13 Approaches to monitoring and evaluation of resource recovery from waste towards a circular economy

Abstract

In this chapter, we explain the importance of monitoring and evaluation approaches in resource recovery processes for achieving a sustainable circular economy. We provide examples of existing monitoring and evaluation approaches and discuss their strengths, limitations, and levers for change. We then expand on the efforts made to classify the indicators (or metrics) used to facilitate coherent and integrated approaches to monitoring and evaluation of the transition to a sustainable circular economy. We argue that existing approaches provide 'snapshot' views of the resource and waste management systems, pointing to the need to develop an approach that looks at the system as a whole, from production to consumption and management of resources, and supports the selection and development of metrics for assessing the sustainable circularity potential of materials, components, and products. We discuss how such an approach can aid the identification of metrics suitable in generating insights into the production, consumption, and management processes and identifying the impacts, as well as the causes of the myriad problems related to resource recovery from waste. This approach can support the evaluation of the progress made towards the achievement of new policy measures and monitor how proposed changes can enable the transition to a circular economy in the long term.

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Approaches to monitoring and evaluation of resource recovery from waste towards a circular economy

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Introduction

Solid waste, the materials, components, and products generated and/or produced by human and animal activities and discarded when they are no longer wanted or have any use, is the aftermath of an increased consumption of resources. Economic growth and technological advancements have given rise to a great variety of materials, components, and products, offering access to goods and services to a large part of the ever-growing global population. This has the unintended consequence of using natural resources at a faster rate than regeneration, while finite resources are severely depleted. In addition, materials, components, and products are often designed to have shorter lifespans, for example, single-use and disposable products, while others are selected or tailor-made to fit the needs of the specific area or aesthetic qualities (e.g., construction components, food), screening out numerous others that are perfectly functional and/or edible (Facchini et al., 2018).

Overuse, misuse, and depletion of natural resources and of the materials, components, and products made of them has escalated the issues associated with solid waste generation and management, with waste pollution becoming the new 'tragedy of the commons' (Hardin, 1968).

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Wastes that are not properly collected and managed remain in the environment, and now, large amounts of them are ubiquitously present in all environmental compartments – soil, air, and marine and fresh waters, as well as in biota across the world, causing detrimental effects on the environment, human health, and wildlife. At the same time, more natural resources are needed to make the same or similar materials, components, and products to meet the needs of the global population, leading to a vast dissipation of valuable resources both upstream and downstream of the point where waste is generated in the value chain. In view of these shortcomings, a number of strategies have been formulated to achieve or maintain sustainability in resource recovery from waste. These involve improving recycling rates, banning single-use materials, promoting prevention, and stimulating innovation in the development of alternative materials, components, and products or developing technologies for dealing with them when they become wastes (Iacovidou et al., 2017a).

The challenge involved with the implementation of such strategies is that they have reinforced siloed thinking, for example, leading to sector-specific activities for tackling issues at a specific stage in the value chain or influencing a certain group of stakeholders, neglecting to account for the multidimensional implications arising from them. Realisation of the flaws in these strategies has led to the development of the all-embracing concept of the circular economy (CE) (European Commission, 2015), where materials, components, and products behave as either 'technical or biological nutrients' that can be returned to the economy via circular loops (McDonough et al., 2003; Ellen MacArthur Foundation, 2014). The CE concept places specific emphasis on the importance of limiting waste generation and instead promoting the remanufacture, repair, reuse, recycling, and recovery of waste resources via, and to, different processes, depending on the remaining properties and characteristics of the materials, components, and products.

Notwithstanding the importance of the CE concept, numerous authors have raised concerns that often the circularity of resources and wastes can be insufficient for achieving sustainability in the system and in a way that reduces reliance on, and consumption of, natural resources (Cullen, 2017; Zink and Geyer, 2017). This is owing to the fact that circularity focuses on partial improvements in the system rather than promoting the sustainable management of resources (Geyer et al., 2016). This has implications in achieving the CE, and it is now advocated that effective management of resources through the concept of CE must be linked to an effective monitoring and evaluation process that measures both the feasibility of closing the material component and product loops and the sustainability of doing so (Iacovidou et al., 2020).

