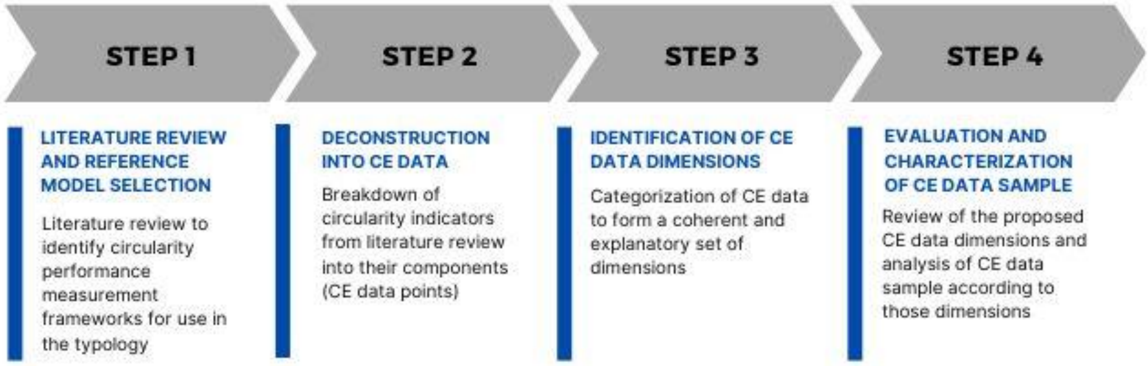

Figure 2. Methodological Steps for Developing CE Data Typology

In a first step, a literature review was conducted to identify relevant frameworks for CE metrics to be used in the typology of CE data. The reference models help answer the question of what constitutes CE data and its components. The objective was not to conduct an exhaustive research of all existing frameworks but rather to identify relevant references, particularly those with a high number of citations or applications in the field. Searches were conducted in English or German academic article repositories, specifically Web of Science and Google Scholar, as well as open internet searches using the Google search engine aimed at obtaining grey literature. The search terms used in the academic research were "measurement," "indicators," and "circular economy." Additionally, articles connected to the product and company levels were incorporated from the literature review conducted by Kuhn et al. (2025), which combines insights from academic and industry specialists to generate a CE performance evaluation framework. In total, from an initial selection of 85 articles, the set was narrowed down to 15 key academic frameworks, which did not overlap and were therefore considered complementary. To perform this task, the authors reviewed the proposed model in each of the articles.

In addition to scientific articles, the search also targeted open-source reference models that encompass circularity indicators in gray literature. The consulted sources needed to demonstrate representativeness and relevance across various groups, including government and businesses. Consequently, reference frameworks from organizations closely collaborating with diverse stakeholders, such as ISO, World Bank, and Ellen MacArthur Foundation, were selected. The selection of non-academic reference models was based on interactions with experts in the field, as well as the authors' knowledge and open research conducted through search engines. As a result, 11 non-academic reference frameworks were selected based on the following key criteria:

- coverage of a large array of CE applications from nano to macro level following Saidani et al. (2017), who distinguishes nano (product), micro (company), meso (industrial parks etc.) and macro (large regions, countries) levels to cover the whole field of CE;
- wide distribution and citation of the frameworks in both academic and non-academic contexts;
- transparency of the frameworks, i.e., existence of descriptions of structure and metrics.

Moving on to step 2, a deconstruction analysis was applied to all 26 CE frameworks identified. All CE metrics and indicators found in the framework were listed and then broken down into their constituent components, i.e., the single CE data points. This resulted in a sample of 334 different CE data points, which meets the requirement mentioned by Stapley et al. (2022) of working with samples with a medium to large size for typology studies. The deconstruction analysis was conducted in a spreadsheet, detailing all types of data points that constitute each CE indicator or metric per reference framework. The CE data information collected includes the reference framework name, indicator name, data name, data description, and data measurement unit. The multi-level structure of the resulting CE data sample is illustrated in Figure 3. Ultimately, CE data serve as the fundamental elements for measuring performance indicators, representing the raw data that are processed to calculate these indicators. The datapoints for four examples of indicators ranging from nano to macro levels are available in Table 2.

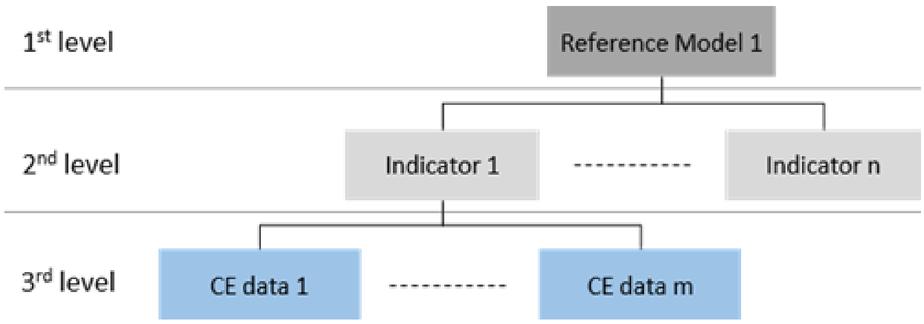

Figure 3. Multi-level Structure of CE Data Sample

The third step of this research focused on exploring the similarities and differences between CE data points within the sample. The aim was to establish a categorization of CE data that forms a coherent and explanatory set of dimensions, characteristic of typological studies The classification process followed three fundamental stages: first, a qualitative analysis of the datapoints obtained from the deconstruction of the indicators; second, a consultation of bibliographic references in CE for specific topics pre-identified by the authors as potential classifications; and third, the proposition of dimensions by the authors based on literature and their expertise. To visualize all datapoints and their respective classifications, it is recommended to consult the supplementary material.

