# What do product-level circular economy indicators measure?



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# What do product-level circular economy indicators measure?

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**Keywords**: Circular Economy; Indicators; Review; Life cycle; Resources.

**Abstract**: Recently, the concept of circular economy (CE) has become more popular amongst researchers and practitioners as a solution to current unsustainable production and consumption practices. Several indicators meant to quantitatively assess the CE have been suggested in both the academic and grey literature. For companies, indicators are crucial for monitoring progress and to support decision making towards improved circularity. However, no consensus regarding the definition of the CE exists and as a result there is a significant divergence of what CE indicators in fact measure. Taking a product-system perspective and focusing on resources, we review existing CE indicators at the product-level and map the physical resource flows they quantify over the life cycle on a novel, generic system model in the form of a flowchart. The analysis highlights the difference between the indicators and shows that most only address parts of the life cycle with a focus on recycling-related flows. Existing gaps identified primarily relate to the use phase, e.g. lifetime extension measures like repair, maintenance, or repurposing, but also include other relevant aspects in the use phase like energy auxiliaries. The constructed flowcharts can guide the future development of indicators or point to ways of combining several indicators to capture larger parts of the product system.

## Introduction

The concept of the circular economy (CE) is widely suggested as a means for addressing and overcoming current unsustainable production and consumption patterns (Geissdoerfer et al., 2017). The CE proposes a system where the value of resources is utilised for as long as possible by closing cycles, and by promoting strategies like design for long-life products, industrial symbiosis, and remanufacturing (Bocken et al., 2016; Ghisellini et al., 2016). Currently, views diverge in terms of what the concept entails, both regarding its definition and of the terminology and strategies related to its operationalisation (Kirchherr et al., 2017; Reike et al., 2018).

To measure progress towards the CE, actions would benefit from being supported by quantitative assessments for monitoring changes and for supporting decision-making. Comprehensive methods like material flow analysis (MFA) and life cycle assessment (LCA) have been widely used for assessing circularity at various scales (Böckin et al., 2020; Haas et al., 2015), but these are time and resource intensive and can be difficult to utilise in practice, especially by practitioners. In contrast, indicators are relatively simple to apply and allow for effective communication and can therefore be a complement to other assessment methods. This is particularly relevant for companies, key actors in implementing the CE, for whom indicators are important tools for assessing changes in their product portfolios, for communication to customers and suppliers and benchmarking with competitors.

In recent years, numerous indicators for assessing the CE at various scales have been developed within academia and by practitioners (Saidani et al., 2019). However, the lack of consensus regarding the CE's definition and its perceived content make assessments problematic, since what exactly should be assessed remains unclear (Moraga et al., 2019). As a result, existing CE indicators vary in terms of scope, focus, purpose, and potential use.

Several studies have reviewed existing indicators for the CE. Kristensen & Mosgaard (2020) analysed what CE strategies micro-level indicators address and how they align with the different dimensions of sustainability. Moraga et al. (2019) found that existing indicators are limited in scope and fail to account for strategies aimed at preserving the function of products.

Saidani et al. (2019) created a taxonomy of CE indicators based on 10 criteria, e.g. the scale an indicator is implemented at, whether it can be generically applied and how it can be used. Elia et al. (2017) evaluated existing indicators' ability of assessing what they identified as the end goals of the CE and Parchomenko et al. (2019) used a multi-correspondence analysis to determine how existing CE metrics are associated with each other and what aspects of the CE they address. They found that few metrics assess CE strategies related to what they identify as maintenance of value, e.g. longevity. Helander et al. (2019) took a systems perspective to analyse the extent to which indicators at different scales capture environmental pressures. They found that indicators only address parts of the material cycle and that none capture environmental pressures directly.

None of the previous reviews have investigated what de facto is captured along the life cycle of a product when existing indicators are applied. Taking a product system perspective and focusing on physical resources, the aim of this paper is therefore to review and map the physical resource flows addressed by existing CE indicators, which can be relevant for companies to assess the resource-related effects of implementing different CE strategies. The reason for focusing on resources is twofold: 1) resources are a key component of the CE, which have been argued to have an overarching aim of, e.g. extending the productive life of resources (Blomsma & Brennan, 2017), retaining resource value (Reike et al., 2018), or closing, slowing, and narrowing resource loops (Bocken et al., 2016), and 2) resource consumption is arguably connected to environmental impacts (Steinberger & Krausmann, 2011). Knowledge of resource use can thus potentially be utilised by companies to gain some level of insight about the environmental performance of their products without necessarily performing a time and resource intensive analysis in the form of, e.g. an LCA or MFA.