There is no 'one size fits all' method of monitoring the diverse mixture of resources and wastes across a range of environmental compartments. It is therefore important to determine exactly why the monitoring is being undertaken, for example, to track the flow of resources and assess environmental impacts; to determine critical thresholds and targets; to identify potential sources, stocks, and transformation mechanisms; or to measure the effectiveness of policy or other implemented measures. Moreover, it is critical to evaluate progress based not only on environmental and economic aspects, as is usually the case, but also based on social, technical, and political considerations. Compiling information from a range of literature, this chapter will outline and discuss the monitoring and evaluation methods proposed for measuring progress in achieving the CE. It will place focus on the implementation of these approaches at various levels and highlight the gaps in governing circularity effectively and, most importantly, sustainably.

Monitoring and evaluation: importance and definitions

Solid waste is a highly heterogeneous mixture, spanning orders of magnitude in size (from obsolete construction structures to microplastics measured in μm in diameter), and it can be in a wide range of shapes and types, arising from an equally diverse range of sources, for example, residential, industrial and commercial, and agricultural. The fate of solid waste once it is disposed of in a receptacle can depend on a number of factors, including, but not limited to, the collection and transport processes, the facilities where it is further processed, the proximity and technological advancement of facilities, and the regulatory framework in the area(s) where it is managed, as well as the physical properties of the waste itself (e.g., size, shape, density). Almost limitless combinations of these factors make it difficult to monitor and evaluate the potential of returning wastes sustainably back to the economy as resources.

As a result, there are various approaches used to monitor progress towards circularity which often depend on a number of factors, such as type of materials, components, and products and the context within which progress is assessed. This chapter adopts a generic view of the monitoring and evaluation methods, focusing particularly on those performed to measure progress towards the transition to a circular economy. As a result, monitoring and evaluation approaches to specific materials, components, and products (e.g., plastics, food, metals) and area of generation and/or presence in environmental compartments (e.g., terrestrial, marine environments) are excluded from the present discussion.

Monitoring is the process of continued collection of data against a specific set of indicators (referred to herein as *metrics*) for measuring progress towards the achievement of defined goals, targets, and other purposes. It can provide information at the beginning of a development, during its implementation, or after completion. Thus monitoring is our means to establish how things perform in relation to a defined purpose, helping us identify where interventions might be needed in relation to achieving the defined purpose. Evaluation is the process of assessing the impact of the progress made in terms of its sustainability potential, using both quantitative and qualitative measures (Sharp et al., 2010). It is useful, as it provides insight into domains/areas where improvements can be made in order to achieve the desired goals; thus, it is causally linked to monitoring. Both monitoring and evaluation must be performed in order to get a full picture of the impact on sustainability of circularity processes.

Monitoring and evaluation of the transition to CE involves the regular tracking of resources and measurement and analysis of the impacts on the environment, economy, society, and engineering systems. It regularly measures progress towards achieving specific objectives, making sure that these are being effectively delivered (Sharp et al., 2010). It also delivers feedback to strategy and planning development (Alaerts et al., 2019).

In the following sections, we will describe the variants between existing monitoring and evaluation approaches.

Monitoring and evaluation approaches in achieving a circular economy

Since the proposal of the Circular Economy Action Plan in Europe (European Commission (EC), 2015), a number of monitoring and evaluation frameworks have sprung up by research centres, academia, governmental agencies, and charities aiming to assess one or more aspects of CE. Monitoring and evaluation are important to estimate the extent to which efforts to achieve CE initiatives are delivering results (Potting et al., 2017; Avdiushchenko and Zajaç, 2019) and to capture critical aspects of CE-related activities, which might result in problem shifting rather than an overall benefit (Corona et al., 2019; Mayer et al., 2019). For example, reuse by repair, refurbishment, or recycling is often assumed to result in net greenhouse gas (GHG) emissions savings. While this is true for the recycling of energy-intensive materials such as steel, aluminium, or plastics, recycling of materials such as concrete, plasterboard, bricks, and paint may result in higher net GHG emissions compared to producing their primary counterparts (Turner et al., 2015, 2016). This implies that monitoring and evaluation methods to assess the transition to a CE need to be scrutinised over their ability to effectively measure progress towards achieving sustainable circularity.

Existing monitoring frameworks seek to measure and evaluate progress of meeting CE policy interventions at different implementation scales, namely the *macro*, *meso*, and *micro* scales. According to some authors, *micro* refers to a single material, component or product, company, or consumer; *meso* refers to eco-industrial parks, industries, and companies; and *macro* refers to a city, province, region, or nation, or it may take a global perspective

(Kirchherr et al., 2017; Moraga et al., 2019). Huysman et al. (2017) and EASAC (2016) have also associated countries and regions with a macro-level analysis and micro-level analysis with products and companies, while reference to the meso level has not been ratified. Edgerton et al. (2018), differentiates the monitoring and evaluation implementation levels into: *nano*, micro, meso and macro, corresponding to products and components; companies and consumers; inter-industry networks; and cities, countries, and international agencies, respectively.