Following Stapley et al. (2022), it involves the systematic comparison of cases or participants to form "ideal types", or groupings of similar cases. Thus, a key activity at this stage involves assigning names and developing detailed descriptions for each formulated dimension of CE data and matching the dimension with observations and classifications from the field of CE research. Emphasis is placed on common or outstanding characteristics, while trivial or incidental ones are excluded. The identification of CE dimensions inevitably leads to a certain level of abstraction, which can be minimized through the application of good classification criteria. These criteria, which are essential for typologies, include (1) exhaustiveness, i.e., encompassing all relevant characteristics within a single classification; and (2) mutual exclusiveness, i.e., no overlap between classifications (Mouton & Marais, 1988). As a purely conceptual and overview paper, the categorization process to define the CE typology was performed without using statistical tools. The process of categorization and definition of the dimensions was also validated through consultation with experts in circular economy (see section 6).

The last step in conceptualizing a CE data typology involved analyzing CE data within the defined dimensions. The objective was to assess the precision of these dimensions rather than to ascertain the "correctness" of the typology, ensuring that interpretations adequately reflect the data. According to Stapley et al. (2022), the write-up of the typology study should include a summary of both the similarities and differences between the cases within each dimension type. It should also include a summary of the differences (and similarities) between the dimension types themselves. To facilitate this analysis, Excel and Power BI software were used for data analysis and visualization, respectively.

3. RESULTS

1.1 Selected CE Reference Frameworks

The selection of different frameworks for measuring circularity is essential to ensuring the inclusion of a sufficiently diverse range of CE data types, which will later be used in the development of the typology. Given the complexity of circularity, a single metric or methodology is often insufficient to capture its various dimensions. Frameworks such as the Material Circularity Indicator (MCI) by EMF (2019) and the Circular Transition Indicators (CTI) by WBCSD (2021) provide industry-focused methodologies for assessing circular performance at the product and company levels. Meanwhile, broader institutional guidelines, such as the United Nations Economic Commission for Europe (UNECE, 2023) *Guidelines for Measuring Circular Economy*, focus on measuring performance at the country or regional level. The literature review process for selecting reference frameworks for measuring circularity yielded a total of 26 references (see Table 1).

Table 1. List of Selected CE Reference Frameworks

No.	Author	Title
1	United Nations Economic Commission for Europe (2023)	Guidelines for Measuring Circular Economy
2	Ozge Zilmay et al. (2016)	Industrial Symbiosis Indicators
3	World Bank (2021)	International Framework for Eco-Industrial Parks
4	EMF (2019)	Material Circularity Indicator (MCI)
5	ISO 59020 (2024)	Circular economy — Measuring and assessing circularity performance
6	Potting et al. (2018)	Circular economy: what we want to know and can measure
7	EFRAG (IVZW/AISBL) (2024)	List of ESRS Data Points - [Microsoft Excel spreadsheet]
8	Hatzfeld et al. (2022)	Modeling circularity as Functionality Over Use-Time to reflect on circularity indicator challenges and identify new indicators for the circular economy
9	VDI (2011)	VDI 2243: Recycliergerechtes Produktdesign (Recycling-oriented product development) (Revised edition)
10	Xing & Belusko (2008)	Design for upgradability algorithm: Configuring durable products for competitive reutilization
11	Patterson (1996)	What is energy efficiency? Concepts, indicators and methodological issues
12	Lokesh et al. (2020)	Hybridised sustainability metrics for use in life cycle assessment of bio-based products: Resource efficiency and circularity
13	Huysman et al. (2015)	Toward a systematized framework for resource efficiency indicators
14	Ritthoff et al. (2002)	MIPS berechnen: Ressourcenproduktivität von Produkten und Dienstleistungen
15	DIN e.V. (2020a)	Allgemeines Verfahren zur Bewertung des Anteils an recyceltem Material von energieverbrauchsrelevanten Produkten (General method for assessing the proportion of recycled material content in energy-related products)

16	DIN e.V. (2019b)	Allgemeines Verfahren zur Bewertung des Anteils an wiederverwendeten Komponenten in energieverbrauchsrelevanten Produkten
17	Huysman et al. (2017)	Performance indicators for a circular economy: A case study on post-industrial plastic waste
18	Mohamed Sultan et al. (2017)	What should be recycled: An integrated model for product recycling desirability
19	DIN e.V. (2019a)	Allgemeines Verfahren zur Bewertung der Recyclingfähigkeit und Verwertbarkeit energieverbrauchsrelevanter Produkte (General methods for assessing the recyclability and recoverability of energy-related products)
20	WBCSD (2021)	Circular Transition Indicators v2.0 – Metrics for business, by business
21	Cerdan et al. (2009)	Proposal for new quantitative eco-design indicators: a first case study
22	Das et al. (2000)	An approach for estimating the end-of-life product disassembly effort and cost
23	DIN e.V. (2020b)	Allgemeine Verfahren zur Bewertung der Reparier-, Wiederverwend- und Upgradebarkeit energieverbrauchsrelevanter Produkte (General methods for the assessment of the ability to repair, reuse and upgrade energy-related products)
24	Giudice & Kassem (2009)	End-of-life impact reduction through analysis and redistribution of disassembly depth: A case study in electronic device redesign
25	Ardente & Mathieux (2014)	Identification and assessment of product's measures to improve resource efficiency: The case-study of an Energy using Product
26	Lee et al. (2014)	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

