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RESEARCH PAPER

Assessing Product Circularity in Practice: Insights from Industry

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Abstract

The use of the concept of 'circularity' and Circular Economy (CE), and within it, product circularity within government, policy, industry, and academia has grown exponentially in the last decade. However, despite this, there is a lack of harmonization on circularity and CE definitions within the literature and a gap in knowledge on how they are understood and implemented within industry. As such, 21 in-depth qualitative interviews were completed with companies that claimed to have a core circular economy business strategy with the objective to gain insight into how circularity is currently understood and is being implemented at a product level and measured by Industry. This research was undertaken as part of the European Commission's Horizon 2020 project, ORIENTING. The data collected from the interviews was analysed using a thematic coding methodology to 1) gain insights into how product circularity (PC) is understood by industry and identify PC strategies currently being implemented across various sectors; 2) identify barriers for implementation that can lead to solutions for remanufacturing, reuse, refurbish and repair and new ways for production and consumption, and 3) contribute to the development of methodologies and tools for measuring product circularity beyond recycled inflows and outflows. A key finding from the interviews was the lack of harmonization of the concept of circularity and CE within industry, and thus how to implement this at a product level across different sectors. Moreover, the surge in methodologies that seek to quantitively assess product circularity performance for internal decision making and external communications, have until recently, focused primarily on assessing the use of recycled material inflows and outflows; thus, positioning circularity as synonymous to recycling. The paper also shows how measuring use phase related product circularity issues e.g., repair, reuse, etc. is still in the early stages due to a lack of data ownership by companies.

Keywords Circular Economy · Eco-design · Product Circularity · Design and Development Lifecycle Sustainability Assessment · Circularity metrics and indicators

1. Introduction

The use of the concept of Circular Economy (CE) within government, policy, industry, and academia has grown exponentially in the last decade. The CE concept builds on multiple schools of thought, some of which date back to the 1960s, including: industrial ecology, industrial symbiosis, performance economy, biomimicry, cradle to cradle, blue economy, regenerative design, and natural capitalism. CE became mainstream due to the policy attention given to it by the European Commission's (EC) 1st Circular Economy Action Plan (CEAP 1.0)

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launched in December 2015 (European Comission,2020a). Additionally, the Ellen MacArthur Foundation (EMF) has played an important role in raising awareness and in engaging business (EMF, 2021). However, despite this growth, presently, there is no internationally agreed definition of the CE concept. In Kirchherr et al. (2017) original study, 114 circular economy definitions in different sources of literature were identified. Building on this, in 2019, Moraga et al. (2019) indicated that CE was primarily defined as a combination of reduce, reuse, and recycle activities. In 2023, Kirchherr et al. (2023) revisited their original study by analysing 221 definitions, making notable findings including: a shift towards the recognition of sustainable development as the principle aim of CE and the increased recognition of the role played by supply chains. However, while the study recognizes that definitional trends are emerging, Kirchherr et al. (2023) indicates that such definitions may still be of more significance to scholars than practice, which is where this paper locates its subject of study. Thus, while progress is being made to come up with a harmonized definition that is applicable across a myriad of industries, e.g., ISO is working on a consensus-based definition of CE within ISO TC323 which will be an important step towards increased understanding, this proliferation of CE conceptualizations remains as a serious challenge to policy makers, business/industry and researchers working on this topic (Charter & Cheng, 2021).

In practice, CE means different things to different people, with some equating CE to recycling, whilst others consider the broader systemic perspective of CE. In an early definition of resources, CEAP focused mainly on "wastes"; quality aspects are also mentioned frequently (i.e., "keep at highest utility and value", "maintaining values", "regenerating, retaining or adding to their value", "maintain the value of products, materials and resources" and "conserve both the quantity and the quality"), although only two definitions also mention temporal aspects explicitly, i.e., "at all times" or "for as long as possible". Several studies have shown that "more circular" does not necessarily always mean "more sustainable" (e.g., de Oliveira et al., (2021) ; Dieterle et al., (2018); Helander et al., (2019); Iraldo et al., (2017)). So, measures towards CE are not an end in itself but need to be evaluated against the overall goal of sustainable development. This also means that maintaining the value of materials "as long as possible" or "at all times" might be changed into "as long as justifiable from a sustainable development perspective" if reference were to be made to temporal aspects. On the other hand, the BSI (2017) definition notes that CE is a state (i.e., not an approach), circularity can be considered a concept or approach. In this context, this paper aims to address the lack of a harmonized understanding of circularity and CE across sectors within the literature, to assess how the concept of product circularity is understood by industry. Through qualitative interviews, the paper analyses the nuances in meaning from primary sources to assess how the concept of PC may be standardized across different sectors to ensure consistent interpretation, implementation, and measurement.

1.1. Circular Economy Measurements, Metrics, and Indicators

Aligned to the interest in implementing PC in industry, there is growing interest in the measurement of CE at various levels (e.g., products, organisations, regions), and several metrics and indicators have been developed. For instance, an ISO working group (WG) has been set up to develop a standard related to measuring circularity: ISO TC 323/WG3. However, to date most of the focus of the standard has been at an organisational rather than a product level. In addition, another ISO WG has been established to focus on the development of Product Circularity Datasheets: ISO TC 323/WG5. Furthermore, the Circular Economy Indicators Alliance (CEIA) has been recently launched with multi-stakeholder membership including the European Commission and the European Environment Agency with the secretariat provided by PACE (2021a). The stated aim of CEIA is to foster collaboration between governments, businesses, entrepreneurs, and experts and to take forward thinking on circularity metrics with a particular focus on different market sectors: food; electronics; textiles; electronics; plastics; and capital equipment. In Europe, there is growing interest at government level, i.e., Bellagio Declaration (ISPRA, & EEA, 2020): this is highlighted in a recent CEIA report on Government (PACE, 2021b). A further CEIA report on Business provides an overview at a company level, although with little mention of product-related circularity issues.