A systematic literature review is carried out to identify relevant indicators in the literature, after which these are analysed by mapping the resource flows captured by each indicator on a novel, generic flowchart system. Furthermore, existing gaps are identified by extending the system model with physical resource strategies for the CE identified in the literature.

The research question guiding the work is stated as follows:

- What resource flows are captured by existing product-level CE indicators and which gaps, linked to processes and strategies related to the CE, can be identified?

## Method

### *Systematic literature review*

A systematic literature search was carried out to find appropriate indicators from both academic and grey literature. 422 publications were found through a search in the Scopus[1] database. Publications with irrelevant topics, CE review papers, and indicators at the meso and macro scale were excluded from the selection. Snowballing was then used to find additional indicators from grey and scientific literature. A total of 41 publications containing 75 indicators resulted from this process. A second selection was then performed to identify indicators that specifically address physical resources. Indicators with unavailable methodologies, or that require economic data, subjective inputs from experts, or are based on software simulations were also excluded from the analysis. Furthermore, seven publications describing indicators based on LCA results were excluded, since the aim is to identify indicators that have a resource focus but does not require a full LCA. The final selection consisted of 36 indicators from 16 publications.

### *Resource flow mapping*

To analyse the flows and processes along the product system that the indicators capture, a generic flowchart model was constructed. The method description and data requirements of each indicator were analysed to determine the specific resource flows or processes that are quantified when the indicator is applied. This was done in an iterative manner, starting with the main industrial processes, i.e. extraction, production, use, and waste management, and continuously extended with new flows and

[1] The following search terms were used: *indicator, metric, score, measur*, index, or indices* in the title, and *circular economy* or *resource efficiency* in the title, abstract or key words.

processes as these became apparent over the course of the analysis. As a result, the flowchart model was made as detailed as needed to cover all aspects of the investigated indicators, while also allowing for a clear comparison of the parts of the product system accounted for by the indicators. The model represents five main life cycle phases: 1) raw material extraction, 2) material production, 3) component and product manufacturing, 4) use, and 5) post use. To visualise the aspects of the CE not yet addressed by existing indicators, the system model was then extended with processes and flows related to physical CE strategies suggested by Böckin et al. (2020).

## Results and discussion

### *What do CE indicators capture?*

Figure 1 shows the result of the flowchart mapping, which indicates all flows and processes that are addressed by at least one of the selected indicators. To summarise the mapping of the 36 indicators, Table 1 presents the indicators, the life cycle phases they address, and whether they also require data on energy, function, or time.

A life cycle phase is considered addressed by an indicator if it captures a flow or process in that part of the life cycle in some capacity. This can relate to a resource flow between two processes, the energy required in a process, or an activity related to a process or life cycle phase, e.g. a parameter expressing the lifetime of the product.

The extraction phase is aggregated into a singular process, raw material extraction. This is, e.g. included as indicator parameters expressing the total material requirements of producing a product or the waste generated in the extraction phase. The material production phase is separated into production of non-renewable and renewable materials, which is, e.g. included through the mass of recycled content in a product or the mass of renewable material used. The manufacturing phase, which includes both manufacturing of components and finished products, is included in many indicators as, e.g. a parameter describing the total weight of the product, the mass of useful co-products or the waste generated. The use phase is accounted through parameters describing the actual use of a product, e.g. the