The authors and sources listed include organizations engaged in CE and sustainability themes, such as UNECE (United Nations Economic Commission for Europe), technical standards and guidelines (e.g., Deutsches Institut für Normung e.V.), and scientific journals addressing circularity performance measurement (e.g., *Journal of Cleaner Production*). The reference frameworks comprise a total of 194 unique circularity indicators, covering all levels of CE, from indicators focused on individual products to those pertaining to larger production systems, such as eco-industrial parks, and even regions and countries. A significant advantage of this list of indicators is its comprehensive coverage of various aspects of circularity, addressing a broad range of subjects and activities relevant to advancing the CE agenda. Activities such as remanufacturing and disassembly, among others, are included, providing the necessary scope to incorporate strategies with a broader impact on the transition to circular production models.

3.2 Deconstruction Into CE Data

Table 2 provides four examples of CE indicators and their deconstruction into nine data points. These examples illustrate the structure of the full sample, which is provided as supplementing material. While certain indicators require multiple types of CE data for their calculation, such as the macro indicator CMUR (circular material use rate), others are less intricate, such as the micro indicator "number of circular courses".

Table 2. Examples of Core Indicators From CE Frameworks and Their Respective Data Points, Units, and Sources

Core indicators	CE data point	CE data unit	Source
Macro level: Circular Material Use Rate (CMU)	Share of used secondary materials in total used primary and secondary materials (Components)	Percent	Eurostat (2018)
	Secondary materials used	Metric tons	
	Economy-wide material flows indicators (composed of: a) domestic extraction, b) imports, c) exports - b and c each with or without footprints)	Metric tons	
Meso level: Environmental impact momentum	Total weight of by-product used in the eco-industrial park	Metric tons	Ozge Zilmay et al. (2016)
	Total weight of by-product not used in the eco-industrial park	Metric tons	
Micro level: Investment in research (in Euros)	Total expenditure on CE research	Euros	Potting et al. (2017)
	Number of circular courses	count	
Nano level: Average lifetime of product or material relative to industry average	Lifetime of outflow (X)	Years	ISO 59020 (2024)
	Industry average lifetime of outflow (X)	Years	

In total, 334 distinct types of CE data were identified, distributed across various subtopics. These include common issues related to material flow monitoring, such as waste generation, as well as other relevant subtopics like impact monitoring (e.g., impacts on water and soil quality) and education and training. This diversity of subtopics is also evidenced by the large number of measurement units associated with CE data, as depicted in Figure 4. In this context, the list of measurement units reflects the units of the raw data obtained from the CE data deconstruction (see supplementary material).

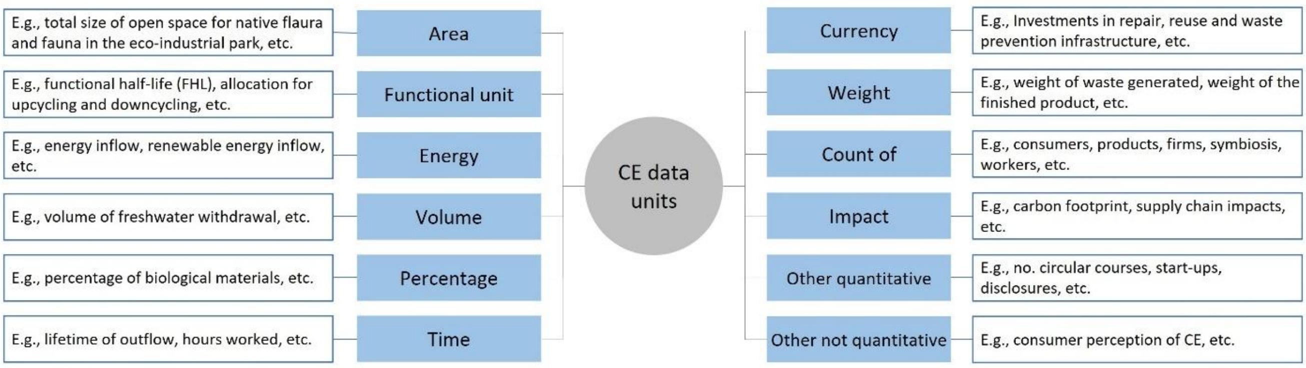

Figure 4. CE Data Unit Types

In the realm of CE data, mass measurements represent the majority of the sample, accounting for 32%. Surprisingly, other quantitative measures not related to flows or stock measures, such as product engineering metrics (e.g., ease of disassembly), account for 14% of the cases. Following this, economic and financial data prominently appear, comprising 8% of the data, including metrics such as disposal costs or the GDP of waste and recycling sectors. Other relevant types of data in the sequence include time units (7%), volume measurements (4%), qualitative data (4%), and energy-related data (4%). Count data on various aspects, such as the number of companies in eco-industrial parks or the number of workers, to cite a few examples, have a significant share when considered collectively (20%).