Business leadership on CE measurement has been taken by the World Business Council for Sustainable Development (WBCSD) and Ellen MacArthur Foundation (EMF), who have developed tools that incorporate PC metrics and indicators e.g., Circular Transition Indicator (CTI) and Material Circularity Indicator (MCI). However, as indicated above, the measurement of circularity in business seems to be primarily focused on a company and business unit level rather than at a product level (WBCSD, 2018). Moreover, details of actual usage of these tools are not in the public domain. ORIENTING conducted a systematic literature review to identify the existing circularity indicators in the scientific and grey literature. The literature review, *A Critical Evaluation of Material Criticality and Product-Related Circularity Approaches,* indicated that there has been a considerable amount of academic research and published papers related to PC indicators and metrics (Bachmann et al., 2021).

Table 1. Non-exhaustive list of CE indicators and metrics. Source: Bachmann et al. (2021).

Indicator (source)	Strategies covered
Product-level Circularity Metric (PLCM) (Linder et al., 2017	Reuse, remanufacture, and recycle
*Material Circularity Indicator (MCI) (EMF & Granta, 2019)	Reuse, recycling, landfill/energy recovery
Longevity (Franklin-Johnson et al., 2016)	Reuse, refurbish and recycle
Circular Footprint Formula (CFF) (Zampori & Pant, 2019)	Recycle, reuse, energy recover
Circularity indicator (Circ (T)) (Pauliuk et al., 2017)	Recycle
Sustainable Circular Index (SCI) (Azevedo et al., 2017)	Recycle, reuse, repair, maintenance
*Circular Transition Indicator (CTI 3.0) (WBCSD, 2022)	Reuse, recycle, repair, maintenance

However, the literature review also highlighted a gap or "lagged effect" between the research and business communities, i.e., several tools and methodologies had been developed in academia, but few are being used by companies due to a lack of external and internal drivers. Many companies are unlikely to be motivated to measure product-related circularity unless there are external drivers (i.e., customers, legislation, standards) or there is a strong business case (i.e., cost saving, efficiency gains) (PACE, 2021a).

As such, this paper aims to contribute to how PC is understood, implemented, and measured by industry. In so doing, the paper further aims to offer guidance that is relevant to industry specific needs in relation to the development of circularity indicators, metrics, and tools. It also aims to identify barriers for the implementation of PC that can lead to solutions for remanufacturing, reuse, refurbish and repair and new ways for production and consumption. Alongside this, the paper also aims to contribute to the development of methodologies and tools for measuring product circularity beyond recycled inflows and outflows.

The findings presented in this paper are the result of 21 in-depth interviews with various industry sectors that focused on evaluating the company's level of maturity in relation to CE, identifying which CE strategies were being implemented at a design and development level and how product circularity initiatives were being measured. The paper has thus been organized into the following sections: Section 2 outlines the research methodology employed for conducting and analysing the interviews; Section 3, presents the key results; Section 4, discusses the contribution and limitations of the research, highlighting topics for future research.

2. Materials and Methods

Interviews were conducted with 21 experts and were planned for up to 1 hour each. The research employed semi-structured qualitative interviews with a blend of closed and open-ended questions, accompanied by follow-up 'why' or 'how' questions. Qualitative interviews were used because they facilitated a 'learning approach' with the interviewees, allowing for the recognition of emerging themes and patterns related to the research topic. The interview process and development of the questionnaire (Annex A) was informed by expert knowledge, along with desk research on CE and PC. The questionnaire was divided into two main topics: 1) General questions to assess the interviewee's level of decision making related to PC and 2) PC specific questions, to probe into more detailed aspects related to measurements, metrics, indicators and the use of eco-design strategies and tools. The use of semi-structured interviews facilitated: 1) an in-depth exploration of PC considerations from industry; 2) insight into the nuances across different industry sectors, in relation to the use of PC, and 3) insight into current CE and PC strategies being implemented within companies and other relevant tools and methods to assess PC that are being used and are not in the public domain.

Participants were selected based on companies' external communication on CE activities. Prior to each interview, background research was conducted by reviewing the company's sustainability reports and website. This was essential to contextualise and inform the strategy for the interview and adapt the questionnaire for each participant. Interviews were then either recorded and transcribed, or handwritten notes were taken to enable the coding and categorisation of patterns and themes that emerged within each interview.

The following research strategy was developed to gain insight into the different stages and decision-making processes that affect (PC) within industry:

- For large companies that have various Business Units and corporate functions ('line and branch'), the aim was to initially interview corporate Sustainability Directors who could provide an overview of PC issues across the Business Units. These interviews aimed to identify those with responsibility for PC issues for potential follow-up interviews.
- For start-ups and micro, small and medium enterprises (MSME's) the aim was to interview the Founder/Managing Director (MD). As responsibility for sustainability and PC related issues within MSME's are likely to be carried out by these functions.

