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Review

Representing Reuse in the Circular Economy: A Study of Circularity Indicators

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Abstract

Reuse is widely regarded as a primary strategy to mitigate plastic packaging waste, occupying a higher position than recycling in the waste hierarchy. However, most existing circularity indicators do not include reuse or include it only as an inferior circularity strategy. This paper evaluates how existing circularity indicators applicable to packaging integrate reuse in their calculation methods and results. A literature review identified 88 circularity indicators, which were filtered to 11 based on active usage and packaging relevance. These 11 indicators were analysed against the ISO 59004:2024 circularity framework using a scoring matrix. The four most relevant indicators (Material Circularity Indicator, Product Circularity Indicator (PCI), Eco-efficient Value Ratio and UP Scorecard) were evaluated using a comparative assessment of a reusable plastic container. Three key variables were tested: recycled content, recycling rate, and number of reuses. No single indicator performed best across all three assessment methods. While combining PCI and the UP Scorecard provides the most thorough assessment currently available, this combination still fails to fully capture sensitivity to varying levels of reuse. Future circularity indicators must evaluate both the level and operational feasibility of reuse, rather than relying on binary inclusion.

Keywords: circularity; circular economy; reuse; packaging; indicators

1. Introduction

Reuse is considered as one of the biggest levers to tackle increasing levels of single-use plastic packaging production and release in the environment [1]. Circular economy practices are also critical in the implementation of the Sustainable Development Goals [2]. The European Commission identifies reuse as a key opportunity to reduce waste, placing it above recycling in the EU waste hierarchy [3]. The 10R framework [4] also ranks reuse above recycling in its hierarchy of strategies for reducing material use and waste generation: Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle, and Recover.

A set of packaging reuse targets for 2030 and 2040 has been implemented in the Plastic Packaging Waste Regulation [5]. This requires final distributors in the takeaway sector to provide 10% of products that are offered for sale in a reusable packaging format by 2030. During negotiations, some reuse targets have been removed from the legislation text due to the difficulty of proving the environmental benefits of reuse [6]. Indeed, the environmental impact of reusable systems varies depending on material, number of uses,

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transport loops, and a range of other factors, all of which can lead to changes in conclusions when comparing reusable systems to single-use.

Reusable packaging solutions may have benefits beyond environmental impact, but these benefits are not universal. Reuse systems that require significant transport to enable cleaning, or require large increases in material mass for limited reuse benefits, may not achieve parity with single-use systems in all environmental impact cases. Circularity indicators enable metrics assessing the successful transition to a circular economy to be combined with Life Cycle Assessment, to avoid potential negative impacts and optimise systems. Few papers associate circularity indicators with environmental performance [7], and there are many definitions of circularity and existing circularity indicators [4]. It is therefore often challenging to identify the most suitable definition of circularity for a given use case, or to link circularity to environmental performance.

This study focuses on micro-indicators assessing circularity, applied to the packaging sector. The aim of the study is to evaluate whether these indicators integrate reuse in accordance with the waste hierarchy, which states that reuse enables better value retention than recycling [3]. The work uses existing literature on circularity definitions and circularity indicators, both generic [8] and specific to the packaging sector [9].

A definition of circular economy and its components is first selected, followed by a detailed review of relevant literature and the collation of a list of circularity indicators. This is refined to give a list of currently available circularity indicators suitable for use in packaging, which are then analysed using a scoring matrix and tested in a realistic use case for reusable takeaway food packaging.

2. The Circular Economy

Many studies have provided definitions of the circular economy, without reaching a final consensus [4,8]. However, differences between definitions are generally relatively minor, with the overarching themes remaining consistent between studies. Standard ISO 59004:2024 [10] was developed through extensive stakeholder consultation and its definition of circularity is based on a consensus across stakeholders. This work also incorporates many themes highlighted as important in previous studies and publications. In this work, the ISO 59004:2024 definition was adopted as the key definition of the circular economy.

This standard defines circular economy as "an economic system that uses a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development". The definition is designed to apply across a range of applications and therefore includes reusable packaging systems. The three key elements of a circular economy highlighted by this definition (circular flow of resources, value or economy, and sustainable development) can be considered individually and ultimately used to evaluate the circularity of a system. The evaluation of circularity of flows can have a positive impact on materials value retention and sustainable development. However, improvement in circularity of flows does not always imply an improvement in value or sustainable development [11], meaning that to enable holistic assessment of circularity, the three elements should all be considered.

2.1. Circular Flow of Resources

A circular flow is defined by ISO 59004:2024 as "a systematic cycling of the provision and use of resources within multiple technical or biological cycles". This includes all methods that break down the linear flow of resources to landfill. Most indicators focus on this component of circularity [12].

2.2. Value

The notion of value is left somewhat open to interpretation in ISO 59004:2024, defined as "gain(s) or benefit(s) from satisfying needs and expectations, in relation to the use and conservation of resources". The standard also states that value is relative to, and determined by, the perception of those interested parties able to capture it. Value can be financial or non-financial (e.g., social, environmental, other gains or benefits) and is dynamic over time. Value currently tends to be assimilated to an economic or functional value. Waste hierarchies commonly aim to preserve value. European Commission Directive 2008/98/EC [3] ranks circularity strategies according to value retention potential. In packaging, food preservation is the main route to value preservation.

2.3. Sustainable Development

Sustainable development is defined by ISO 59004:2024 as "development that meets the environmental, social and economic needs of the present without compromising the ability of future generations to meet their own needs". In order to truly evaluate the sustainability of a system, each of the three pillars (environmental, social and economic) should be considered and analysed.

3. Materials and Methods

3.1. Literature Review

Following the definition of circular economy, indicators can be developed which enable this definition to be used to assess circularity. This concept of circularity indicators is the subject of a body of academic literature, with publications found both in academic journal papers and project reports or consortium initiatives.

To assess the state of the art in circularity indicators, a literature review was undertaken. The review was undertaken using Scopus. The search terms used were "Circularity" AND "Indicator" (including both upper and lower case), which identified 147 articles; "Circularity" AND "Metric", which identified 31 articles; and "Circularity" AND "Tool", which identified 68 articles. Combining these terms to avoid duplication gave a final field of 234 articles. These broad search terms were used in preference to packaging-specific terms to include generic indicators that do not have a specific focus on packaging. Those not suitable for packaging were removed later.

Results showed a steadily increasing trend for publications in the subject. Though the first publication was in 1986, 2013 was the first year with more than one publication on the subject. Numbers increased since 2016, to 12 in 2020, 31 in 2023 and 58 in 2025. In total, 36% of all identified articles were published in 2025 or 2026.

