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Circularity Indicators for Packaging: A Literature Review and System-Based Classification

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Abstract: The transition to a Circular Economy (CE) in the packaging industry is vital to address growing environmental problems. Circularity indicators play a critical role in evaluating progress and guiding decision-making. However, existing indicators lack suitability for packaging and do not factor in the systemic considerations required for successful transition to CE. This study identified 21 circularity indicators relevant to packaging, critically assessing their: suitability for the packaging industry; and inclusion of systemic considerations across lifecycle stages such as sourcing, design and production, distribution, use, and end-of-life. Using a three-point scale (extensive inclusion, partial inclusion and none), the indicators are classified to establish the extent to which they consider systems, such as Packaging Characteristic, Infrastructure, Value and Regulation. The analysis highlights several gaps, including overemphasis on end-of-life systems, limited consideration of value for stakeholders, insufficient alignment with upstream systems, and inadequate consideration of regional infrastructure and regulation. The findings underline the need for future indicators to adopt a holistic approach, integrating diverse systems to enable effective CE strategy implementation. By highlighting these gaps, this research lays the groundwork for developing robust indicators that not only assess circularity but also guide the packaging industry toward a realistic implementation of CE strategies.

Introduction

Packaging refers to products used for the containment, protection, handling, delivery, and presentation of goods as they move from the manufacturer to the consumer (*Packaging*, 2025). While packaging is essential for safeguarding goods throughout their lifecycle, it is also a major contributor to environmental problems. Packaging waste, often ending up as litter or in landfills, not only harms the environment but also results in a considerable loss of valuable resources (Pongracz, 2007). This problem is driven by the current linear economy system of “take-make-dispose,” which prioritises short-term use over long term resource conservation (Murray, 2017).

One emerging way to tackle this problem is to consider circular economy (CE) strategies, such as reduce, reuse, recycle etc. for designing packaging solutions (Kirchherr et al., 2017). The CE is a restorative and regenerative system in which resource input and waste, emissions, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops (Geissdoerfer et al., 2017). CE strategies are also advocated by legislations such as the new circular economy action plan, which aims to make packaging reusable and recyclable by 2030 (NCEAP, 2021). Additionally, the Packaging and Packaging Waste Regulations (PPWR) aims to promote CE strategies such as reduce and high-quality recycling (*PPWR*, 2022).

A system-based approach to CE transition

While the CE holds immense potential, its transition remains slow and inconsistent, with a significant gap between its conceptual promise and real-world implementation (Mubarik et al., 2024). Its implementation is impeded by numerous challenges and without addressing these, a true CE will remain unattainable (Velis, 2018). Existing literature highlights these challenges. Bressanelli et al. (2019), identified 24 challenges and categorised them into economic and financial viability, market and competition, product characteristics, standards and regulation, supply chain management, technology, and user behaviour. Similarly, Mubarik et al. (2024) categorised challenges into policy, economic incentives, consumer engagement, market dynamics, stakeholder engagement, operational, and logistics. While these categorisations are insightful, fragmenting CE issues and treating them in isolation can hide their interdependencies (Iacovidou et al., 2021). For example, improving

recycling technology alone will not solve the problem of waste if collection and sorting systems are inadequate. Similarly, even if technology and supply chain inefficiencies are addressed, regulatory restrictions may still prevent recycled materials from entering regulated markets, such as food grade. Therefore, a systems-based approach is necessary to incorporate these interdependencies. Zeeuw Van Der Laan & Aurisicchio (2021) addressed this by classifying CE systems into principle, value, actor, data, infrastructure, and resource, emphasising that the integration of their elements is critical to overcoming systemic barriers. We suggest that these systems should be considered into the tools supporting the transition to a CE, enabling a more realistic assessment of CE strategies.

Circularity indicators for CE transition

Circularity indicators, especially micro-level indicators that assess the circularity of products, components, and materials (Kirchherr et al., 2017), are emerging as essential tools for evaluating and tracking progress. By measuring circularity, these tools inform the product design process and provide decision-makers with insights on how to redesign products to align with CE strategies. For example, the material circularity indicator (MCI) is the most commonly cited and used indicator (Vadoudi et al., 2022; Elia et al., 2017). It has been developed to measure how restorative flows are maximised and linear flows are minimised (EMF, 2021). However, the MCI has limitations in the packaging context. It allows users to input general recycling rate based on the material type (e.g. plastics, glass), while ignoring critical packaging characteristics such as shape, size, and colour, which significantly influence the recycling rates (CEFLEX, 2024). Moreover, the MCI does not account for local recycling infrastructure and regulations, both of which are critical in determining the feasibility of circularity strategies. Similarly, indicators designed for disassembly, such as Disassembly Effort Index (DEI), and Ease of disassembly (EDT) are unsuitable for packaging, as packaging is generally not designed for disassembly (Matos et al., 2024).