3.3 CE Data Dimensions

The preceding stages ultimately enable the definition of the key characteristics of CE data, referred to here as CE data dimensions. This stage addresses the main objective of the paper and aims to answer the question: *What are the dimensions that define CE data?* As asserted in the methodology section, the possible dimensions for distinguishing and grouping Table 3. different types of CE data were derived from CE literature and based on the authors' assessments and observations. Table 3 summarizes the resulting dimensions, their values, and supporting literature.

Table 3. CE Data Dimensions

Dimension	Dimension values (subdimensions)	Supporting references
(1) CE levels	(a) nano; (b) micro; (c) meso; (d) macro	Kirchherr et al., 2017; Sassanelli et al., 2019
(2) Stakeholder groups	(a) federal government; (b) state/city government; (c) communities/civil society/ngo; (d) media; (e) companies; (f) consumers; (g) workers	Chiappetta Jabbour et al., 2020; Eisenreich et al., 2022
(3) Specific value chain stages	(a) design; (b) take; (c) make; (d) distribute; (e) use; (f) end-of-life; (g) not applicable; (h) all life cycle stages	European Commission, 2022; Prieto-Sandoval et al., 2018
(4) CE strategies	(a) intensification of product use (refuse, reduce, reuse) / narrow and slow down; (b) dematerialization (rethink) / narrow; (c) extension of product use (repair, refurbish, and remanufacture) / slow down; (d) product circulation (recycle, recovery) / close; (e) no specific CE strategy; (f) all CE strategies	Bocken et al., 2016; Potting et al., 2017
(5) Technical or biological cycle	(a) technical cycle; (b) biological cycle; (c) technical & biological cycle	Ellen MacArthur Foundation, 2013; Navare et al., 2021
(6) Technological and/or socio institutional focus	(a) technological; (b) socio-institutional; (c) technological & socio-institutional	Vercalsteren et al., 2018
(7) Quantitative and qualitative data	(a) quantitative; (b) qualitative	OECD, 2008
(8) CE transition process status	(a) transition; (b) effect	Potting et al., 2018

For the first dimension, namely the CE levels, Kirchherr et al. (2017) identify the micro level (products, companies, consumers), meso level (eco-industrial parks), and macro level (city, region, nation, and beyond) as central to understanding the scope of CE. Sassanelli et al. (2019) later introduced the nano level to be likewise fundamental for evaluating performance in CE. The second dimension recognizes the central role of stakeholders in the transition to CE, as stakeholders tend to exert pressure on firms' objectives regarding sustainability and CE initiatives. Chiappetta Jabbour et al. (2020) suggested that clients, governments, shareholders, employees, non-governmental organizations, and the media all tend to exert pressure on firms' objectives regarding sustainability initiatives, which include CE.

The third dimension involves the value chain and its various segments: design, take, make, distribute, use, and end-of-life. This perspective is supported by Prieto-Sandoval et al. (2018), who propose that CE can be understood through five main fields of action: take, make, distribute, use and recover. Ultimately, the design stage was also included as a key step in the value chain due to its significant impact on the product circularity, recognized by the European Green Deal's emphasis on product design (European Commission, 2022). Next, the fourth dimension introduces the 9-R framework by Potting et al. (2018), or circularity strategies, as another key aspect to differentiate among the different types of CE data. Here, the different circularity strategies are prioritized based on their final impact, and CE data play a crucial role in setting goals and monitoring progress.

Another dimension assigned includes the type of resource loop, i.e., whether it involves biological nutrients (i.e., the resource base for any type of biological system) or technological nutrients (i.e., the resource base for any type of technical systems). Biological nutrients are intended to safely re-enter the biosphere, contributing to natural capital, while technical nutrients circulate at a high quality without entering the biosphere (Ellen MacArthur Foundation, 2013). Mestre & Cooper (2017) have affirmed that both biological and technical approaches are crucial in offering practical strategies for designers, product developers, policymakers, and business managers involved in CE.

The next dimension focuses on management aspects, specifically whether it is technology-centered and/or socio-institutional centered. Technology-related data typically measures "hard" parameters expressed in volumes (e.g., kg) or environmental impacts, while socio-institutional data refers to governance and infrastructure aspects (e.g., systems for sharing, repairing, or reusing products). Vercalsteren et al. (2018) state that both physical parameters and socio-institutional aspects are relevant for properly monitoring CE progress.

Proceeding, the seventh dimension presents the differentiation between quantitative and qualitative data within the context of CE. As defined by the OECD (2008), qualitative data describes the attributes or properties that an object possesses, while quantitative data expresses a certain quantity, amount, or range, typically using units associated with the data, such as meters. The final dimension, known as the CE transition process status, aims to distinguish between the data related to the transition process and the outcomes achieved. Potting et al. (2018) argue that evaluating progress in the transition to a CE is essential, as it enables governmental bodies and their partners to confirm that the transition is advancing as planned and to make necessary adjustments to maintain the intended trajectory.

3.4 Evaluating and Characterizing CE Data

The purpose of this final section is twofold: first, it aims to validate the proposed typology and its dimensions, as recommended in similar studies; second, it seeks to address one of the research questions: *How is CE data currently being utilized according to these dimensions?* Figure 5 presents the analysis of CE data and dimensions using a bubble chart visualization, with a complete result table is included in the supplementary material.