To collect the widest range of circularity indicators possible, review articles (such as Kirchherr [4] and Saidani [13]) were first used to create a list of indicators, then additional articles were reviewed and any indicators not already included in the list were added. In total, 88 individual indicators were identified.

Many of the review articles identified included assessments of indicators. These assessments included a range of aims and criteria, differing between articles, but in general aimed to confirm whether indicators existed at the time of the review, how commonly used they were, and their scope. The most useful included a comparison of multiple circularity indicator tools, with comprehensive and transparent scoring criteria. These assessments were applied to our work to remove indicators which no longer exist or are not in use. The key review articles considered are described in the following section.

3.1.1. Key Review Articles

A first type of review is proposed by Saidani [13] presenting an overview of 55 sets of circularity indicators. The indicators described vary based on their objectives, the assessment level (macro, meso, micro), the intended user group (civil servants, engineers, designers, scientists) and the level of detail in input data required. The review proposes a set of criteria that enables categorisation when comparing or creating indicators. Moraga [12] also presents a framework to study the focus of a series of indicators. It focuses on micro indicators, which are classified according to circular economy strategies and measurement scopes. The work defines these using three levels: Scope 0 (does not include Life Cycle Thinking), Scope 1 (includes Life Cycle Thinking to analyse technological cycles), and Scope 2 (analyses the cause-and-effect of technological Life Cycle Thinking). The ORIENTING project [8] created a matrix to score the completeness and robustness of the currently most used micro indicators. Nine indicators have been selected from a series of review papers [12,13] and analysed according to a set of criteria developed within the project. Results suggest that the best-performing indicator is the Material Circularity Indicator, followed by the Product-Level Circularity Metric, Longevity Indicator, Circular Footprint Formula, Product Circularity Indicator and in-use occupation-based indicators.

Some reviews consist of comparing circularity indicators on a selected use case. The first review considered six circularity indicator tools and ultimately assessed four using a tidal stream turbine as a case study [14]. The considered tools were Material Circularity Indicator (MCI), Eco-costs Value Ratio, Circular Economy Toolkit and Circular Economy Indicator Prototype. REPRO2 and C2C methods were excluded early in the study due to their output format being limited to guidance only, with no quantitative output. The study compared results to a full LCA and found that the open-loop Eco-costs Value Ratio method best replicated the relative results of the full LCA study. However, the Eco-costs Value Ratio is based on full LCA modelling and therefore brings complexity far beyond the other methods considered. Acknowledging this complexity, the study found that MCI was the best-performing simplified tool (outperforming the closed-loop Eco-costs Value Ratio method).

Two reviews specific to the packaging sector were found. Matos [9] studied the relevance of existing circular economy micro-indicators for the plastic packaging sector. Indicators were related to circular economy guiding principles and 'Design for X' approaches. Of the 18 indicators studied, those identified as most relevant to the packaging sector were Circularity Calculator, Circularity Design Guidelines, Circular Economy Index, Circular Economy Indicator Prototype, Model of Expanded Zero Waste Practice, Longevity Indicator, Material Circularity Indicator, Material Reutilization Score, Product-level Circularity Metric, Recycling Desirability Index, Reuse Potential Indicator, and Value-based Resource Efficiency. Results showed three micro-level indicators as the most relevant for circularity calculation in packaging: Material Circularity Indicator, Value-based Resource Efficiency, and Circular Economy Indicator Prototype, because their methodology and approach address most of the circular economy guiding principles and "Design for X" approaches relevant for the packaging sector.

Pathan and Aurisicchio [15] performed a review of 21 circularity indicators specific to the packaging sector. Indicators were assessed by considering whether each included all life cycle steps at different system levels: packaging characteristics, infrastructure, value and regulation. The results identified the following indicators as incorporating the greatest number of systemic considerations: Value-based Resource Efficiency [16], Packaging Index [17], quality model for recycled plastics [18], reusable packaging in circular supply chains [19], Recycling Desirability Index [20], Product Circularity Indicator [21], Circularity Index [22] and Circular Economy Toolkit [23].

3.1.2. Refinement of Indicator Pool

The 88 indicators collected from review articles and individual articles during the literature review were refined to a final set using a six-stage process, illustrated in Figure 1. Some reviews of indicators included simple ratios or factors (for example, the ratio of virgin to recycled content input) as circularity indicators. These simple indicators may be useful in combination with others, but are not suitable alone as a circularity indicator, so they were removed from consideration in an initial filtering. This removal step was called "Not an indicator". The literature review considered circularity indicators from all sectors and therefore included some which specifically target other sectors and were not suitable for plastic and packaging sectors. These were removed ("packaging unsuitable" step), but generic or non-specific indicators were included. Some reviews included indicator calculations which form part of the calculation used in other indicators, for example the Linear Flow Index used in the MCI and PCI calculations. These were not included as standalone indicators and were removed at the "sub-indicator" step. A number of the initially identified indicators were found to no longer be available for use, with many having been developed during projects but no longer maintained after the end of these projects. These were also removed ("no longer available" step). A further group were found to only offer qualitative guidance or outcomes and were thus considered unsuitable for this work and were removed ("qualitative outputs" step). The remaining indicators were assessed in terms of the regularity of their use. Those which were not reported in any literature, or those where it was not possible to confirm the previous filtering criteria, were also removed ("not applied" step). In some cases, an indicator may be reported as unavailable or unapplied but may also fall into one of the other filtering criteria. The process of filtering is illustrated in Figure 1, and a full list is given in Appendix A. This resulted in a final selection of eleven indicators shown in Table 1.

Benchmarking and comparison were undertaken to understand the suitability of the identified circularity indicator tools to assess the circularity of reusable packaging, and their alignment with the circular economy definition.

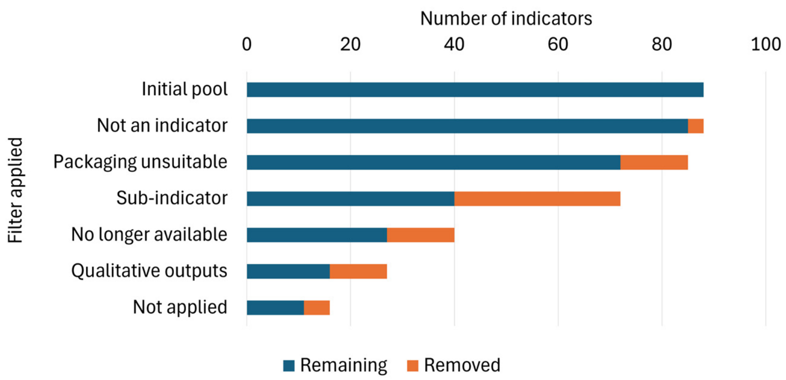


Figure 1. Filtering of indicators from the literature review to final selection.