Packaging challenges hindering the adoption of circularity indicators can be summarised as follows:

- Short lifespan and single-use nature of packaging limits the suitability of indicators developed for durable products with longer lifecycles and strategies like repair or remanufacturing.
- Low material value of packaging materials, especially single-use plastics reduces economic incentives for recycling and reuse (Bening et al., 2021).
- Circularity indicators focusing primarily on isolated aspects of circularity rather than the broader interconnected systems that underpin circularity (Corona et al., 2019; Saidani et al., 2017).
- Material and design complexity existing in packaging, such as use of multilayered materials, adhesives, and additives, making it more difficult to recycle than monomaterial products (Walker et al., 2020).

Overall, the challenges highlight the pressing need for including systemic considerations in the formulation of micro-level circularity indicators to ensure their suitability to the packaging sector.

Aim of study

This study aims to identify existing micro-level indicators which are suitable for measuring packaging circularity and consider if the systems essential to the transition toward a CE are accounted for by such indicators. The research focuses on two key objectives:

- *Assess indicators' suitability for packaging*: Identify the circularity indicators which are specifically designed or adaptable to packaging-related CE strategies.
- *Classify indicators based on systemic considerations*: Analyse the extent to which these indicators include system considerations essential for circularity.

Methodology

This study uses comprehensive literature review and classification analysis to identify micro-level indicators and classify them based on their suitability for packaging and inclusion of systemic considerations.

Literature review:
General CE indicators search
The review followed a systematic approach to identify and analyse micro-level CE indicators. The process began with a broad literature search in databases such as Scopus and

Google Scholar using combinations of terms from this list: “micro", “product”, “circular economy", "circularity", "measure", "indicators", "indices", "index", and "metrics”. The results were restricted by the English language and year range from 2009 to the submitted date of this research.

We focused on review papers for their structured compilation of diverse sources. From these, we traced references to identify the original sources for each indicator mentioned and analysed them to ensure a comprehensive and accurate identification of existing micro-level indicators. From this initial search, 10 systematic review papers were identified (Corona et al., 2019; De Oliveira et al., 2021; De Pascale et al., 2021; Kristensen & Mosgaard, 2020; Matos et al., 2023; Moraga et al., 2019; Parchomenko et al., 2019; Roos Lindgreen et al., 2020; Saidani et al., 2019; Vural Gursel et al., 2023). These papers were selected for their structured evaluation of CE indicators across various domains. From these papers, 247 micro-level indicators were first identified. Afterwards, the identified indicators underwent a rigorous screening process based on the following exclusion criteria:

- *Duplicate Removal*: Duplicate indicators across different papers were removed.
- *Clarity*: Indicators lacking a clear methodology were excluded.
- *CE-Specific Relevance*: General sustainability indicators, such as those derived from Life Cycle Assessment (LCA), were omitted.
- *Packaging Suitability*: Indicators specific to processes like disassembly, refurbishing, and remanufacturing which are typically not relevant for packaging were removed.

This phase reduced the number of indicators from 247 to 18.

Packaging-Specific CE indicators search
To address the unique requirements of packaging circularity, an additional search using the keywords “packaging” “circularity", "measure", "indicators", "indices” “index", and "metrics” was conducted in Scopus and Google Scholar databases. The search identified 3 packaging-specific indicators; these include the Reusable Packaging in Circular Supply Chains (RPSC) (Betts et al., 2022), the Quality Model for Recycled Plastics (QMRP) (Golkaram et al., 2022a), and the Packaging Index (PIX) (Scagnetti et al., 2022). These 3 indicators,

along with the 18 identified from the general CE indicators search and screening, brought the total number of relevant CE indicators for packaging to **21**. The final list of 21 CE indicators is shown in (Table 1).