The first dimension (D1) on CE levels was also applied to all other dimensions as an analysis criterion. For instance, in D3 (life cycle stages), 2% of all examined CE data at the nano level relate to all life cycle stages, while 76 % relate to end-of-life. In contrast, at the macro level 37% relate to all stages, and only 24% to end-of-life. The total for each dimension at each level always adds up to 100%. If no bubble is visible, the share equals 0%. For dimension two (D2) and four (D4), it was possible to differentiate between various stakeholders and CE strategies. Hence, one CE data example could be allocated to up to two stakeholders and CE strategies, even though it might address more than two. For the remaining dimensions, a single option was allocated. Furthermore, it is important to note is that for dimension five (D5) and six (D6), there is the option to select technical and/or biological cycles, as well as technological and/or socio-institutional data, either individually or in combination. Especially for D5, the majority of CE data refers to both the technical and biological cycles, while for D6, the share of CE data related to both options is not significant.

D1: CE levels	macro	meso	micro	nano	average
data set share	29%	13%	24%	34%	
D2: stakeholder groups					
federal government	60%		20%	44%	37%
communities/civil society/NGO	9%	12%	1%		5%
media	1%				
workers	2%	20%			3%
companies	19%	68%	76%	52%	50%
consumers	9%		3%	4%	4%
D3: value chain stages					
all life cycle stages	37%	7%	13%	2%	15%
end of life	24%	29%	54%	76%	49%
use	4%		3%	9%	5%
distribute			1%		
make	7%	56%	15%	13%	17%
design			5%		1%
take	25%	9%	10%	1%	11%
not applicable	3%				1%
D4: CE strategies					
all CE strategies	34%	11%	16%	9%	18%
dematerialization	1%	4%			1%
extension of product use	4%		5%	28%	12%
intensification of product use	2%		5%	11%	5%
product circulation	20%	40%	28%	41%	32%
no specific CE strategy	38%	45%	46%	11%	32%
D5: technical | biological					
biological cycle	5%	22%	10%	4%	8%
technical cycle	3%				1%
technical & biological cycle	92%	78%	90%	96%	91%
D6: technolgical|socio-institutional					
technological	54%	31%	73%	97%	70%
socio-institutional	46%	69%	28%		29%
technological & socio-institutional				3%	1%
D7: quantitative and qualitative					
quantitative	97%	100%	73%	100%	93%
qualitative	3%		28%		7%
D8: CE transition process status					
effect	62%	51%	38%	92%	65%
transition	38%	49%	63%	8%	35%

Figure 5. Shares of CE Dimensions Values (D2 -D8) Differentiated for Each CE Level (D1)

The results for D2 suggest that CE data at the nano and micro level primarily address companies or the federal government, with consumers receiving only minimal attention. Moreover, across all CE levels, consumers seem to receive comparatively less attention as stakeholders of CE data. Workers are almost exclusively considered at the meso level, while communities or NGOs are only addressed at higher CE levels.

The predominance of companies as the main stakeholders on lower CE levels could be explained by the fact that, at these levels, companies are typically the main decision-makers, requiring more data and information than other stakeholders. It was further found that government stakeholders, encompassing both local and federal levels, are prioritized at macro level. This seems reasonable considering that they are the most powerful stakeholders operating and "managing" on this scale, which means they require significant amounts of diverse data in order to make the best decisions for society as a whole.

Overall, most CE data is dedicated to companies, with many metrics addressing this group, and the second-most predominant stakeholder is the federal government. Considering the complexity of CE measurements and assessments, it is crucial though to incorporate needs of various stakeholders at different levels of implementation (Nika et al., 2021). Thus, it could be argued that the gaps in CE data visualized in Figure 5 for D2 highlight certain insufficiencies of current CE data. As supported by De Pascale et al. (2021), there is currently a lack of structured and standardized methodologies for evaluating CE that can be uniformly applied across different levels. Consequently, this scenario results in a greater availability of metrics and data for specific topics of interest, to the detriment of other relevant topics, such as consumers.

Regarding life cycle stages (D3), most CE data examined focuses first on the end-of-life stage, followed by the make phase, and lastly, all life cycle stages. However, the higher the CE level, the lower the focus on the end-of-life stage. When correlating CE metrics with life cycle stages, an integrated view of all life cycles, such as subsidies and other transfers supporting CE, is prioritized at the macro level. At the meso level, there is a clear predominance of the make phase. In contrast, the micro level predominantly focuses on the end-of-life phase, which is also the primary focus at the nano level.

Interestingly, most CE data examined at higher CE levels is not related to a specific CE strategy (D4), indicating that this dimension might only be relevant for a CE data typology at the nano (and micro) CE level. However, at all CE levels, product circulation (recycling, recover) is the most predominant CE strategy. This disproportionate emphasis on recycling as a CE strategy, and thereby the end-of-life stage, aligns with previous literature reviews on CE indicators (De Pascale et al., 2021; Ghisellini et al., 2016; Moraga et al., 2019) and is explained, for example, by a lack of reliable data apart from waste data (Lohan & Kylä-Harakka-Ruonala, 2018). Since the transition towards a sustainable circular economy requires addressing all CE strategies with a focus on higher R-strategies (Potting et al., 2017), the CE data gaps and disproportions on D3 and D4 present an issue that could be addressed and more thoroughly examined in future research. The extension of product use (repair, refurbish, and remanufacture) and the intensification of product use (refuse, reduce, reuse) are most commonly referenced within nano level CE data. On macro level, CE data predominantly relates to either no specific CE strategy or addresses all CE strategies collectively without differentiation. Finally, there are CE-associated metrics that do not pertain to any specific CE strategy, e.g., the employee satisfaction data in eco-industrial parks.