Table 1. Selected circularity indicators from the literature review to be considered in the analysis.

Method	Acronym	Author
Product-Level Circularity Metric, C-metric	PLCM	Linder et al., 2017 [24]
Material Circularity Indicator	MCI	EMF & Granta, 2019 [25]
Longevity	Long.	Franklin-Johnson et al., 2016 [26]
Circular Footprint Formula in PEF	CFF	Zampori et al., 2019 [27]
Product Circularity Indicator	PCI	Bracquené et al., 2020 [21]

Table 1. *Cont.*

Method	Acronym	Author
Circularity Index	Circ(T)	Pauliuk et al., 2017 [28]
Value-based Resource Efficiency	VRE	Di Maio et al., 2017 [16]
Sustainable Circular Index	SCI	Azevedo et al., 2017 [29]
In-use occupation-based indicators	UOI	Moraga et al., 2021 [30]
Eco-costs Value Ratio	EVR	Scheepens et al., 2016 [31]
UP Scorecard V1.0	UPS	Single-Use Material Decelerator, 2025 [32]

3.2. Assessment of Indicators

The eleven circularity indicators identified from the refined literature review results were assessed using a scoring matrix and a specific case study. The literature review identified a number of circularity indicator scoring systems. The method developed during the ORIENTING project [8], which developed assessment systems from previous work [12,13], was used in this study to quantitatively assess circularity indicators. The method uses a scoring matrix, with each indicator given a score (A to D or N/A) in each of the subcategories across six overarching categories. Overall, 20 of the 57 subcategories in the method are defined for the assessment of circularity. Scoring criteria are defined in each subcategory ([8], Annex D), for example in the Stakeholder acceptance, credibility and suitability category and Acceptance by policymakers subcategory an A score is achieved if the method is endorsed by the EU, a B if endorsed by another multinational body, a C if endorsed by one or more EU countries, D if endorsed by one or more non-EU countries, and E if not accepted by any governmental or public bodies).

Scores can ultimately be combined to give a total score for the indicator. This scoring method was applied to the eleven indicators identified in the literature review (Table 1). Scoring categories and subcategories are given in Table 2.

In parallel, four indicators were tested using a case study. The indicators selected were the most commonly referenced in the literature review and are commonly seen in studies related to circularity of packaging. It was also noted that these indicators were able to provide fully quantitative results. Though other indicators were able to provide partially qualitative results (and were therefore not excluded during the “Qualitative only” filtering step), those that do not provide fully numerical results were difficult to include in this numerical case study.

The case study was assessed using the Material Circularity Index (MCI), the Product Circularity Indicator (PCI), Eco-costs Value Ratio (EVR), and UP Scorecard (UPS). A case study product, based on the Vytal reusable takeaway bowl from the BUDDIE-PACK project [33] was used to allow a comparative test in a realistic scenario. Three key variables were tested: recycled content, recycling level at end of life, and number of reuses. Recycled content was tested at levels of 25%, 50% and 75%. Recycling rate at end of life was tested at 50% and 100%, and the number of reuses was tested at 0, 50 and 100. All variables were combined and assessed in combination, giving 18 cases for each indicator.

The case study product is a 1250 mL bowl, manufactured from Polypropylene. The bowl is designed for use within the Vytal reuse system, which is offered as an alternative to single-use packaging in cafes and takeaway food locations across Europe. The design of the bowl considered in this case study was developed during the BUDDIE-PACK project, but the assessment of the ability of circularity indicators to compare recycled content, recycling level and reuse numbers is not contingent on the specific design of the case study. For the purposes of the case study, potential challenges related to additives and contamination were not considered, though their potential impact is discussed.

Table 2. Scoring categories and subcategories for assessment of circularity, from the method proposed by Bachmann et al. [8].

Category	Subcategories
Stakeholder acceptance, credibility and suitability	Acceptance by policymakers Acceptance by industry Acceptance by academia Acceptance by civil society Credibility among stakeholders
Applicability/complexity	Technical feasibility Data availability and accessibility (primary and secondary) Data intensity requirement
Transparency	Traceability of the modelling data and model used Transparency of documentation Reproducibility
Scientific robustness	Peer-reviewed or verified by a third party State-of-the-art Quality of the modelling data (spatial and temporal) Description of the uncertainties (factors, modelling data, other parameters)
Completeness	Ability to be applied to specific contexts Ability to be applied in unspecified contexts
Compatibility with life-cycle approach	Takes into account the life cycle thinking approach

Transport and washing can affect the viability and sustainability of a reuse system but are considered in only some circularity indicators. UP Scorecard includes assumptions for transport distance and washing water consumption based on the manufacturing and use locations specified in the model. MCI and PCI do not explicitly include washing and transport in calculations (a limitation highlighted in previous work [34]). Since EVR calculations are undertaken in Life Cycle Assessment software, transport and washing are included in the method if modelled correctly. Transport and washing were not assessed during the case study.

The calculation methods provided in the relevant publications were used to calculate MCI and PCI values. The PCI builds on the MCI, so the same values were used in both cases, with additional values such as efficiencies of feedstock production and material separation required by the PCI calculated in addition. Eco-costs Value Ratio results were calculated using the 2024 V1.0 impact assessment method, which was downloaded and used in SimaPro LCA software version 10.1. The UP Scorecard online tool works through built-in material cases or custom cases. Such a case was built to represent the Vytal case study bowl. Using this, the impact on results of variation in recycled content, recycling level and number of reuses was tested. It should be noted that the eco-costs, being an LCA-based method and therefore inherently focused on the impact caused by actions, differs from the other three methods considered here, which focus primarily on material circularity. Eco-costs inform the user of the cost of mitigating the environmental impact of a case, whereas the other methods inform the user of the level of circularity relative to a single-use baseline (UP Scorecard) or linear system (MCI and PCI). Though environmental impact and circularity are strongly linked and often follow the same trends, there can be conflicts between the two [35], so care is required when using one as a proxy for the other.

4. Results

4.1. Circular Economy Definition Alignment

As highlighted, the definition of circular economy is not only the study of the circularity of flows, but also the analysis of value preservation and sustainability. The eleven methods resulting from the literature review (Table 1) were compared to the definition of circular economy given by ISO 59004:2024 [10] and the three key elements therein (circular flow of resources, value, sustainable development) and were marked in Table 3 based on their apparent ability to include the element (✓), partially include the element (−), or exclude the element (✗). Definitions of the three components within ISO 59004:2024 are quite broad. Here, circular flow of resources was defined as being included if the indicator was able to differentiate between linear and circular flows; value was defined as being included if the indicator measured or demonstrated the retention or loss of product value, and sustainable development was defined as being included if the indicator presented outputs in relation to wider or longer-term environmental, social and economic sustainability.