All interviews commenced with a brief description of ORIENTING project, followed by the aims and objectives of the interview and the following working definition for circularity: "approach to promote the extended and/or cyclical use of materials", modified from Moraga et al. (2019). The interviews were divided into two phases. During phase one, 10 interviews were conducted from September to December 2021, while during phase two, 11 further interviews were completed in March 2022. Learnings from the first ten interviews were used to inform and adapt questions for phase two, with the aim to prompt a more detailed response regarding PC considerations within D&D. An example of adaptations made to the questionnaire for the second phase was the inclusion of a definition for eco-design and specifically asking participants about their awareness of IEC 62430:2019 and ISO 14006:2020, as it emerged early on, that knowledge regarding the use of eco-design within D&D was significantly lower than expected. At 21 interviews, data saturation had been achieved and thus, it was agreed by UCA and ORIENTING leadership that interviews would be capped at 21.

Table 1 below shows the industry sectors interviewed, as well as product categorization and company size. (15) interviewed companies were classified as 'final' products, (3) as 'intermediate' and (3) as 'hybrid', which refers to companies that offer a combination of a final or intermediate product and a service. Regarding company size, interviews have been conducted with: (6) start-ups, (3) SMEs, and (12) multinationals.

Table 2. Sample Information

No.		Industry Sector	Size	Product Category
1	Corporate Social Responsibility Manager	Fashion/Apparel	SME	Final
2	Visionary and CEO	Footwear	Start-up	Final
3	Engineering and Field Services Manager	Infrastructure	Start-up	Hybrid
4	Head of Circular Economy and Partnerships	White goods	Multinational	Final
5	Senior Circular Economy Design Manager	Toys	Multinational	Final
6	Senior researcher	Automotive	Multinational	Final
7	Sustainability Manager	Outdoor footwear	SME	Final
8	Head of Research and Sustainability	Textiles	Start-up	Intermediate
9	Director of Sustainability and Innovation	Furniture	SME	Final
10	Sustainability Impact Programme Manager	Hardware & Software	Multinational	Final
11	Global Sustainability Manager	Engineering/Aerospace	Multinational	Final
12	Founder	Fashion	Start-up	Hybrid
13	Managing Director	Footwear	Start-up	Final
14	Vice President Product Design & Portfolio Management	Flooring	Multinational	Final
15	Head of Sustainable Design	Automotive	Multinational	Final
16	Head Office Sustainability	Fashion/Apparel	Multinational	Final
17	Director Global Product Stewardship and Sustainability Manager	Consumer goods	Multinational	Final
18	Sustainability Lead	Software & Hardware	Multinational	Final
19	Founder	Textile	Start-up	Intermediate
20	Product Sustainability	Construction	Multinational	Intermediate
21	Technical Leader for CE-R&D	Automotive	Multinational	Final

2.1. Analysis of Data: Thematic Coding

The data from the 21 interviews was analysed using thematic coding, which consists of categorising and assigning different values to the key themes and topics that emerge from each interview. Thematic analyses or thematic coding is a method for analysing qualitative data that entails labelling and organizing data to identify different themes and patterns (Braun & Clarke, 2006). A distinguishing feature of this method is its flexibility to be used within a wide range of theoretical frameworks such as grounded theory and discourse analysis, and to be applied to a wide range of study questions, designs, and sample sizes (Kiger & Varpio, 2020). Thematic analysis can be used as a stand-alone analytical methodology or as a foundation for other qualitative research methods.

The interviews were transcribed, whilst simultaneously adding notes to summarize the key areas that emerged from each interview. After this initial analysis, labels were assigned to words or phrases that represented important and recurring themes related to PC issues within each response from the sample frame. Themes were identified by analysing patterns in words used during the interview and sentence structure. Subsequently, key concepts/themes were coded. The key themes were then categorized and arranged to produce a summary that highlighted key findings related to the following topics: eco-design, PC strategies, indicators and metrics, barriers to implementation of PC strategies, awareness, and use of LCA as well as the use and development of other impact assessment methodologies and frameworks. With qualitative research, and within it, thematic analysis being iterative, the summaries were discussed between the papers' two authors to identify further concepts or themes that may have been missed during the first analysis and further areas of enquiry which were addressed with follow-up questions via email and/or in subsequent interviews.

The table below (see Table 3) highlights examples of the codebook that was generated for the study. The code book was developed after the third interview. Within thematic coding analysis, a codebook is a document that lists code labels, in this case referring to interviewees' understanding of the term "circularity", PC strategies understood as "sustainability decisions at a design and development level", "indicators and metrics", and "barriers to implementation" as highlighted above. Along with the themes, the codebook offered comprehensive descriptions and extracts from the transcript for each code per company. Codebooks are iterative and thus, while the overall structure remains constant, when analysing the data, new concepts observed were added and previous coded data was reviewed to determine whether the new codes applied.

Table 3. Example transcript with codes used for thematic analysis

Sustainability decisions at a Design and Development Level	
Company 1	• Due to the size of the company (14 employees) the co-owner is also the product developer and therefore, they 'already influence a lot of things, not only as product developer but also as co-owner. They know very well the direction of where they want to take the brand.'
Company 2	• Due to company 2 being a start-up CEO/Founder is involved in all decisions, 'we design everything ourselves'. CEO/Founder makes sustainability decisions at a level, which are to 'being entirely plastic free'. Design for disassembly for the repair scheme and aim to produce locally.
Company 3	• Because of company 3 being a 'young company' no sustainability decisions have been made at a D&D level, as it has focused on 'improving functionality'.
Company 4	• Interviewee is based within the 'front-end' design team, focused on understanding consumer experience to 'nudge' users towards sustainable consumption. • The company has shifted focus from 'products' to
How is product circularity considered within the company?	
Company 1	• The CE is seen as an extension of sustainable development. • *'Circularity is about efficiency and effective use of materials and conserving and protecting the environment.'* • Circularity is considered at a product and business level. • At a product level, the company starts with a '*circular design',* meaning 'we work with materials that are either recyclable, or biodegradable. We don't incorporate anything that cannot be recycled'; 'Stick to a handful of materials that are all a combination of post-consumer recycled (materials)'; Reduce the number of components to ease disassembly. • At a business level, through the implementation of product leasing. Product service system and extended producer responsibility (EPR).
Company 2	• Sees the CE as part of sustainable development. • *'Keeping things in the loop and nothing going to waste.'* • *'To up cycle before we recycle'.*