Most of the examined CE data includes both the biological and technical cycles, which is why it could be argued that D5 appears neglectable for a CE data typology. However, more CE data addressing exclusively the biological cycle (4 – 22 %) than focusing on the technical cycle (0 – 3 %). In addition, important CE assessment frameworks, such as the Material Circularity Indicator (EMF, 2019), clearly distinguish biological/renewable/compostable material contents from other types of feedstock/waste, thus justifying their consideration in the typology.

Regarding the differentiation between qualitative and quantitative data (D7), it is notable that the great majority of the examined CE data appears to be quantitative. Only at the micro level does a significant share of CE data appear to be qualitative, which again raises the question of the relevance of D8 for a CE data typology. In retrospective, it might be reasonable to add a third option: "semi-quantitative data". The data set includes a number of CE data points that cannot be quantitatively measured, such as "actions taken supporting R-strategies" or "disassembly difficulty data" (EFRAG (IVZW/AISBL), 2024). However, for an objective (comparative) assessment, it can be a useful methodology to establish a scale for converting qualitative data into semi-quantitative data. Roughly half of the qualitative CE data in the examined data set is categorized as socio-institutional (D6). This is an expected outcome since, for example, data needed for Social Life Cycle Assessment is usually collected qualitatively through interviews or surveys, naturally inheriting a certain level of subjectivity (Donati et al., 2022; Grubert, 2018). Furthermore, the data analysis suggests that socio-institutional CE data is more predominant at higher CE levels, while technological data or hard parameters are more prevalent at nano and micro levels. At macro and meso level, there was a balance between socio-institutional data, such as management, and technological data.

Finally, it was identified that metrics focused on the transition process (D8) to CE, rather than solely on outcomes or effects, were more present at the micro and meso level than at the macro and nano level. Meanwhile, at the nano level, almost exclusively effect- and outcome-based data were required. Hence, the analysis of D8 indicates that higher CE levels feature a greater share of transition-related CE data. This could be due to the fact that, for example, at the macro level, CE represents a long-term system change, which requires tracking and monitoring the transition process. In contrast, at the nano level, product systems are changed towards higher circularity, usually over a shorter time scale. Therefore, short-term focused "effect" CE data may be sufficient for decision-making in most nano level case studies.

4. DISCUSSION

This research presents a novel typology of CE data, developed through a literature review and analysis of existing circularity metrics. To date, the specialized literature lacks studies specifically addressing the classification of CE data. Although studies on the taxonomy of CE indicators exist (e.g., Fraccascia & Giannoccaro, 2020; Saidani et al., 2019), research explicitly focusing on the typology of CE data remains absent. The proposed typology contributes to a clearer understanding of the data underlying performance measurement systems in circularity, thereby aiding in the standardization and effective communication of CE data types and classifications.

The reference frameworks employed for the breakdown and analysis of circularity indicators are well-established within the specialized CE performance measurement literature and cover different scopes of analysis, such as products, supply chains, and regions. Their relevance is supported by their usage in multiple studies (see, for example, De Pascale et al., 2021; Kristensen & Mosgaard, 2020). Integrating grey literature with scientific sources helps bridge the gap between practical applications and theory, as highlighted by Saidani et al. (2019), who noted that grey literature, such as reports and policy communications, is a vital source of circularity metrics.

As previously presented, a total of eight dimensions are defined for the universe of CE data. These dimensions meet the classification criteria of typological studies, specifically exhaustiveness and mutual exclusiveness, as outlined by Mouton & Marais (1988). The first dimension focuses on the different scopes of CE implementation and analysis, ranging from products to regions and countries, also referred to as CE levels. As described by Saidani et al. (2019), by highlighting multi-level circularity, decision-makers can identify the specificities of different objects, such as products, which may, for instance, support strategic and innovative changes. Ultimately, this classification can enhance organizational efforts by providing a more detailed segmentation of the extensive CE data.

The role of stakeholders is highlighted and treated as a distinct dimension in this study, given its direct connection with CE data. Specific types of data are available and tailored to distinct groups, reflecting their characteristics and needs, such as data regarding the impact of eco-industrial parks on surrounding communities at the meso level (World Bank, 2021). This view is shared by Corona et al. (2019), who affirm that stakeholders may have specific interests and priorities within the scope of CE, ultimately leading to distinct data characteristics. In total, six distinct value types are identified for the stakeholder dimension. The sample of reference frameworks in the study shows that a larger quantity of CE data is present for two specific stakeholders: companies and governments. The greater presence of data related to governments may be linked to their active role in enacting laws and regulations to promote CE (Chiappetta Jabbour et al., 2020). In contrast, for companies, this may be related to their direct participation in new business models, production processes, and the development and adoption of innovative technologies (Lieder & Rashid, 2016; Rincón-Moreno et al., 2021).