Table 3. Assessment of circularity indicators against the three components of the ISO 59004:2024 definition of circular economy.

Indicator	PLCM	MCI	Long.	CFF	PCI	Circ(T)	VRE	SCI	UOI	EVR	UPS
Circular flow of resources	✓	✓	–	✓	✓	✓	–	–	✓	✓	✓
Value	–	✗	–	✗	✗	–	✓	–	–	✓	–
Sustainable development	–	✗	✗	✗	✗	✗	–	✓	✗	✗	✓

Most indicators included the circular flow of resources element, and most did not include the sustainable development element. Notable differences were the SCI [29], which appeared to include sustainable development, but did not fully include the value or circular flow of resources elements. PLCM and VRE include value calculations which incorporate economic elements, but do not include social impact calculations. UP Scorecard includes consideration of social and economic factors contributing to the sustainable development element of the definition and partially includes value calculations. PLCM and UP Scorecard appeared to be the closest to an assessment covering the full ISO 59004:2024 definition of circular economy.

4.2. Circularity Indicator Scoring Matrix

Results of the assessment using the method developed by Bachmann et al. [8] are shown in Table 4. Seven of eleven indicators were awarded an overall score of A or A-, with the other four scoring B or better. The lowest score of all was seen in the Stakeholder acceptance, credibility and suitability category, where the Value-based Resource Efficiency method (VRE) [16] method scored D+. This was largely due to a low score in the Credibility among stakeholders subcategory, due to an unclear definition of “stressed” resources, making it unclear which resources should be included in calculations. The Circularity index (Circ(T)) and Eco-costs Value Ratio (EVR) were the only methods not to score A in any category, but both ultimately scored B overall.

The category in which the fewest A scores were awarded was the Stakeholder acceptance, credibility and suitability category, followed by the Scientific robustness category. In the former category, low scores were most often driven by low scores in the Credibility among stakeholders subcategory due to opaque methodology or the use of techniques or methods only available to those with subject expertise or access to specific software or data. Low scores were also frequently seen in the Acceptance by industry subcategory, where methods were only available or relevant to academia and were not accepted or known in industry. In the Scientific robustness category, a notable difference was seen between scores in the first three subcategories (Peer-reviewed or verification from third party, State-of-the-art and Quality of the modelling data), in which most methods scored A or B scores, and the final subcategory (Description of the uncertainties behind the (characterisation) factors, modelling data, or other parameters used for the indicators). In this final subcategory, most indicators scored C or below due to a lack of discussion of uncertainty in the calculations. UP Scorecard V1.0 (UPS) [32] and Circularity index (Circ(T)) [28] were notable for their higher score in this subcategory, since both provided some uncertainty information.

Table 4. Overall and category results for eleven circularity indicator methods using the ORIENTING project method. Full subcategory results are given in Table A2 (Appendix B). Scoring is specific to each subcategory and defined in [8], ranging from A to D or N/A.

Indicator	PLCM	MCI	Long.	CFF	PCI	Circ(T)	VRE	SCI	UOI	EVR	UPS
Overall Score	A−	A	A−	A−	A−	B	B	B+	A−	B	A
Stakeholder acceptance, credibility and suitability	C	A+	B	B	B+	C+	D+	B	B+	B	B
Applicability/Complexity	A+	B	A	A	B	C+	A	B	B+	C	B
Transparency	A+	A	B	A	A	B+	C+	A	A+	B	A
Scientific robustness	A+	B	B	B+	B	B+	B	B+	A	B	B
Completeness	A+	A+	B+	B	A+	B+	A+	B+	C+	B	A
Compatibility with life-cycle approach	C+	A+	A+	A+	A+	C+	B+	C+	A+	C	A

4.3. Reusable Packaging Case Study

Four circularity indicators (Material Circularity Index (MCI), Product Circularity Indicator (PCI), Eco-costs Value Ratio and UP Scorecard, selected as described in Section 3.2) were compared using a case study.

Variation in three areas was used to test indicators using a case study: Recycled content percentage, percentage of material recycled at end-of-life, and number of reuses. Results of the case study (Figure 2) show normalised calculated scores from four circularity indicators when applied to the Vytal bowl case study, with variation in recycled content, end-of-life recycling and reuse numbers. The horizontal axis shows three sets of results for three levels of reuse: 0, 50 and 100 reuses. Within these, recycled content rates are shown at 25%, 50% and 100%. End-of-life recycling rates are illustrated by two bars on the chart: One showing 50% end-of-life recycling and one showing 100% recycling.