Indicator	**Authors**
Value-based resource efficiency (VRE)	(Di Maio et al., 2017)
Quality model for recycled plastics (QMRP)	(Golkaram et al., 2022b)
Packaging Index (PIX)	(Scagnetti et al., 2022)
Circular Economy Toolkit (CET)	(Bocken, N.M.P., 2013)
Circular Economy Index (CEI)	(Di Maio & Rem, 2015)
Product Circularity Indicator (PCI)	(Bracquené et al., 2020)
Recycling Desirability Index (RDI)	(Mohamed Sultan et al., 2017)
Reusable packaging in circular supply chains	(Betts et al., 2022)
Circularity Index (CI)	(Cullen, 2017)
Circular Design Guidelines (CDG)	(Bovea & Pérez-Belis, 2018)
Circularity Calculator (CC)	(IDEAL&COExplore, 2016)
Combination Matrix (CM)	(Figge et al., 2018)
Product Level Circularity Metric (PLCM)	(Linder et al., 2017)
Circular Economy Indicator Prototype (CEIP)	(Cayzer et al., 2017)
Material Circularity Indicator (MCI)	(EMF, 2021)
Circular economy performance indicator (CPI)	(Huysman et al., 2017)
End-of-life Index (-I)	(Lee et al., 2014)
In-Use occupation Indicator (IUOI)	(Moraga et al., 2020)
Reuse Potential Indicator (RPI)	(Park & Chertow, 2014)
Recyclability Benefit Rate (RBR)	(Huysveld et al., 2019)
Degree of material cycle closure (DOMC)	(Nelen et al., 2014)

Table 1 : CE Indicators identified from literature review

Systems-based classification to analyse indicators

Building on the broader classification by Zeeuw Van Der Laan & Aurisicchio (2021), this study proposes a system-based classification to analyse indicators focusing on four key systems: Packaging Characteristic (PC),

Infrastructure (I), Value (V), and Regulation (R). The systems and their definitions along with corresponding system elements are shown in (Table 2). With reference to the broader classification mentioned above, the PC system maps to Resource, the I system to Infrastructure, the V system to Value, and the R system to Principle. These four systems can feature across each of the five lifecycle stages, namely Source (S), Design and Production

(D&P), Distribution (Di), Use (U), and EOL. To evaluate the degree of consideration of these systems in the formulation of indicators, a classification criterion was developed based on inclusion of system elements at each lifecycle stage. The system elements (SE) at each lifecycle stage were extracted from the circular design guidelines (CEFLEX, 2024; RECOUP, 2024; Recyclass, 2024) and regulatory documents (e.g. *PPWR*, 2022).

Systems	Definition	Lifecycle stage	System Elements
Packaging Characteristic	The physical packaging that moves through various stages of the lifecycle.	S	Virgin, recycled, biological
		D&P	Packaging material, labels, attachments, additives, fillers, colour, adhesives, dimensions, shape
		Di	Packaging material, labels, attachments, additives, fillers, colour, adhesives, dimensions, shape
		U	Packaging material, labels, attachments, additives, fillers, colour, adhesives, dimensions, shape
		EOL	Packaging material, labels, attachments, additives, fillers, colour, adhesives, dimensions, shape
Infrastructure	The physical, technical, and organizational structures that support the circular flow of packaging.	S	Equipment for procuring raw materials and transport infrastructure
		D&P	Manufacturing equipment and filling lines
		Di	Transport vehicles
		U	Reverse logistics systems for reuse
		EOL	Regional kerbside collection bins, sorting, and recycling infrastructure
Value	Value is derived from services, transactions, and resource management between stakeholders	S	Raw materials cost
		D&P	Manufacturing cost, Labour cost, Filling cost
		Di	Transportation cost for distributors and retailers
		U	Packaging selling price
		EOL	Packaging Collection cost, sorting cost and Processing cost
Regulation	The legal frameworks, policies, standards, and enforcement mechanisms that guide and influence CE strategies.	S	Substances of concern, sustainable sourcing, and regenerative practices
		D&P	Provision for minimising packaging weight and volume to avoid overpackaging
		Di	Reuse transport packaging
		U	Compliance with food safety, chemical substance regulations, and information labelling requirements
		EOL	High-quality recycling and collection, recycling, and reuse targets, EPR costs

Table 2. CE Systems for Packaging

The indicators are categorised into three levels of systemic inclusion at each stage:

- **Extensive inclusion**: An indicator is classified with this label if it includes equal two or more than half of the mentioned system elements. If there is a single system element for a lifecycle stage, then inclusion of that will be considered as extensive.
- **Partial inclusion**: An indicator is classified with this label if it includes less than half of the mentioned system elements.
- **No inclusion**: An indicator is classified with this label if it includes none of the system elements.