Likewise, while the interview questionnaire was adapted and improved after each interview, the core questions were maintained for comparability (see Appendix A). Subsequently, as mentioned previously, companies were also categorized by sector, size, and relevant PC related data, as well as PC awareness levels. The following section provides a more detailed description of each awareness level and how these were assigned.

2.2. Multilevel Awareness Descriptors

A multilevel awareness descriptor was developed based on the ZBIA model (which describes levels of awareness that range from zero to basic, intermediate, and advanced) (Charter & Tischner, 2001) and the WBCSD's 2018 report, 'Circular Metrics Landscape Analysis' (see **Table 4**). The table offers 3 circularity strategy stages which are based on a company's PC awareness level, level of PC implementation, and if and how PC is measured. It is pertinent to highlight that from the ZBIA model, level "zero" was removed as companies interviewed were already identified as being on a CE journey. Subsequent research has indicated that in larger companies, Sustainability Directors might have relatively advanced knowledge of PC and CE topics, but the organisation overall might be at much lower levels of awareness and understanding (zero to basic).

Table 4. Multilevel Awareness Descriptor (Source: authors' adaptation of WBCSD 2018 report)

Circularity Strategy Stage	Description
Level 1 or Basic	Company has started to research, explore CE strategies but has not yet defined a product and/or company strategy. 1-2 years' experience within the remit of circularity.
Level 2 or Intermediate	Company has started to implement CE strategies but has not yet integrated CE indicators and metrics. 2-3 years' experience within the remit of circularity.
Level 3 or Advanced	CE trailblazers or 'advanced' CE companies with 4+ years' experience in developing company and product level CE strategy and has started to implement some CE indicators and metrics.

3. Results

The findings from the interviews show how different industry sectors are considering and/or measuring product circularity. Based on the themes that emerged during the interviews, the findings have been divided into the following sections: **3.1. Interviewed Organization's Maturity Level**: which highlights the sample breakdown of PC maturity levels **3.2. Defining Circularity:** which highlights the multiple meanings identified amongst interviewees for circularity - at a product level – and how PC is being considered and implemented within industry; **3.3. Measuring Circularity:** highlights how companies are currently measuring PC or considering PC measurements, indicators, and metrics *vis-à-vis* available product circularity tools and methods. This section also highlights the use and adaptation of standard LCA's to conduct sustainability assessments that include circularity indicators and metrics. Lastly, **3.4. Barriers Identified for the Implementation of PC**: highlights existing PC barriers across sectors and explores potential solutions to overcome the barriers identified. For each section, edited and condensed quotations have been integrated into the findings to support the thematic analysis highlighted in the methodology section of this paper. Including quotations as a source of raw data, aims to offer the reader transparency, validate the findings, and convey the interviewee's contextual experience (Eldh et al., 2020). As Patton (2002) suggests, quotations capture the "informants'" views by representing these in their own words, which in turn, offers the possibility of assisting the development of future research in the field by providing a historical record of shifting CE discourses as the CE agenda moves forward.

3.1. Interviewed Organization's Maturity Level

Based on the maturity levels descriptor in (**Table 4**) only 3 of the interviewed companies were classified as level 1/ *basic* level. At this early stage, CE is not formally recognised, and any circular metrics used are at an 'operational efficiency' level. This means that any associated metrics at this early stage are often 'standard performance metrics' that measure for example, resource efficiency, energy consumption, water, and waste, which can be measured before a corporate sustainability programme is adopted (WBCSD, 2018)**.** A further 8 companies were classified as level two or *intermediat*e, as they appear to integrate 'circular thinking into the [company's] sustainability strategy', by measuring 'sustainability performance' which addresses some of the environmental and social impacts of the company's activities and products. 10 companies were identified as being within level three or *advanced* on the circularity journey where circularity appears to be integrated within the company's corporate strategy to track business improvement through circularity initiatives (WBCSD, 2018). However, a caveat to the *advanced* level is that companies might be advanced at a corporate level or business function level, but not necessarily at PC level. As a result of assigning awareness levels to each participant, needs and requirements related to the implementation of PC strategies, metrics and indicators were identified per level. An example of this is that companies classified as level 3, require PC assessment frameworks that address a 'cradle to cradle' perspective.

3.2. Defining Circularity

CE was seen as part of sustainable development across all companies interviewed. Moreover, the companies interviewed were identified as being in the early stages of defining a circularity strategy *vis-à-vis* their sustainability goals (e.g., Participant 5 and 9); having been founded on CE principles (e.g., Participant 1, 8 and 19); or having a longstanding tradition in developing and implementing eco-design strategies (e.g., Participant 4, 10, 11, 14). Based on the answers provided by the twenty-one interviewees with regards to their sustainability goals, 'circular economy' or 'circularity' was highlighted as 1 of 3 sustainability focus areas by all participants. While the other two sustainability focus areas were 'climate action' which was ubiquitously associated to 'decarbonization' and 'social' and/or 'ethical' business practices which encompassed: health and safety, equality, diversity, inclusivity, and working conditions, amongst other topics. The interview findings suggest that an understanding of circularity and how to implement it, is fragmented. The findings thus show that the concept of CE and how circularity is implemented at a product level varies depending on the type of product and industry. For example, to implement a closed loop circular strategy, requires organizations to evaluate the value of their waste streams and compare this to the economic trade-offs. In this context, an electronic company may perceive increased economic benefits to recovering waste from their value chain when compared to a textile organization in which the value of the recovered material is significantly lower and requires costly processing to reuse recovered materials.