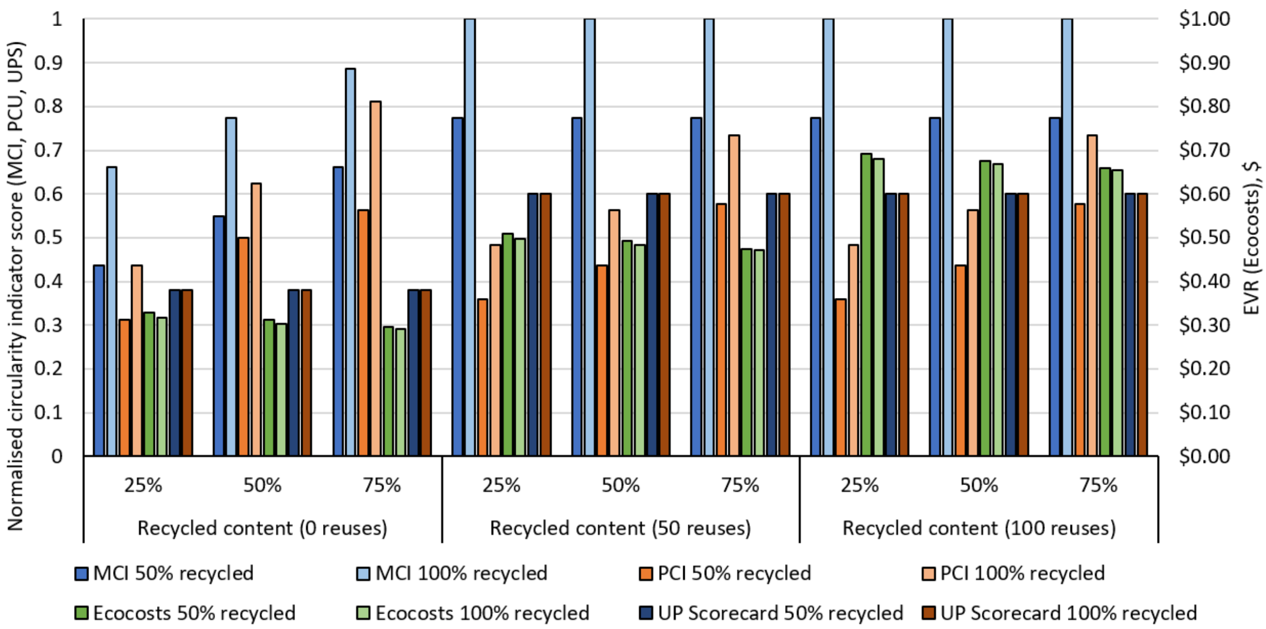
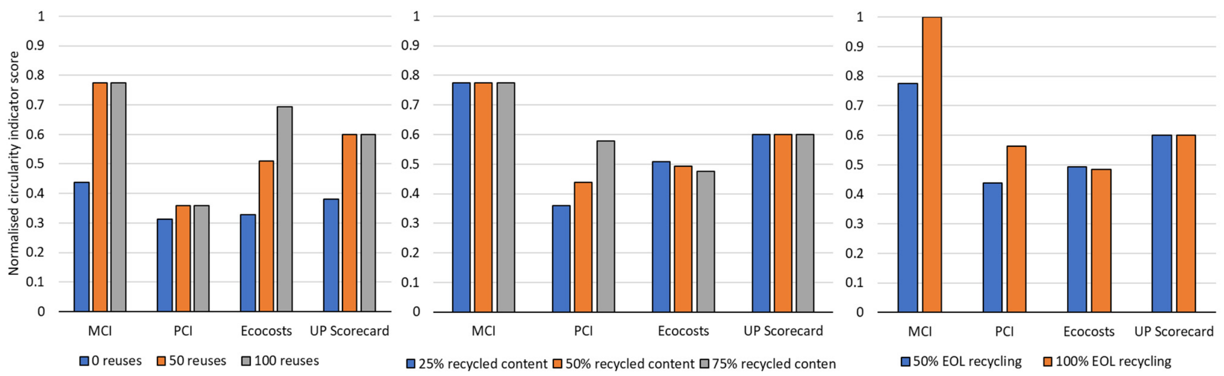


Figure 2. Variation in normalised circularity indicator scores for four circularity indicators for the case study at three recycled content levels, three reuse case numbers, and two end-of-life recycling level cases.

The vertical axis of Figure 2 illustrates the results of the circularity indicators. MCI and PCI both provide a dimensionless result between 0 and 1, eco-costs provide a result in US Dollars, and UP Scorecard provides a result between 0 and 100. MCI and PCI results were therefore presented using their original values and UP Scorecard results were divided by 100 to present them in the same range (left axis). Eco-cost results fell between $0.291 and $0.693, and values were presented on the same chart (right axis). These results are illustrated together since the focus of this study is to assess the potential for each method to resolve changes in recycled content, end-of-life recycling rates and reuse numbers by giving a different result for each combination, rather than absolute results.

These results show that, in general, the results of the four circularity indicators selected increased (indicating greater circularity) as recycled content, end-of-life recycling and reuse numbers increased. However, although this general trend was observed, not all methods showed increasing results with all variables. As Figure 3 shows, not all methods showed changes in circularity indicator value with changes in the number of reuses, recycled content or end-of-life recycling level. This is largely due to the use of discrete "yes or no" indicators rather than continuous indicators. For example, where a circularity indicator asks the user whether a product is reused or not, results will illustrate a difference between 0 reuses ("no") and 1 reuse ("yes"), but will not show any further difference between cases with 1, 100 or 1000 reuses (all "yes").



(**a**) (**b**) (**c**)

Figure 3. Variation in normalised circularity indicator scores for four circularity indicators: (**a**) number of reuses (at 25% recycled content and 50% EOL recycling). (**b**) Recycled content (at 50 reuses and 50% EOL recycling). (**c**) EOL recycling (at 50 reuses and 50% recycled content).

Figure 3 illustrates this effect when only a single feature is varied, but the effect is compounded when multiple effects are considered, as illustrated in Figure 2. This results in some indicators showing no difference between cases with varying reuse numbers and levels of recycled content.

Examples of this can be seen in results for the MCI method when reuse numbers or recycled content were varied. Whilst the calculated MCI result increases with increasing recycled content when the container is not reused, results do not change with recycled content when the container is reused, and the method gives the same result for any recycled content and any number of reuses greater than zero. This is a structural feature of the MCI method. Similar results have been reported in previous case studies [36]. The PCI method does provide different results for varying recycled content, but again does not differentiate for reuse numbers greater than zero.

In contrast to the MCI and PCI methods, eco-cost results do differ between each case, distinguishing between recycled content, reuse number, and recycling at end-of-life and giving a different quantitative result in each case.

4.4. Insensitivity to End-of-Life Recycling

The UP Scorecard does not allow representation of variance in end-of-life recycling, only a binary “yes or no” selection. Consequently, 50% and 100% end-of-life recycling cases give identical results. The UP Scorecard summary result is made up of the subcategories described in the previous section (Plastic Pollution, Chemicals of Concern, Climate, Water use, Sustainable Sourcing and Recoverability). Changing reuse numbers and recycled content did lead to variation in individual scores for plastic pollution, water use and climate, but due to the maximum (100) scores given to Sustainable Sourcing and Recoverability in every case, this variation is lost in the final score. For example, changing from 50 to 100 reuses changed the Plastic Pollution result from 95 to 98 and the Climate result from 39 to 41. However, when combined with identical results for the Chemicals of Concern (22), Water use (1), Sustainable Sourcing (100) and Recoverability (100), the final result is 60 in both cases. In the case study considered, only two different final scores resulted: 38 for cases with no reuse, and 60 for cases with 50 or 100 reuses (shown in Figure 3 as 0.38 and 0.60 respectively).

5. Discussion

Eco-costs Value Ratio (EVR) and UP Scorecard (UPS) were identified as meeting two or more of the three elements of the ISO definition of circular economy. Product-Level Circularity Metric (PLCM), Material Circularity Indicator (MCI), Longevity, Circular Footprint Formula in PEF (CFF), Product Circularity Indicator (PCI), In-use occupation-based indicators (UOI) and UPS scored A or A- in the scoring system, and of the four methods considered in the case study, EVR and PCI were the best able to resolve variation in reuse and recycled content. No one indicator performed well across the three methods used to assess indicators, but EVR, PCI and UPS each performed well in two out of three.