For instance, with respect to the PC system:

- At the EOL stage, if an indicator includes only packaging material for calculating the recycling rate but excludes other critical elements like shape, size, and colour then it is classified as Partial inclusion**.**
- At the Source stage, if an indicator incorporates all material types (e.g., virgin, recycled, biological, reused) into its formulation, then it is classified as Extensive inclusion.
- At any stage, if an indicator includes no PC system elements in its formulation, then it is classified as No inclusion.

Similar classification logic applies uniformly to all other systems, ensuring a structured approach for analysing the indicators.

The indicators are also classified based on the CE business model embedded in their methodology. Two types of CE business models are used for classification. The first is *Single Use*, which focuses on improving circularity for the single lifetime of packaging by employing the CE principles of narrowing and closing resource loops. The second is *Reuse*, which focuses on improving circularity for multiple lifetimes of packaging by employing the CE principles of narrowing, closing, and slowing resource loops. (Bocken et al., 2016).

Results

The analysis of the indicators is presented in (Figure 1), where Extensive inclusion is depicted as green cells, Partial inclusion as yellow cells and No inclusion as empty cells.

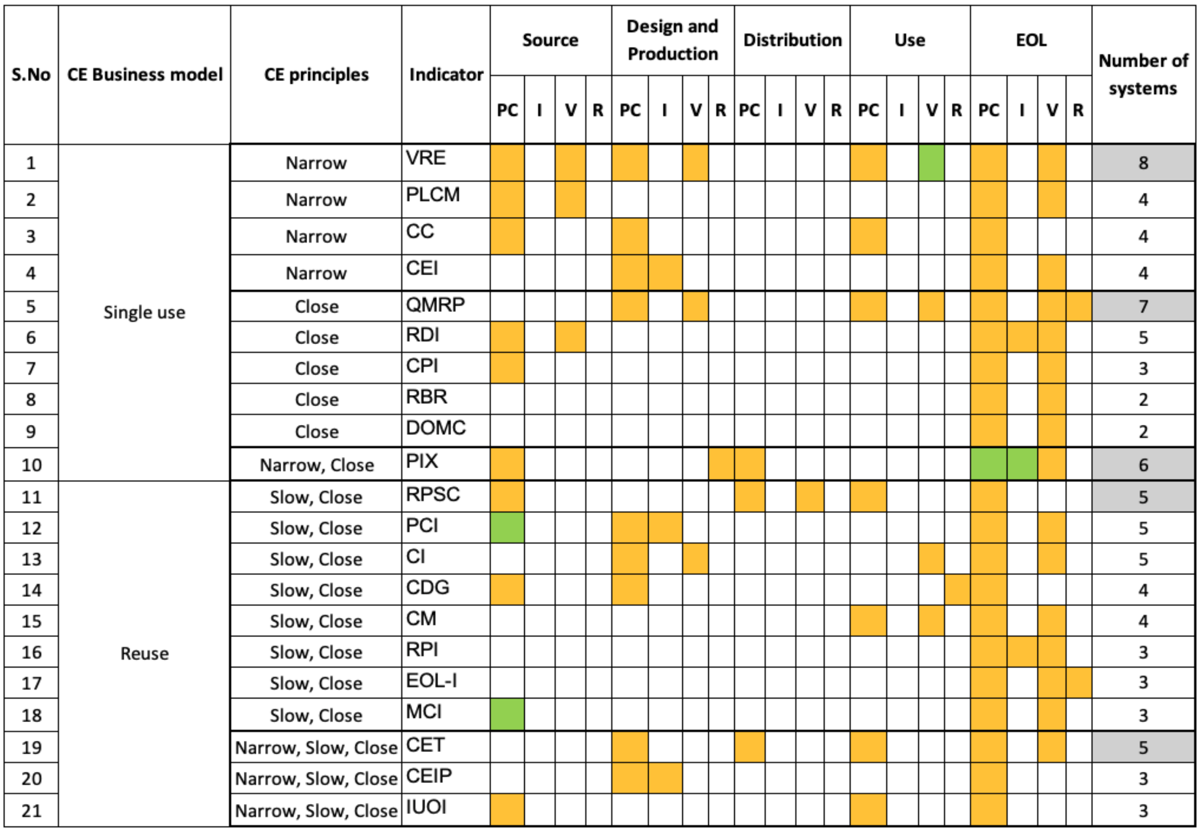

Figure 1 Classification Analysis of 21 Indicators Extensive Inclusion (■), Partial Inclusion (■), No inclusion (□)

Classification of the 21 circularity indicators reveals critical insights regarding their inclusion of systemic considerations across lifecycle stages. These insights are summarised below into three themes.