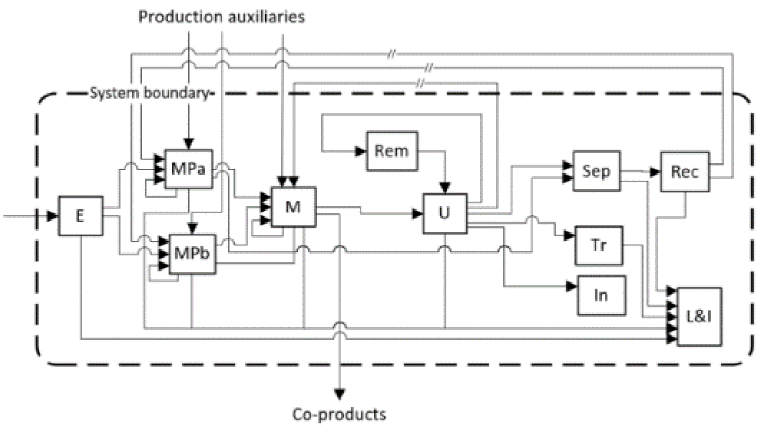


**Figure 1. The generic flowchart system constructed through an analysis of the flows and processes addressed by existing resource-based product-level CE indicators. Abbreviations: E, extraction; MPa, non-renewable material production; MPb, renewable material production; M, component production and product assembly; Rem, remanufacturing; U, use; Sep, pretreatment and separation; Tr, biological treatment, In, incineration; Rec, recycling, L&I, treatment of wastes (landfilling & incineration).**

service lifetime. Finally, the post use phase is captured in several ways, e.g. material rates that are recycled at end-of-life, the ratio of a product that potentially can be incinerated for energy recovery, or the mass of unrecoverable wastes.

The most common flows included in the indicators are those related to recycling. 28 of the 36 indicators incorporate recycling in some capacity, e.g. through various recycling efficiencies, by quantifying the amount of potentially recyclable materials, or the recycled content of a product. Only two indicators, RR and CR (Haupt et al., 2017), make an explicit distinction between open- and closed loop recycling. All other indicators treat these as the same.

Eight indicators require energy data. For instance, the EI and CPEI (Lokesh et al., 2020) incorporate this by comparing the energy requirements of the production process to the mass of useful products and co-products, while the CEV (Fogarassy et al., 2017) includes the energy used in production and in recycling as one of several parameters. Six indicators also make use of data on function and/or time in their computation. As an example, in the MCI, PCI, and MCI-BB (Bracquené et al., 2020; Ellen MacArthur Foundation & ANSYS Granta, 2019; Razza et al., 2020), this is addressed through a

**Table 1. The 36 selected CE indicators describing the life cycle phases in which resource flows are addressed and whether they also include data on energy, function, or time. Abbreviations: E, extraction; MP, material production; M, component and product manufacturing; U, use; PU, post use; F, function, T, time.**

| Reference | Name | Life cycle phases | | | | | Energy | Function/Time |
|---|---|---|---|---|---|---|---|---|
| (Marvuglia et al., 2018) | RBR | E | | | | PU | X | |
| (Juntao & Mishima, 2017) | RE-EEE | E | | M | U | PU | | |
| (Cullen, 2017) | CI | E | MP | | | PU | X | |
| (Lokesh et al., 2020) | CPEI | E | MP | M | | PU | X | |
| (Lokesh et al., 2020) | CPWF | E | MP | M | | PU | | |
| (Lokesh et al., 2020) | EI | E | MP | M | | | X | |
| (Ljunggren Söderman & André, 2019) | RNL | E | MP | M | U | PU | | F+T |
| (Winzer et al., 2017) | SERI | E | MP | | U | PU | X | F+T |
| (Lokesh et al., 2020) | WF | E | MP | M | | | | |
| (Cradle to Cradle Products Innovation Institute, 2016) | C2C | | MP | | | PU | | |
| (Fogarassy et al., 2017) | CEV | | MP | M | | PU | X | |
| (Lokesh et al., 2020) | CPFI | | MP | M | | PU | | |
| (Lokesh et al., 2020) | FI | | MP | M | | | | |
| (Mesa et al., 2018) | LFI2 | | MP | M | | PU | | |
| (Ellen MacArthur Foundation & ANSYS Granta, 2019) | MCI | | MP | M | U | PU | | F+T |
| (Razza et al., 2020) | MCI-BB | | MP | M | U | PU | | F+T |
| (Graedel et al., 2011) | OSR | | MP | M | | PU | | |
| (Bracquené et al., 2020) | PCI | | MP | M | U | PU | | F+T |
| (Lokesh et al., 2020) | PMC | | MP | M | | | | |
| (Lokesh et al., 2020) | PR | | MP | M | | | | |
| (Graedel et al., 2011) | RC | | MP | M | | | | |
| (Ardente & Mathieux, 2014) | RCR | | MP | M | | | | |
| (Ardente & Mathieux, 2014) | Rrec | | | M | | PU | | |
| (Ardente & Mathieux, 2014) | Rrecov | | | M | | PU | | |
| (Ardente & Mathieux, 2014) | Rreuse | | | M | | PU | | |
| (Mesa et al., 2018) | PRI-rec | | | M | | PU | | |
| (Mesa et al., 2018) | PRI-reuse | | | M | U | | | |
| (Figge et al., 2018) | C | | | | U | PU | | |
| (Figge et al., 2018) | L | | | | U | PU | | T |
| (Haupt et al., 2017) | CR | | | | | PU | | |
| (Graedel et al., 2011) | EOL-RR | | | | | PU | | |
| (Marvuglia et al., 2018) | LRR | | | | | PU | X | |
| (Graedel et al., 2011) | OSCR | | | | | PU | | |
| (Graedel et al., 2011) | RPER | | | | | PU | | |
| (Haupt et al., 2017) | RR | | | | | PU | | |
| (Marvuglia et al., 2018) | RYR | | | | | PU | X | |