At the macro level, monitoring and evaluation are mainly performed on mass flow exchanges between the economy and the environment, on international trade, and on material accumulations in national economies (Vercalsteren et al., 2018; Mayer et al., 2019). Macro monitoring and evaluation methods towards achieving the CE have been carried out via an economy-wide perspective at the national or higher scale (Giljum et al., 2015; Haas et al., 2015; Schandl et al., 2018). Mayer et al. (2019) suggest that only at this level it is possible to capture system-wide effects such as displacement or rebound effects and to assess whether absolute reductions in resource use and waste flows are achieved. As a result, they developed a mass-based monitoring framework based on a system-wide assessment of a CE at the global and European level from an economy-wide material flow (ew-MFA), using data on material consumption, transformation and use. Material flow analysis (MFA) – a quantitative procedure for determining the flow of materials and energy through the economy on multiple scales (e.g., area-, process-, and/or product-specific) – has been commonly used for the systematic monitoring of resources and wastes through socioeconomic systems, assessing where in the system loop-closing processes occur (Brunner and Rechberger, 2016). Mayer et al. (2019) underlined that although the MFA is useful in tracking the flows of materials, components, and products, its use is often hampered by the non-homogeneity of data available and uncertainties around the material, component, and product stocks (Mayer et al., 2019). As a result, the ew-MFA, which includes macroeconomic aspects, can be better suited to evaluate material circularity (Mayer et al., 2019) and to assess the state and changes of a system over time (Avdiushchenko, 2018).

In line with this approach, the material circularity indicator framework was developed by the Ellen MacArthur Foundation (2017) to monitor and evaluate progress to achieving the CE at the meso level. Meso-level monitoring and evaluation processes focus on mapping the consumption activities of industries and/or companies in relation to specific material, component, or product consumption patterns (Edgerton et al., 2018). The purpose of this framework is to monitor the activities of an industry or company and identify wastage incidents, pollution sources, and opportunities for improving their efficiency yields in the economic, environmental, or social domains (Vercalsteren et al., 2018). Nonetheless, the environmental and/or economic assessment elements of this framework are optional and often performed by companies that have the appropriate tools for their performance (Ellen MacArthur Foundation, 2015). This hampers the wider utilisation of the MCI framework for evaluating the sustainability potential of material, component, and product circularity (Vercalsteren et al., 2018).

It can be argued that MFA and ew-MFA approaches, albeit useful in monitoring the flows of materials, components, and products, tend to place focus on the technical and/or socioeconomic aspects of CE at the macro- and meso-level implementation, while considerations regarding specific materials, components, and products in other domains (e.g., environmental, social) are not properly addressed (Iacovidou et al., 2017a). Some authors associate this limitation with the lack of targets (Potting et al., 2017), as well as the fact that there has been significantly longer experience in solid waste management, while CE is a new and underdeveloped concept (Kristensen and Mosgaard, 2020). With regard to the former, the European Commission has set specific targets for waste and material management but did not set targets that could facilitate stakeholders in defining priorities and carrying out comparative research (Potting et al., 2017).

To address this gap, the circular economy monitoring framework (CEMF) was developed for, and applied by, the European Commission to evaluate circularity performance at the national and European levels. In this framework, CE is evaluated through the use of metrics adopted by resource efficiency scoreboards (RESs) and raw material scoreboards (RMSs) measuring progress towards a circular economy in a way that encompasses its various dimensions at all stages of the life cycle of resources, products, and services. As a result, metrics are classified into production and consumption, waste management, secondary raw materials, and competitiveness and innovation (European Commission, 2019). Among the limitations of this framework is the lack of focus on product design towards the development of better components and products, while the export of recyclable materials to non-EU countries (exporting waste to third-world countries does not guarantee environmentally or socially friendly utilisation) has not been accounted for, raising issues with regard to our ability to evaluate the sustainability of transitions to CE (Moraga et al., 2019).