The life cycle view constitutes a significant dimension, as CE influences multiple stages of the value chain, thereby necessitating a life cycle-based approach to data collection and assessment (Moraga et al., 2019). This perspective aligns with the European Union's Circular Economy Action Plan, which prioritizes life cycle thinking as a core principle (European Commission, 2020). The sample analysis not only confirms the segregation of CE data by life cycle stages but also highlights a greater diversity of data related to the end-of-life phase rather than the early stages of the life cycle. This finding is consistent with the observations of Pacurariu et al. (2021), who identified a disproportionate focus on end-of-life strategies in the EU's Key Circularity Indicators, which limits the scope of circularity to waste generation and material recovery processes. The product life cycle phases also influence the frequency of data collection. Although, in general terms, higher amounts of data are collected at the early stages of the product life cycle, this observation may not hold for all product types (e.g., Alcayaga et al., 2019).

Another important dimension involves the type of CE strategy employed, whether it focuses on extending product lifetime, intensifying product use, ensuring product circulation, or promoting dematerialization (Bocken et al., 2016; Geissdoerfer et al., 2020). The examination of the data sample reveals a greater emphasis placed on product circulation strategies (i.e., recycling and recovery). Other authors have similarly noted this increased focus on capturing product circulation data, while minimizing data availability for other CE strategies (de Oliveira & Oliveira, 2023; Moraga et al., 2019; Negri et al., 2021). This reality ultimately fails to promote the preservation of product integrity (den Hollander et al., 2017), as it is essential to first more intelligent product usage, design, and production, followed by efforts to extend its lifespan, and only then consider the need for material recovery.

The distinction between biological and technological cycles, as defined by Braungart & McDonough (2002), also constitutes a relevant dimension of CE data. During the examination of the data sample, the difference between technological and biological cycles was also evident, although with a limited focus on biological data. According to Kusumo et al. (2022), research and data on the biological cycle are scarce and fragmented, with numerous practices (e.g., cascading of material from industrial residual streams) within this cycle remaining unexplored.

Including a dimension to distinguish between technological data (primarily focused on physical parameters, e.g., kilograms) and social-institutional data (focus on governance and infrastructure, e.g., circular business models adoption) is relevant, as a transition to a CE cannot be viewed solely from a material perspective (Pitkänen et al., 2023). However, currently, there is more data in monitoring frameworks focusing on physical parameters than on socio-institutional parameters. This is evident in the practical analysis of the data sample, which shows a higher incidence of technological data compared to socio-institutional data. Vercalsteren et al. (2018). support this conclusion by stating that socio-institutional metrics are less frequently incorporated into monitoring frameworks. Pitkänen et al. (2023) conclude that the monitoring of multifaceted socio-institutional aspects critical to the CE transition is hindered by reliance on secondary data sources, such as databases and literature. To effectively track and evaluate progress, the availability of primary and case-specific data is essential.

CE data is further categorized based on its quantitative or qualitative nature, reflecting the diverse measurement and management approaches within CE. In this sense, the data sample revealed a predominance of quantitative data, with a specific emphasis on metrics quantifying mass, volume, currency, energy, and product lifespan. As stated by Evans & Bocken (2013), while quantitative metrics are more prevalent, qualitative data, such as those on product circularity, waste prevention (United Nations Economic Commission for Europe, 2023), or consumer perception (Potting et al., 2018), offer valuable insights into the intangible aspects of circularity.

The final proposed dimension relates to the temporal stages of CE implementation, dividing it into two phases: the process stage, referred to as transition, and the outcome stage, termed the effects. The study's data sample exhibits a higher proportion of effect data compared to transition data, particularly at the micro and nano levels, suggesting that companies lack sufficient metrics to track their circularity policies, strategies, and plans. As noted by Potting et al. (2018), although greater data availability exists for the effects classification, effective monitoring of CE implementation progress also requires the inclusion of transition data. This need has been confirmed by other authors (Pauliuk, 2018; Vinante et al., 2021), who examined the development of CE monitoring tools at the organizational level.

The proposed typology advances theoretical knowledge while facilitating practical applications. Its theoretical contributions are diverse, with a primary focus on providing a comprehensive understanding of the CE data landscape. This understanding enables the identification of key data components and characteristic patterns within each dimension. Practically, the study supports the implementation of metrics for measuring circular performance and contributes to the broader adoption of CE principles within organizations. As Neely et al. (2000) highlight, metrics are essential for defining organizational goals and performance expectations. Thus, the proposed typology aids in the interpretation and measurement of circularity. The insights gained from this study facilitate effective decision-making through various analyses, such as benchmarking. By incorporating the temporal dimension (i.e., transition or effect), the typology significantly contributes to the development and application of a data repository focused on CE implementation, enabling organizations to foster innovation and growth.

Another contribution of the typology is its guidance on the data collection process. By identifying existing data types and prioritizing those of greater interest, the typology streamlines and enhances the efficiency of data collection, as observed by Neely & Jarrar (2004). Consequently, it guides users in adopting a systematic and structured approach to gathering data. Following the data analysis phase, the typology aids in dissecting the data and presenting it from different perspectives, facilitating an initial understanding of the message it contains.