ratio that benchmarks the lifetime and function of the product to a market average. The inclusion of these aspects makes it possible to detect changes in the function provided or the use intensity of a product, despite this not necessarily having direct resource implications.

*Comprehensiveness and scope*

A majority of the indicators address only one or two life cycle phases, primarily material production, manufacturing, or post use. For instance, some indicators only account for processes related to recycling and thus only address the post use phase. Others focus on the material production and manufacturing stages, e.g. by benchmarking an input to the total mass of a product. As a result, many indicators only cover a limited set of resource flows and can thus only provide insights about changes that occur in parts of the product system. This highlights the importance of fully understanding which parts of the system that are, and are not, quantified when the indicators are applied. Furthermore, to avoid potential burden shifting between life cycle phases going undetected, either several indicators could be used in parallel or other assessment methods should be used.

A number of indicators are more comprehensive in their coverage of the product system. For instance, the RNL (Ljunggren Söderman & André, 2019) is the only indicator that covers aspects of all five life cycle phases. It includes losses occurring throughout the life cycle, the function provided by the product and the service lifetime. To illustrate the range of comprehensiveness and focus in the indicators, Figure 2 compares the flows captured by the Rrec (Ardente & Mathieux, 2014), which has a sole focus on recycling, and the RNL. The significant difference between the indicators is suggestive of the broadness, and potentially of the current lack of consensus, of the CE concept itself (Blomsma & Brennan, 2017; Kirchherr et al., 2017).

*Existing gaps in resource-based indicators*

To highlight the existing gaps found when analysing the CE indicators, the generic flowchart model was extended to include