Overall, PCI is likely to be the most useful method for assessment of packaging in the context of recycled content, end-of-life recycling and reuse. However, additional calculation would be required alongside the method to provide any understanding of wider impacts.

The Eco-costs Value Ratio method provides valuable insight and is able to resolve compound differences within recycled content, end-of-life recycling and number of reuses. However, it has significant barriers to widespread adoption, such as the requirement for Life Cycle Assessment software and expertise, bringing with it licensing costs and potential data availability challenges due to more complex input data requirements. The method does not provide information on the sustainable development element of the circular economy definition.

The UP Scorecard method scored well in the matrix assessment and offers major advantages when considering wider impacts beyond those considered in the case study. It allows some variation in recycling rates and recycled content to be considered, but does not resolve the full compound variation as the Eco-costs Value Ratio method was able to. However, the wider range of additional impacts and the relative ease of use may make this method the best choice for representation of holistic circularity.

The four tools considered in the case study all have advantages. The MCI is the simplest to use but is unable to differentiate between different circularity strategies; the PCI enables this differentiation to a degree but is more complex and does not differentiate levels of recycled content. The Eco-costs Value Ratio results do distinguish between recycling, reuse and end-of-life cases, but the method is complex to use and lacks the efficiency and transparency of other circularity indicators. The UP Scorecard is relatively easy to use and enables the inclusion of reuse, as well as washing and transport, but includes only a broad consideration of circularity and does not differentiate between different levels of recycling or recycled content. This tool appears to offer the best current balance of simplicity, completeness, and transparency and whilst it does not yet fully enable the integration of reuse into circularity assessment, its use alongside other tools would enable this.

Limitations

Though not explicitly tested during this case study, transport and washing processes are an important aspect of reuse systems. MCI and PCI are unable to represent differences in transport distance or washing procedures directly, and results would only change if other factors were influenced, such as fraction of material recovered or design life. UP Scorecard and Eco-costs Value Ratio are able to represent washing and transport variation. The exclusion of these factors is a limitation of the present study. Additives and potential contamination were also not explicitly considered in this case study. However, the inclusion of material processing efficiency factors in the PCI calculation enables this method to consider these impacts, whereas the MCI is not equipped to do so. The underlying LCA model used in an Eco-costs Value Ratio calculation would enable the inclusion of these effects, and through modification of generic cases it would also be possible to include these effects in the UP Scorecard method.

6. Conclusions

This work aims to evaluate whether circularity indicators enable the integration of reuse into circularity assessment, in accordance with the waste hierarchy. After identifying 88 circularity indicators via literature review, eleven were assessed against the ISO 59004:2024 definition of circular economy and scored using an assessment methodology. Four that provide numerical outputs were compared via a case study. Though only one case study was undertaken, and further similar studies would be beneficial to the sector, the findings are meaningful and illustrate a number of limitations in currently available circularity indicators.

A key finding from this assessment of circularity indicators is that despite the large and growing number of indicators, and the growing body of literature on the subject, reuse is not fully represented in circularity indicators relevant to packaging. Whilst reuse is included in many indicators, details on reuse numbers are often neglected and a simple "yes or no" indicator is used. This makes the comparison of different reuse systems using circularity indicators challenging. The studied indicators enable assessment of the circularity of a product but lack granularity to fully incorporate the impact of reuse alongside other factors such as recycled content, end-of-life recycling, ease of use, transparency and completeness, and wider elements of the circular economy.

This work suggests that the best route to a holistic assessment of circularity to the ISO 59004:2024 definition using currently available indicators is a combination of PCI and UP Scorecard. The former provides detail on the circularity element of the circular economy definition with the greatest level of detail available without significant barriers to use, and the latter enables a product to be considered against the full definition of the circular economy. In comparison to using one single assessment method, this combination naturally increases the level of user input required. However, some input data is relevant to both methods, so the input is not equivalent to calculating both methods for separate cases. The usefulness of results from two methods may present challenges when communicating outputs, and this work suggests results are presented independently for each of the three components of the ISO 59004:2024 definition of circular economy, with PCI calculations used for the circular flow of resources component, and UP Scorecard for value and sustainable development. As with any method, results should be presented clearly and transparently, and the chosen methods explained.

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Future circularity indicators should enable the assessment of reuse beyond this combined method, and allow all elements of the circular economy to be considered using one system. Including levels of reuse would enable circularity indicators to better represent the opportunities and compare benefits of reuse, both against other reuse systems and other options in the waste hierarchy.

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Abbreviations

The following abbreviations are used in this manuscript:

LCA	Life Cycle Assessment
PLCM	Product-Level Circularity Metric
MCI	Material Circularity Indicator
Long.	Longevity
CFF	Circular Footprint Formula in PEF
PCI	Product Circularity Indicator
Circ(T)	Circularity Index
VRE	Value-based Resource Efficiency
SCI	Sustainable Circular Index
UOI	In-use occupation-based indicators
EVR	Eco-costs Value Ratio
UPS	UP Scorecard
EOL	End Of Life
UNEP	United Nations Environment Programme

Appendix A

As discussed previously and illustrated in Figure 1, a series of filtering steps were used to remove indicators from the initial pool that were not suitable as indicators, not packaging-relevant, sub-indicators, no longer available, provided only qualitative information, or were not in regular use. The detailed filtering of these indicators and the steps at which each indicator not included in the final selection was removed are shown in Table A1.

Table A1. Refinement of indicator pool from 88 indicators to final selection. '×' indicates the filtering stage at which the indicator was removed. Final selection of indicators is shown in bold.