At a product level, the most common focus areas for addressing circularity within participating companies, are the use of recycled content and biobased materials, along with ensuring that product components can be easily recovered and recycled through eco-design strategies such as design for product life extension that includes standardization, compatibility, and design for disassembly (Appendix B). However, it transpired that few companies appeared to use the term eco-design, which was unexpected, given the companies' longstanding tradition in eco-design. The responses from the interviewees also indicated that whilst CE and within it, PC was seen as part of the companies' sustainability strategies, CE activities were undertaken in isolation across the organisation, perhaps indicating "newness" in many organisations. In other words, there is a lack of communication amongst business functions with regards to CE activities. In addition, where eco-design was recognized as a practice in companies, PC aspects were considered separately to eco-design, despite being inherently aligned with eco-design strategies. The lack of awareness of eco-design within the interviewed companies led the authors to complete a non-exhaustive literature review of recently published information on the application of eco-design and discussions with other experts in the field, indicating a lack of research in this area in recent years.

Furthermore, the following quote by [participant 1] illustrates how circularity is also used to refer to the use of recycled materials, as well as the emergence of new concepts and terminology such as 'circular by design' and 'circular-ready design', which are increasingly becoming synonymous with specific design strategies and products that are aligned with Design for Material Sourcing, Design for Manufacturing and Design End-of-life (Appendix B): *'At a product level, the company starts with a 'circular design', meaning 'we work with materials that are either recyclable, or biodegradable. We don't incorporate anything that cannot be recycled and stick to a handful of materials that are all a combination of post-consumer recycled [materials]' or 'Reduce the number of components to ease disassembly.'* A potential consequence of organisations' directly associating circularity with the use of recycled material and design for disassembly, is that other PC strategies such as re-use and repair remain excluded from CE discourses. The exclusion of such strategies from industry discourse can potentially lead to some companies, particularly MSME's, to remain unaware of the existence of PC strategies within the use phase of the product's lifecycle. Furthermore, as current PC assessments focus primarily on measuring the use of recycled or biobased content to define a product's circularity, this could lead to some companies not necessarily being aware of strategies beyond the use of recycled material and thus, hinder the implementation of design for disassembly, reuse, or repair as a viable PC strategy.

However, while the majority of companies interviewed focused on the use of recycled and bio-based materials and components, and design for disassembly due to the constraints described above, some of the more 'advanced' companies (as defined Table 3) have started to address the challenges associated with solely focusing on recycling as a means towards circularity by differentiating between for example, '*Material sustainability initiatives'*, from *'circularity initiatives'* and appear to be assigning a hierarchy to circularity strategies. In this context, 9 of the companies categorized as level 3 or 'advanced' as per **Table 4**, indicated a shift in their circularity ambitions towards product and part reuse through designing for repair, maintenance, and upgradability, as well as exploring product service systems (PSS) such as 'pay-per-use', 'product leasing' and 'take back' schemes. This highlights the differing understanding of PC amongst interviewees as it shows that the precise definition of the concept varies from one company and product to another, and perhaps with the level of awareness/understanding/experience of PC/and CE more generally.

The following quotes exemplify this further. The first, indicated by a consumer electronics company, highlights that PC is considered as a mechanism to reduce the environmental impact of products by using recycled materials to replace virgin materials: '*There is varying understanding of the scope of circularity. At a basic level there is a large push towards more 'circular materials' (recyclable, use of recycled, and partnerships with recyclers). Then there is exploring the concept of 'pay-per-use', product service systems* (PSS) *and repair and refurbishment'* [participant 4]. While a second quote shows how in other industry sectors such as aerospace, PC may be considered from a supply risk perspective. As [participant 11] indicated: *'The way I look at this [circularity] is why we manage materials supply risks. So, we take the mitigation strategy that we use for materials supply risk, which is very context dependent, it depends on the material, how we are using it, why there might be a risk there […], but I would class most of these as circularity aspects.'* For companies classified as intermediate (e.g., producers of materials) who do not have control over the end-use of their product, the focus of PC appears to be on recovering and reusing internal waste and process materials, as [participant 20] stated: *'In terms of circularity, we are making use of waste and process materials and looking at the recovery of other residues […] as an intermediate product we have less control over the use of the product or the final application [and] do not own our downstream business.'* Therefore, while the company is fully aware that their product is highly recyclable, they do not have full traceability of where that material ends up at its end-of-life and thus do not include percentage of material recovered for recycling or the use of recycled content as part of their circularity strategy.

This section has highlighted some of the concepts and nuances that are emerging within industry when defining circularity. Regarding the development of PC assessments, this section also highlights the importance of considering how circularity is interpreted from a myriad of perspectives, which will ultimately affect the approach adopted for measuring PC. For example, [Participant 16] circularity means to *'create products that are made to last, from, recycled and sustainably sourced materials that can be repaired, reused and remade multiple times*. Based on the above findings, it is suggested that tool development for measuring PC should offer guidance for adapting measurements and indicators to meet industry specific requirements or at a basic/entry-level, help companies to define a starting point for their PC journey. In this context, the following section aims to offer insight into how companies are currently measuring PC or considering PC measurements and indicators based on the available PC tools.