The CE data typology is based on a literature review and a range of broadly accepted indicator frameworks. Since this is a conceptual paper, the amount of included CE data is not exhaustive, and the analysis results are not tested for statistical significance. The findings show that, for example, not all stakeholders, CE strategies and life cycle phases are equally addressed. Hence, the sample of CE frameworks metrics could be further expanded in order to minimize bias. A further possible limitation of the typology is its focus on currently used CE data. The typology does not include aspects concerning the required effort and difficulties to collect specific CE data, nor does it consider specific data collection and data management strategies for different types of application. Furthermore, the typology does not account for the technical characteristics of data, such as different data formats, types of data (structured, semi-structured, unstructured) or different levels of data quality.

5. CONCLUSIONS AND FUTURE RESEARCH

The present study aimed to develop a comprehensive typology of the circular economy data landscape, encompassing all levels of the data hierarchy, from nano to macro. This effort resulted in the identification and classification of characteristic data types, organized into eight dimensions and thirty possible values (subdimensions). The diversity of existing data types, which span different stages of the life cycle and various stakeholders, was concluded from the analysis of a sample of 334 circular data points, as well as from the consideration of specialized literature. This approach has provided a clear definition of what constitutes circular economy (CE) data, contributing positively to business applications, such as, circularity performance measurement through the categorization and structured analysis of circular flows and practices. The proposed typology can support a more comprehensive consideration of circularity aspects, including for example aspects such as, biological cycles and socioeconomic dimensions, as opposed to perspectives that are often narrowly focused on technological cycles (e.g., recycling). Also, it can assist in strategic decisions focused on circular business models (e.g., extension of product use), besides supporting the analysis of circularity improvement opportunities, where it can suggest areas of expansion for companies to enhance their performance (e.g., new consumer niches).

The following evaluation and characterization of the circular economy data sample using the proposed typology had a dual purpose. It aimed to validate the classification in terms of exhaustiveness and mutual exclusivity and assess the current state of reference frameworks regarding completeness and information prioritization. Consequently, the study identifies which data were most frequently used and covered by various frameworks, revealing that stakeholders such as businesses and governments are more relevant in circularity measures compared to others. Similar patterns were observed in other dimensions, with certain groups or specific cases being more frequently addressed.

Thus, the detailed categorization of circular economy data via a typology can enhance its collective utilization by various stakeholders. More importantly, the typology not only supports the development and use of performance evaluation models for circularity in businesses but also aids in the implementation of circular economy principles across the value chain of a company, a network of companies, or even in processes at more strategic hierarchical levels. At the level of governmental and multilateral organizations, the typology may support the further development of environmental-economic accounting systems, as they are not yet sufficiently prepared to measure particularly the higher R-strategies. The aforementioned development of Digital Product Passports may prove to be an inflection point with regard to this – both towards research on CE data and concerning the nexus of CE-focused research with empirical Circular Economy practices. Such passports are stipulated to become a major source for CE data in the future. Many materials and products, at least within the EU, will have to provide master and lifecycle data, including specific battery types, textiles, iron and steel, as well as furniture. How such data can be meaningfully extracted and used for the purposes mentioned above and for the understanding of CE as a whole will have to be subject to future research.

The enhanced detail in circular economy data types facilitates the entire process of data capture and processing, enhancing participants' understanding, streamlining the planning and deployment of circular action plans, driving innovation overall, and supporting the implementation of genuinely circular business models. In summary, typology studies can offer a parsimonious framework for describing complex organizational forms and explaining their outcomes, as previously articulated by Doty & Glick (1994). In this way, the present study demonstrates how circular economy data can be broadly used to enhance organizational circularity at various levels. However, the successful implementation of the proposed CE data typology will depend heavily on improving data competencies within organizations. As the typology covers diverse data types—from physical metrics to socio-institutional parameters—it requires a broad set of skills in data management, analysis, and interpretation. Future research should, therefore, focus on enhancing data literacy and training programs, equipping professionals with the ability to handle both the technical aspects of data and the specific requirements of CE. This includes advanced analytical skills, such as the use of big data techniques and data visualization tools, paired with a strong understanding of CE principles and their applications across different levels of the value chain. Cross-disciplinary competencies are also crucial, as CE data spans multiple fields, including environmental science, engineering, economics, and public policy. Research should investigate how to foster a cross-functional skill set that integrates technical data expertise with CE strategies, facilitating more informed decision-making processes. This will help organizations better interpret the multifaceted nature of CE data and apply it to operational improvements.

While the current study has established a comprehensive typology, future work must also delve into the technical details of CE data types. This includes developing standardized data formats and ensuring interoperability across systems. Standardizing data exchange protocols will be essential for ensuring that CE data can be effectively integrated and used across various models and stakeholders. Furthermore, future research should focus on data infrastructure, exploring how emerging technologies such as data spaces and semantic interoperability, can support scalable and secure CE data management. These technologies are essential for handling the growing complexity of circularity data, particularly in real-time scenarios involving IoT devices and sensors.

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AUTHOR CONTRIBUTIONS

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Holger Berg: methodology and concept, writing and editing, supervising
Monika Dittrich: methodology, review, supervising findings
Kathrin Greiff: analyzing, review & editing, supervising, funding
Christiane Plociennik: methodology and concept, writing and editing, supervising
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DECLARATIONS

Competing interests The authors declare no competing interests.

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