Title	Acronym	Author	Not an Indicator	Non-Packaging	Sub-Indicator	No Longer Available	Qualitative Only	Not Applied
Assessing Circular Trade-offs	ACT	Circle Economy and PGGM, 2014 [37]						×
Building Circularity Indicators	BCI	Verberne, 2016 [38]		×				
Material Reutilization Part	C2C	C2C, 2014 [39]					×	
Circle Assessment	CA	Circle Economy and PGGM, 2014 [37]						×
Circularity Assessment Tool	CAT	PGGM, 2015 [40]					×	
Circular Benefits Tool	CBT	Advancing Sustainability LLP, 2013 [41]				×		
Circularity Calculator	CC	ResCoM, 2017 [42]					×	
Circular Economy Company Assessment Criteria	CECAC	Verberne, 2016 [38]				×		
Circular Economy Index	CEI	Di Maio and Rem, 2015 [43]					×	
Circular Economy Indicators for India	CEII	Talwar, 2017 [44]		×				
Circular Economy Indicator Prototype	CEIP	Cayzer et al., 2017 [45]				×		
Circular Economy Monitoring Framework	CEMF	European Commission, 2017 [46]		×				
Circular Economy Performance Indicator	CEPI	Huysman et al., 2017 [47]				×		
Circular Economy Toolkit	CET	Evans and Bocken, 2013 [48]				×		
Circular Economy Toolbox US	CETUS	US Chamber Foundation, 2017 [49]		×				
Circular Economic Value	CEV	Fogarassy et al., 2017 [50]		×				
Circularity Index	Circ.	Cullen, 2017 [22]						
Circular Impacts Project EU	CIPEU	European Commission, 2016 [51]				×		
Circularity Material Cycles	CIRC	Pauliuk et al., 2017 [28]				×		
Closed Loop Calculator	CLC	Kingfisher, 2014 [52]						×
Circular Pathfinder	CP	ResCoM, 2017 [42]					×	
Circularity Potential Indicator	CPI	Saidani et al., 2019 [13]						×
Super-efficiency Data Envelopment Analysis Model	DEA	Wu et al., 2014 [53]		×				
Evaluation of CE Development in Cities	ECEDC	Li et al., 2010 [54]		×				
Evaluation Indicator System of Circular Economy	EISCE	Zhou et al., 2013 [55]				×		
Indicators for Material input for CE in Europe	EMCEE	EEA, 2016 [56]			×			
End-of-Life Recycling Rates	EoL-RRs	Graedel et al., 2011 [57]			×			
Environmental Protection Indicators in a context of CE	EPICE	Su et al., 2013 [58]		×				
Evaluation of Regional Circular Economy	ERCE	Chun-Rong & Jun, 2011 [59]		×				
Eco-efficient Value Ratio	EVR	Scheepens et al., 2016 [31]						
Economy-Wide Material Flow Analysis	EWMFA	Haas et al., 2015 [60]			×			
Five Category Index Method	FCIM	Li & Su, 2012 [61]				×		
Hybrid LCA Model	HLCAM	Genovese et al., 2017 [62]	×					

Table A1. *Cont.*

Title	Acronym	Author	Not an Indicator	Non-Packaging	Sub-Indicator	No Longer Available	Qualitative Only	Not Applied
Indicators for Consumption for CE in Europe	ICCEE	EEA, 2016 [56]				×		
Circularity Indicator Project	ICT	Viktoria Swedish ICT, 2015 [63]				×		
Indicators for Eco-design for CE in Europe	IECEE	EEA, 2016 [56]						×
Indicators of Economic Circularity in France	IECF	Magnier, 2017 [64]		×				
Integrative Evaluation on the Development of CE	IEDCE	Qing et al., 2011 [65]	×					
Input-Output Balance Sheet	IOBS	Marco Capellini, 2015 [66]			×			
Indicators for Production for CE in Europe	IPCEE	EEA, 2016 [56]			×			
Industrial Park Circular Economy Indicator System	IPCEIS	Geng et al., 2012 [67]		×				
Material Circularity Indicator	MCI	EMF, 2015 [25]						
Measuring Regional CE–Eco-Innovation	MRCCEI	Smol et al., 2017 [68]		×				
National Circular Economy Indicator System	NCEIS	Geng et al., 2012 [67]				×		
Product-Level Circularity Metric	PLCM	Linder et al., 2017 [24]						
Regional Circular Economy Development Index	RCEDI	Guo-gang and Jing, 2011 [69]	×					
Resource Duration Indicator	RDI	Franklin-Johnson et al., 2016 [26]			×			
EU Resource Efficiency Scoreboard	RES	EC, 2015 [70]			×			
Recycling Indices for the CE	RIs	Van Schaik and Reuter, 2016 [71]			×			
Resource Productivity	RP	Wen and Meng, 2015 [72]			×			
Reuse Potential Indicator	RPI	Park and Chertow, 2014 [73]			×			
Recycling Rates	RRs	Haupt et al., 2017 [74]			×			
Sustainable Circular Index	SCI	Azevedo et al., 2017 [29]						
Value-based Resource Efficiency	VRE	Di Maio et al., 2017 [16]						
Zero Waste index	ZWI	Zaman and Lehmann, 2013 [75]			×			
Eco-costs		Vogtlander, 2001 [76]			×			
REPRO2		Gehin, 2008 [77]					×	
Linear Flow Index	LFI	EMF—Ellen MacArthur Foundation, 2015 [78]			×			
Utility factor	F(x)	EMF—Ellen MacArthur Foundation, 2015 [78]			×			
Old scrap collection rate	CR	Graedel et al., 2011 [57]			×			
Recycling rate	RR	Graedel et al., 2011 [57]			×			
EoL recycling rate	EOL-RR	Graedel et al., 2011 [57]			×			
Recycling input rate	RIR	Graedel et al., 2011 [57]			×			
Old scrap ratio	OSR	Graedel et al., 2011 [57]			×			
Longevity		Franklin-Johnson et al., 2016 [26]						
Total Restored Products	TRP	Pauliuk, 2017 [28]			×			
Lifetime of Materials on Anthroposphere	LMA	Pauliuk, 2018 [79]			×			
Ease of Disassembly Metric	eDiM	Vanegas et al., 2018 [80]			×			
Global Resource Indicator	GRI	Adibi et al., 2017 [81]		×				

Table A1. *Cont.*

Title	Acronym	Author	Not an Indicator	Non-Packaging	Sub-Indicator	No Longer Available	Qualitative Only	Not Applied
Average Number of Times of Use of a Material in Society	NTUM	Daigo, Matsuno & Adachi, 2007 [82]			×			
Circularity Design Guidelines	CDG	Bovea and Pérez-Belis, 2018 [83]					×	
Model of Expanded Zero Waste practice	MEZWP	Veleva et al., 2017 [84]			×			
Material Reutilization Score	MRS	Cradle2Cradle, 2016 [85]			×			
Product Circularity Indicator	PCI	Bracquené et al., 2020 [21]						
Recycling Desirability Index	RDI	Mohamed Sultan et al., 2017 [20]			×			
Quality model for recycled plastics	QMRP	Golkaram et al., 2022 [18]			×			
Packaging Index	PIX	Scagnetti et al., 2022 [17]					×	
Reusable packaging in circular supply chains		Betts et al., 2022 [19]					×	
Circular Design Guidelines	CDG	Bovea & Pérez-Belis, 2018 [83]					×	
Circularity Calculator	CC	IDEAL&CO Explore, 2016 [86]					×	
Combination Matrix	CM	Figge et al., 2018 [87]				×		
End-of-life Index	I	Lee et al., 2014 [88]			×			
In-Use Occupation Indicator	IUOI	Moraga et al., 2021 [30]						
Reuse Potential Indicator	RPI	Park & Chertow, 2014 [73]			×			
Recyclability Benefit Rate	RBR	Huysveld et al., 2019 [89]			×			
Degree of material cycle closure	DOMC	Nelen et al., 2014 [90]			×			
UP Scorecard V1.0	UPS	Single-Use Material Decelerator, 2025 [32]						
Circular Footprint Formula in PEF	CFF	Zampori et al., 2019 [27]						

Appendix B

Table A2 gives full category and subcategory scores for the eleven indicator methods considered in detail. This table presents the full results of those presented in simplified format in Table 4.