3.3. Measuring Circularity

The Ellen MacArthur Foundation's MCI (2021) and the WBCSD's CTI tool (WBCSD, 2023) were selected for the development of ORIENTING's LCSA due to their compatibility with LCSA methodology, the objectives of ORIENTING and their potential wider usage amongst industry. However, when interviewees were questioned about the specific use of the EMF's MCI or the WBCSD's CTI tool, from the twenty-one companies interviewed only two companies claimed to measure circularity at a product or business level using the EMF's MCI, whilst no participants mentioned the use of the WBCSD's CTI tool.[2] Therefore 19 companies of the companies interviewed are not using these or any other PC tools to support the development of their circularity strategy. Furthermore, [Participants 2, 4, 5, 11, 15, 16, 17, 18, 20, 21] indicated that they do not find the tools – available in the public domain or commercially – to be useful for quantifying and communicating their organization's PC strategies, indicating practical non-usability and lack of stakeholder involvement in developing these tools.

One of the companies using the EMF's MCI, [Participant 10] stated that the circularity percentage highlighted in their annual sustainability report refers to the company's '*total annual product and packaging content by weight, that will come from recycled and renewable materials and reused products and parts'.* As this company has been classified as 'advanced' in terms of the PC strategies being implemented, this highlights that for companies with advanced level of awareness, the focus of PC measurement remains on quantifying inflows of recycled content or the use of biobased materials within a product and outflows through recovery percentages. This is due to companies indicating that this is what they can pragmatically control, measure, and report; with the use phase often being seen as outside their control in current business models. Nonetheless, as [Participant 15] indicated, some companies are seeking to explore the feasibility of measuring PC beyond the use and recovery of recycled content by developing *'KPI's for circularity'* that could potentially include indicators such as reuse rates through take-back schemes or repair and refurbishment, or disassembly times in relation to cost. As one of the more advanced companies indicated: *'[PC] is measured [...] an indicator is time: time for dismantling. How fast can you dismantle'* [Participant 15].

Companies appear to also be '*working on how to integrate circularity into design and development, while figuring out where the boundaries are for measuring circularity.'* The boundaries for circularity appear to be driven by product type and industry sector. For example, a toy manufacturer that designs for longevity where their products are rarely recycled (as there is significant reuse of the products), would have to assess the trade-offs associated with replacing the current materials used with recycled or bio-based materials, which would then have to be measured during the *use* phase. Aligned to the extension of the system boundaries, [Participant 5] has started to explore ways to incorporate the *use* phase by conducting '*internal investigations to gain insight into what happens to the product once it has left the manufacturer'* and what influence it might bring to the *use* phase through design decisions that 'nudge' or 'educate' the user to make decisions that have a lower environmental impact during the use phase.

Other companies appear to also be measuring the recycled content that is reintroduced within their production line as an indicator of a products' circularity. However, due to the nature of some businesses, measuring the inflow of recycled content within a product represents a challenge. As [Participant 11] indicated, *'[...] moving things through can span a couple of years sometimes, or certainly a couple of reporting periods. So, I think the measures that we have, we do have them I just don't think they are well developed to really give*

[2] The numbers presented here are based on the interviewee's awareness of the use of either the EMF's MCI or the WBCSD's CTI 2.0 within their company and background research into company sustainability reports. Since most of the interviewees formed part of D&D units, it is possible that more companies are looking into these PC measurements and indicators, but this information is held elsewhere within the company.

a representation of circularity. I mean questions like the recycled content of certain aloeids from that process is difficult to quantify'. Considering the current work being undertaken by companies at different circularity readiness stages and/or levels of awareness, it is important to promote the importance of a multilevel approach within sustainability assessment methodologies. As from a circularity perspective, companies classified as zero to basic might start by measuring the inflow of recycled content as an initial step toward implementing PC. While the more 'advanced' companies that have started to explore PC considerations within the use phase, will potentially be interested in measuring beyond the use of recycled material and towards a 'cradle to cradle' perspective.

3.4. Identified Barriers for the Implementation of PC

A key barrier identified for the implementation of PC, was the lack of communication across business functions. A disconnect was identified between the various business functions (e.g., environmental, CSR, supply chain, marketing…) and those directly or indirectly involved in the design and development (D&D) process. In other words, business functions operate in isolation. internal communication within organizations depends solely on the culture of the company and individual company policies. For example, when [Participant 15] was asked how communication was established between the D&D and the environmental teams. It was highlighted that such connections are dependent on individual employee interests and initiatives, as the following quote shows: *'Every kind of connection is based on the people who do it. There is no natural connection between them, it is something I established because it is within my job and my network that I'm going to bring these people in. I do talks in their department, and they do talks in my department. So, this is something that I enforced a lot, that we do have a lot of exchange and ... I really pushed that. And that colleagues talk directly to my people, to the designers'*. Thus, as recognised in the literature, it is key to establish a common language and a shared vision of PC, which can ultimately assist in communicating PC strategies across an organisation's various business functions. This is seen as fundamental for the implementation of eco-design and product circularity (Pigosso et al., 2013).