Lifecycle stage coverage

- Most indicators primarily focus on systems at the EOL, for example, PC at EOL is partially included by all the indicators. In contrast, focus on the upstream lifecycle stages of Source, Design and Production, Distribution, and Use is limited.

Number of systems considered

- None of the indicators considers all the four systems (PC, I, V, R) together at any specific lifecycle stage.
- Considering that each system can be accounted for in each lifecycle stage (4 system elements for 4 lifecycle stages which corresponds to a total of 16 system occurrences), the greatest number of systems included amount to 8 by the VRE indicator, with many indicators addressing fewer than 4 systems.
- Notably, VRE, PIX, PCI and MCI are the only indicators that address at least one system extensively.

System elements inclusion

- Packaging Characteristic: Most indicators include basic PC elements like material type, but only PCI and MCI extensively consider Source stage PC elements such as virgin, recycled, reuse, and bio-based content. At EOL, only PIX extensively includes all elements like shape, size, colour, adhesives, and labels
- Infrastructure: Few indicators include regional infrastructure elements. RDI and PIX partially address aspects like collection, sorting, and recycling.
- Value: Value elements are mostly considered at EOL, with limited inclusion across other lifecycle stages.
- Regulation: Regulatory elements are rarely included; only PIX considers packaging minimisation and QMRP promotes high-quality recycling in their methodology.

The classification results identified the following indicators as incorporating the greatest number of systemic considerations for given CE business models:

- Single use: VRE (narrow), PIX (narrow, close), QMRP (close)
- Reuse: RPSC (slow, close), CET (narrow, slow, close)

Given the CE business models currently employed by companies (single use or reuse), the above indicators provide a comprehensive approach for assessing circularity.

Discussion

This paper reviewed a large body of literature on CE indicators. In total, 21 indicators specific to packaging were identified addressing the need to move towards a sector-specific tool for measuring circularity in the industry. Indicators that employ CE strategies such as repair, refurbish, remanufacture, and repurpose were excluded.

The results of this research can help packaging designers identify indicators suitable for specific CE business models (single use or reuse) and CE principles (narrow, slow, close). Additionally, they allow packaging designers to determine the extent to which systemic considerations were included in an indicator's methodology. To the best of the author's knowledge, this is the first review study that classifies CE indicators based on systemic considerations, making it its most novel aspect. This differentiates this work from a recent review on packaging-specific CE indicators by Matos et al. (2024).

The results can also help packaging designers assess the comprehensiveness of different CE indicators. They also allow them to determine the level of input data required for circularity assessments, as a greater number of system elements considered by an indicator corresponds to a higher number of input parameters needed for the assessment.

The study also highlighted several key gaps in CE indicators, such as an overemphasis on EOL systems, insufficient coverage of systems in the early lifecycle stages, limited value inclusion, and a lack of alignment with regional infrastructure and regulation. For instance, while indicators like VRE, QMRP, and PIX show promise, they still fail to fully capture the systemic nature of CE by neglecting upstream stages, like infrastructure, and regulation. To overcome these limitations, future circularity indicators must ensure that systems are equally represented across all lifecycle stages, from source to EOL. Further, they should ensure the inclusion of all packaging characteristics system elements across lifecycle stages.

Indicators must be formulated to capture the value for all relevant stakeholders, including manufacturers, consumers, recyclers, etc. Indicators should also be adapted to reflect regional differences in infrastructure, such as collection, sorting, and recycling capacities, to enhance practicality. Furthermore, indicators should be aligned with existing and emerging CE regulations. Additionally, further work on developing a comprehensive list of system elements for each lifecycle stage will provide more actionable strategies for developing new indicators.

Conclusion

The transition to a CE for packaging is a complex challenge that requires the consideration of systems such as Packaging Characteristic, Infrastructure, Value, and Regulation at various lifecycle stages. Circularity indicators play a critical role in evaluating progress and guiding decision-making. However, existing indicators show limited suitability for packaging and rarely account for the systems required for a successful transition to the CE. This study critically evaluated 21 CE indicators identified from existing literature, assessing their suitability for measuring packaging circularity and inclusion of systemic considerations across lifecycle stages. The analysis highlighted several strengths and limitations of existing CE indicators. The analysis also helped in deriving guidance for development of future circularity indicators.

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