Table A2. Full category and subcategory results for eleven circularity indicator methods using the ORIENTING project assessment method. Simplified category results are given in Table 4.

Indicator	PLCM	MCI	Long.	CFF	PCI	Circ(T)	VRE	SCI	UOI	EVR	UPS
Overall Score	A-	A	A-	A-	A-	B	B	B+	A-	B	A
Stakeholder acceptance, credibility and suitability	**C**	**A+**	**B**	**B**	**B+**	**C+**	**D+**	**B**	**B+**	**B**	**B**
Acceptance by policymakers	N/A	N/A	N/A	A	N/A	N/A	N/A	N/A	N/A	N/A	B
Acceptance by iIndustry	C	A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	B	B
Acceptance by academia	D	A	C	C	A	B	C	C	C	B	B
Acceptance by civil society	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Credibility among stakeholders	C	A	B	D	C	D	E	B	A	B	B
Applicability/complexity	**A+**	**B**	**A**	**A**	**B**	**C+**	**A**	**B**	**B+**	**C**	**B**
Technical feasibility	A	A	A	A	A	A	A	A	A	B	A
Data availability and accessibility	A	N/A	B	B	C	C	A	C	C	N/A	N/A
For primary data (activity data)	N/A	C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C	C
For secondary data (activity data)	N/A	C	N/A	N/A	N/A	N/A	N/A	N/A	N/A	C	B
Data-intensity requirement	A	C	A	A	C	E	C	C	B	C	C
Transparency	**A+**	**A**	**B**	**A**	**A**	**B+**	**C+**	**A**	**A+**	**B**	**A**
Traceability of the modelling data and model used	A	A	C	A	A	D	A	A	A	A	A
Transparency of documentation	A	A	A	A	A	A	C	A	A	B	A
Reproducibility	N/A	C	C	C	C	A	E	C	A	C	C
Scientific robustness	**A+**	**B**	**B**	**B+**	**B**	**B+**	**B**	**B+**	**A**	**B**	**B**
Peer-reviewed or verified by a third party	A	A	A	A	A	A	A	A	A	A	A
State-of-the-art	A	A	A	A	A	A	A	A	A	B	A
Quality of the modelling data	N/A	C	C	B	N/A	C	N/A	C	N/A	B	C
Description of characterisation uncertainties	N/A	E	E	E	E	C	E	D	C	D	E
Completeness	**A+**	**A+**	**B+**	**B**	**A+**	**B+**	**A+**	**B+**	**C+**	**B**	**A**
Ability to be applied to specific contexts	A	A	C	D	A	C	A	A	C	B	A
Ability to be applied in unspecified contexts (generalisation)	A	A	A	A	A	A	A	C	A	B	B
Compatibility with life-cycle approach	**C+**	**A+**	**A+**	**A+**	**A+**	**C+**	**B+**	**C+**	**A+**	**C**	**A**
Takes into account the life cycle thinking/approach	C	A	A	A	A	C	B	C	A	C	A

Appendix C

A summary of the calculation methods applied in each of the four methods considered in the case study is given below.

Appendix C.1. Material Circularity Index (MCI)

The MCI calculation method follows that described in the original publication by the Ellen MacArthur Foundation [25]. A key step in the method is the calculation of a Linear Flow Index (*LFI*) from a series of input variables and prior calculations. The LFI is calculated as follows:

$$LFI = \frac{V + W}{2M + \frac{W_{rfp} - W_{ms}}{2}}$$

where V is the mass of virgin material, calculated from the total mass M minus the masses of reused and recycled materials, and W is the mass of waste, calculated from the total collected waste minus waste from material separation (W_{rfp}) and from recycled feedstock production (W_{ms}). Fundamentally, the LFI gives the ratio of material subject to linear flow to overall mass.

The final MCI value is then the product of the LFI and a utility factor X. X is calculated based on industry average values of design life and use intensity.

Appendix C.2. Product Circularity Index (PCI)

The PCI calculation method follows that described by Bracquené et al. [21] (which gives a useful side-by-side overview of the MCI and PCI calculation methods). As in the MCI, the PCI method also calculates a Linear Flow Index (*LFI*). The PCI calculation is more complex, incorporating net exchanges of recycled material ($|R|$) and reused components ($|C|$)

$$LFI = \frac{V + W + \frac{1}{2}\,|R| + \frac{1}{2}\,|C|}{V_{linear} + W_{linear}}.$$

Recycled material net exchange ($|R|$) is calculated using recycled content, mass of recycled elements, and efficiency of material recycling. $|C|$ is calculated similarly, considering the fraction of reused components.

Again, the LFI is used to calculate the final value of the indicator by using a utility factor X.

Appendix C.3. UP Scorecard

The UP Scorecard calculation method is undertaken using an online tool. Firstly, the product region of use and use case are selected. A series of use case examples are provided (such as cold drink cups, hot drink cups, straws, bottles, cold food containers, hot food containers, utensils, etc.). Following selection of a product, the user answers questions that inform the scorecard calculation across the six subsections. First, the product type that will be contained is selected or defined. The user then selects products to compare and can view results for the calculation.

The initial calculation includes a large range of assumptions, such as reuse numbers, recycled content, product mass and volume, chemicals of concern and transport distance. These and many more input values can be adjusted, or default values can be used.

Final results are given as a numerical score for each category (Climate, Water use, Chemicals of Concern, Sustainable Sourcing, Recoverability, and Plastic Pollution), summarised into a final score.

Appendix C.4. Eco-Costs Value Ratio (EVR)

As highlighted, a key difference between the other three methods considered in the case study and the EVR method is the requirement for implementation of EVR in Life Cycle Assessment software. The Eco-costs Value Ratio can be calculated using various Life Cycle Assessment software packages, and may therefore require a software licence. Whereas the UP Scorecard method uses a questionnaire approach and the MCI and PCI methods rely on data and calculation, the EVR method relies on a user with the ability to build and run an LCA model.

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