Assessing the trade-offs associated with the implementation of PC strategies was also perceived as a barrier for the implementation of PC. In this context [Participant 5] highlighted how the sustainability department is currently weighing the trade-offs of material substitution versus product longevity: *'As I mentioned earlier, do we move away from ABS towards using recycled PET or a biobased material? An LCA is going to tell us that's going to have carbon impacts as a trade-off, that's going to have a longevity impact, it might not be as recyclable, so in terms of making bold choices in the future, we are currently working through this, but it is part of the core plan.'* Moreover, the costs associated with material substitution, development of new infrastructure and business models was also mentioned by most interviewees as barrier. As one participant pointed out: '*[...] recycled plastic costs more than virgin, so if we want to implement it in the product, it will cost more. Reusing the product has a huge cost associated with reverse logistics so there are costs related to the closed loop management of the products. On the other hand, it's not so clear that the consumer is willing to pay more, and I... don't want to say that it's a lack of interest, because the consumer today is really interested in sustainability, the point is, are they willing to spend more? And so that is the key point that is still blocking our development.'* For some of the smaller companies interviewed, the scalability of PC strategies such as the production of materials utilising by-products from other industries appears to also be a challenge. For example, currently some materials (e.g., vegan leathers) can only be produced in small quantities and therefore securing a sufficient supply for manufacturing certain products represents a barrier to the implementation of this specific PC strategy. With regards to material substitution, it is not only that cost that represents a barrier, but also maintaining product functionality, performance and consumer expectations whilst using an alternative material such as recycled PET or biobased materials. Finally, a key concern mentioned by the interviewees, is the aesthetics of sustainability and how this needs to align to customer/market demands. For example, this includes consumer willingness to accept aesthetic/external product changes associated with sustainability interventions such as the 'feel' or 'look' of recycled materials or bio-based materials e.g., bio-based leathers. Some of the companies interviewed are addressing concerns related to the potential impact of PC strategies on a product's aesthetics by, for example, using recycled materials only on non-consumer facing product surfaces such as packaging interiors/inner linings.

The authors thus argue that if the barriers to implementing PC are to be overcome, it is recommended that:

- PC assessment methodologies and tools need to address how to effectively communicate and present results across business functions.
- Additionally, strategies should aim to educate/raise awareness of the sustainability decisions being made and how this impact on the product aesthetics and price, to increase market acceptability. For example, [Participant 1] organizes regular workshops to raise awareness amongst consumers on their product development alongside sustainability considerations.

4. Conclusion

The objective of this research was to gain a better understanding of how PC is understood by industry, existing barriers to the implementation of PC and which indicators and metrics are currently being used. While best practice was ensured to avoid potential bias on the selection and emphasis of the themes highlighted from the interviews, the authors acknowledge that limitations of the study exit due to the nature of qualitative research and potential subjectivity to the researcher's interpretations. Nonetheless, While the findings presented in this paper are based on 21 interviews and are therefore not representative of any sector, they do however, shed light on some of the challenges being faced by industry when attempting to implement and quantify PC. The following section outlines the main recommendations to start to address these challenges, along with limitations of the study and recommendations for further research.

4.1. Harmonising Product Circularity Concepts

The interviews highlighted that circularity is context specific and is understood differently at an individual, organisational, and sectorial level. Furthermore, the research also identified that the multiple understanding of circularity is aligned to the levels of awareness regarding PC. For example, companies at a level 3 or advanced level of awareness understood circularity beyond the use of recycled materials and recycling at end of life. At a product-level, circularity is predominately being addressed by calculating the percentage of recycled and/or biobased materials used within a product as well as by quantifying a product's recyclability. In turn, this has arguably led to PC being perceived by many individuals and companies as being directly associated with recycling. Moreover, the interviews revealed that few companies use the term eco-design when discussing product circularity. While many would consider PC as part of eco-design, in the context of the interviews, PC appears to have evolved as a separate topic, and in some instances, even separately to D&D. As such, this research emphasizes the need to harmonise PC related concepts to ensure that the way in which PC is implemented, monitored, and measured is standardized. ISO TC323, will play a significant role in the standardization of defining and measuring CE.

4.2. Circularity Indicators and Metrics: addressing products' full life cycle and enabling a multilevel approach.

The introduction of this paper showed that from the 100 plus circularity indicators and metrics related papers assessed as part of ORIENTING, the vast majority focused on a 'cradle to gate' perspective, which excludes the *use* phase (Bachmann et al., 2021). The findings from the interviews, however, reveal that there is a need from industry to go beyond the 'gate' and include the *use* phase. The 'advanced' participants highlighted the need for methodologies to integrate measurements that include the *use* phase such as product repair, re-use, and refurbishment. In this context, barriers identified by the interviewees for assessing PC during the *use* phase are directly linked to challenges associated with accessing user data, confidentiality concerns and the lack of availability of methodologies that include use phase considerations. Moreover, the interviews highlighted different levels of awareness related to PC metrics and indicators that ranged from 1 to 3 or *basic* to *advanced* as per Table 4. Alongside this, differences were identified in relation to how PC was understood at an individual and business function level. From a methodological development perspective, this calls for the need for PC assessments to be flexible and adaptable to the needs of business functions, with clear communication of results adapted to multiple audiences that might have zero to advanced PC awareness levels.

4.3. Addressing Consumer Acceptance of Direct Product Effects Related to the Implementation of PC Strategies

The cost (e.g., increase in material costs to replace virgin materials with biobased or recycled materials, investment in updating manufacturing equipment, infrastructure, etc.) and change in product aesthetics associated with PC implementation were perceived as the most significant barriers to the implementation of PC strategies. Both issues require consumer/user acceptance as a percentage of the cost would most likely be passed on to the user. While the introduction of new product aesthetics could potentially affect the company's capacity to sell its products. As such, there is a need for companies to raise awareness amongst consumers of the costs associated with transitioning towards more circular products, alongside the potential environmental, economic, and social impacts associated with consuming such products. Furthermore, there is a need from industry, academia, and policy to develop strategies that address consumer concerns regarding product aesthetics, quality, and performance related to the impact of sustainability considerations on a product's physical features.