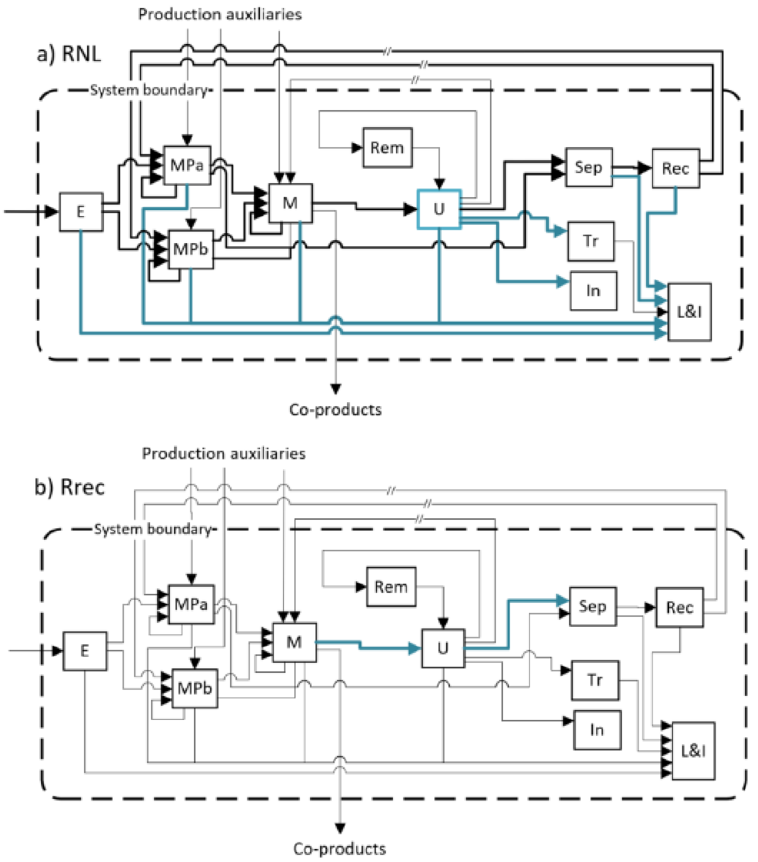


**Figure 2. The constructed flowchart model for two of the 36 indicators, showing flows or processes directly measured (blue), flows indirectly accounted (black), and unaccounted flows (thin lines).**

processes related to physical CE strategies as outlined by Böckin et al. (2020). Figure 3 shows the system model in which the identified gaps are highlighted in red. These are primarily related to strategies aimed at extending the lifetime of products and resources. For instance, no indicator accounts for maintenance or repair, neither in terms of the materials required for these activities nor the wastes produced. Repurposing, meaning reuse of a product in a different function than originally intended, is not accounted for by any of the indicators. Furthermore, use phase auxiliaries, in terms of materials or energy, are also not captured. This makes it particularly difficult to make informed decisions about the resource performance of active, long-lasting products where auxiliaries like fuels or water potentially make up a significant part of the total resource consumption over the life cycle (Kim & Wallington, 2013; Wasserbaur et al., 2020).

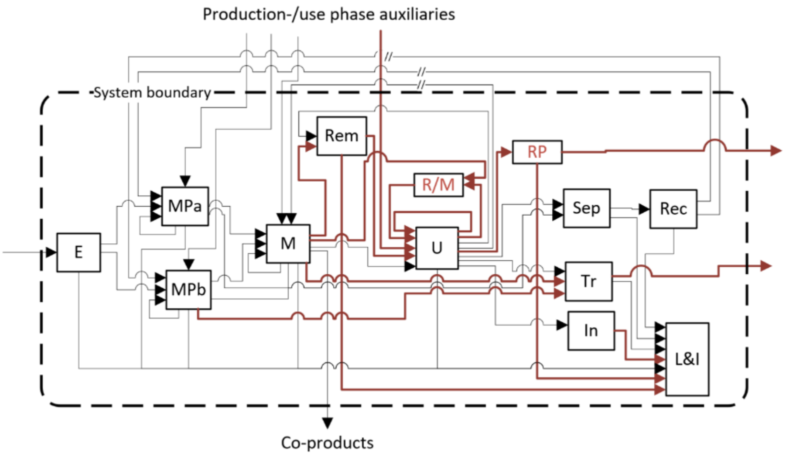


**Figure 3. The flowchart model showing (in red) the flows and processes related to CE strategies not addressed in the reviewed indicators. Abbreviations previously not mentioned: R/M, repair/maintenance, RP, repurposing.**

## Conclusions

This paper has identified existing resource-based CE indicators at the product-level and, in a detailed and systematic manner, mapped the resource flows they incorporate in their calculations. While there is a vast difference in the comprehensiveness of the indicators, most address only a section of the life cycle with a specific focus on flows related to recycling. The divergence in terms of focus and scope highlight the necessity of selecting indicators carefully, since the insights gained are likely to depend heavily on the parts of the product system that are quantified. By making the flows and processes captured by resource-based CE indicators explicit, the constructed flowcharts clarify how indicators can be applied in specific cases and facilitate an interpretation of the results of their computation. The flowcharts can also act as a guidance for choosing complementary sets of indicators, e.g. by ensuring that the necessary parts of the product system are covered.

Current gaps are primarily related to lifetime extension strategies, e.g. repair, maintenance, and repurposing, or to flows relevant to the use phase, like material and energy auxiliaries during use. As a result, there is a risk of resource implications related to some of the activities identified as key for the CE remaining undetected if indicators are applied. Other assessment methods should therefore be used to evaluate the effects of such measures. Furthermore, the highlighting of currently unaddressed flows and processes can be used as a starting point for the development of new indicators.

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