4.4. Limitations and Further Research

The findings presented in this article focused on the analysis of the use of the Ellen MacArthur Foundation's MCI and the WBCSD's CTI tool within industry due to their potential wider industry usage and compatibility with the LCSA methodology-context in which the overall study was situated. While the authors acknowledge that in doing so, specific indicators or metrics for PC strategies that focus on individual R strategies such repairability and reuse have been deliberately excluded, alongside standards that may also be used by R&D departments to achieve sustainable product design; the interviews included prompts in relation to individual PC strategies as per Annex B. Such prompts included questions related to designing for disassembly, repairability, refurbishment, etc, with follow up questions on if, and how these were measured. This was done to gain insight into specific R strategies used as part of an eco-design strategy, which do not necessarily fall under the term product circularity. Furthermore, the interviews highlighted measurements and indicators for assessing individual R strategies such as examples of "mean time to repair" (MTTR) measurements as indicated by an interviewee from the automotive industry, recognising that these types of measurements are not considered within existing CE indicators and metrics. Nonetheless, while examples of individual R strategies were highlighted within the study, these were limited and therefore, research on the usage of specific indicators or metrics for PC strategies that focus on individual R strategies such repairability and reuse alongside standards that are potentially used by R&D departments to achieve sustainable product design, are seen as an area for future research, which has the potential to enhance the findings presented in section 3 of this article. Examples of this include follow up research focusing on the usage of for example, the "BS 8887: Design for Manufacture, Assembly, Disassembly and End-of-life processing MADE" series which is intended to help designers "make informed choices about a product's function and use, the materials from which it is made, manufacturing processes and ability to recycle or reuse the product at the end of its life" and how its effective implementation is measured.

As mentioned in earlier sections of the article, the study focused on identifying how product circularity was understood, implemented and measured within industry with a focus on measurements being compatible with LCSA methodology. Lastly, the interviews highlighted that further research is needed to develop strategies to enable access to 'use' phase data whilst complying with data privacy to facilitate the inclusion of the use phase within PC assessment methodologies and tools; as well as a need for a multilevel approach for measuring PC that is aligned to individual awareness levels.

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Appendix

Appendix A: Interview Questionnaire

General Questions

- Could you describe the company's sustainability goals?
- Could you name a few key sustainability decisions that the design and development department are responsible for?
- To what extent have the design and development processes been altered, to include sustainability considerations?

Product Circularity (PC) Questions

- Does the company see CE as part of sustainable development, or does it see CE as a separate topic?
- Based on the definition provided for product circularity, how is this considered within company? What (PC) strategies are relevant to [Company X]'s products?
- How is product circularity measured?
- Does the company have an ecodesign strategy? If so, could you describe this strategy, and how does it incorporate PC considerations within Eco design?
- Does the company conduct LCA's, internally or outsourced? How are PC issues considered in LCAs? How often are LCA's conducted?
- What tools does the company use to think through (PC) issues: has [Company x] developed internal tools and/or use existing tools that are adapted?
- Who applies the results of LCA's conducted (for example, business sectors, top-managers, designers, marketing…)?
- Have you used the a) Ellen MacArthur Foundation's Material Circularity Indicator (MCI) or the b) World Business Council for Sustainable, Development's, Circular Transition Indicators (CTI) tool? If so, what are your comments on a) and/or b)
- What barriers have been identified when designing for circularity? A) external and b) internal?
- What are the main changes made to the product to align it with the CE?

- What are the biggest barriers to implementing product circularity?
- To what extent have the design and development processes been altered, to include circularity?

Appendix B: Generic eco-design checklist that features product circularity strategies in *italics* (non- exhaustive). Adapted from Charter M, Designing for the Circular Economy, 2017 [Routledge]

Design Focus Area	Options for Design Improvement
Design for Material Sourcing	*Reduce weight and volume of product*
	Increase use of recycled materials to replace virgin materials
	Increase use of renewable materials
	Increase incorporation of used components
	Eliminate hazardous substances
	Use materials with lower embodied energy and/or water
Design for Manufacture/Assembly	Reduce energy consumption
	Reduce water consumption
	Reduce process waste
	Use internally recovered or recycled materials from process waste
	Reduce emissions to air, water and soil during manufacture
	Reduce number of parts
Design for Transport and Distribution	*Minimise product size and weight*
	Optimise shape and volume for maximum packaging density
	Optimise transport and distribution in relation to fuel use and emissions
	Optimise packaging to comply with regulation
	Reduce embodied energy and water in packaging
	Increase use of recycled materials in packaging
	Eliminate hazardous substances in packaging
Design for Use (Including installation, maintenance and repair)	Reduce energy in use
	Reduce water in use
	Increase access to spare parts
	Maximise ease of maintenance
	Maximize ease of reuse and disassembly
	Avoid design aspects detrimental to reuse
	Reduce energy used in disassembly
	Reduce water used in disassembly
	Reduce emissions to air, water and soil
	Eliminate potentially hazardous substances that can be released during use
	Maximize ease of materials recycling
Design for End of Life	*Avoid design aspects detrimental to materials recycling*
	Reduce amount of residual waste generated
	Reduce energy used in materials recycling
	Reduce water used in materials recycling