Potting et al. (2017) suggested broadening the scope of the CEMF by combining all three levels of implementation, that is, macro, meso, and micro. Micro-level monitoring and evaluation refers to the assessment of the activities performed for specific materials, components, and products in relation to, for example, their extraction, manufacturing, and end-of-life management practices. As a result, they proposed expanding the list of the ten metrics used in the CEMF to highlight linkages with the micro level and suggested associating the implementation levels of CE (i.e., macro, meso, micro) with metrics as a constructive and useful approach to enabling the monitoring and evaluation of the transition towards a CE. Classification of metrics to the macro, meso, and micro scales of implementation can make their selection best suited to the issues of concern and the questions being addressed, as methods and tools for ‘calculating’ indicators can be very divergent (Vercalsteren et al., 2018).

Macro-, meso-, and micro-level metrics used for monitoring and evaluation of achieving the circular economy

Metrics are fundamentally needed for evaluating, monitoring, and improving various policies and programs, and, as a result, they are closely associated with the implementation scales of the monitoring and evaluation frameworks towards the CE, the micro, meso, and macro. At the macro level, mass-based metrics summarise the progress at (supra)national level, while meso and micro metrics are tailored towards assessing circularity at the level of companies and/or materials, components, and products, respectively (Alaerts et al., 2019; Kristensen and Mosgaard, 2020).

Vercalsteren et al. (2018) describe macro-level metrics as those that can be used to support decisions in areas such as economic, trade, and environmental policy integration; sustainable development strategies and action plans; and national waste management and resource conservation policies. Meso-level metrics are those that can measure the economic, environmental, or social performance of a region (domain specific) or a product group or industry (process specific) and enable a more detailed analysis of material flows within the economy. Micro-level metrics provide detailed information for specific decision processes at the business or local level or concerning specific substances or individual products. Table 13.1 outlines three different types of metrics used in monitoring and evaluation methods for measuring progress towards achieving the CE based on macro, meso, and micro implementation scales. Domain refers to environmental, economic, social, and technical considerations that metrics should be able to measure for evaluating the sustainability of CE transitions.

Table 13.1 The scalability of metrics used in monitoring and evaluation frameworks proposed for measuring progress towards achieving the circular economy

Source	***Macro***	***Meso***	***Micro***
(Potting et al., 2017)	*Area specific – Lead (generic)*	*Domain specific – dashboard (generic)*	*Product specific*

(Alaerts et al., 2019)	*Area specific (supranational or regional)*	*Function specific (societal needs)*	*Product/service specific*
(Vercalsteren et al., 2018)	*Macroeconomic – area specific*	*Domain and process specific*	*Product specific*

According to Potting et al. (2017) in the macro category, the lead metrics for monitoring (transition-related metrics) and evaluation (effect-related metrics) are mass-based metrics and circularity strategies, respectively. Circularity strategies refer to circularity assessment tools that can either provide single or aggregate metrics or multiple metrics for specific case studies (CE assessment frameworks) (Corona et al., 2019). Moraga et al. (2019) classify the circularity metrics into three types, according to focus: (1) on a specific CE strategy, (2) on more than one CE strategy (e.g., cumulative exergy extraction from the natural environment [CEENE] indicators used to assess performances for post-industrial plastic waste recycling (Huysman et al., 2017), and (3) extrapolated from other assessment methods not directly related to CE assessment (e.g., resource efficiency scoreboard; European Commission, 2019). Kristensen and Mosgaard (2020) highlight that monitoring and evaluation of CE through single macro metrics might preclude a deeper understanding of CE achievements, and industry- and/or material-, component-, and product-specific indicators should be developed to promote utilisation by companies at the meso and micro levels to enable better evaluation processes.

In line with this, Potting et al. (2017) expanded their metrics list to include both meso- and micro-level metrics which are relevant to specific materials, components, and products. In the meso level, metrics are domain specific, that is, focusing on the environmental and economic domains (effect-related metrics) and process specific (transition-related metrics), while at the micro level, product-specific metrics are proposed for the transition process and its effects. However, macro-, meso-, and micro-level implementation of the CEMF seem to be divorced in time, as it is not clear how the metrics at the different implementation levels will be concurrently used to monitor and evaluate progress towards CE.

To address this shortcoming, Alaerts et al. (2019) refined the meso-level metrics as a way to link macro- and micro-level metrics to measure CE achievements and effects. They proposed that these metrics should be function specific, measuring the satisfaction of societal needs. The metrics proposed should be able to measure the functional aspects of material, component, and product circularity (Alaerts et al., 2019). In contrast, Vercalsteren et al. (2018) explained that lack of data and the time and effort investment required to perform such analyses are often key barriers to linking metrics on a macro and meso level with those on a micro level.

At the micro level, where the focus is on the material, component, or product, there are a large number of metrics that can be used for assessing aspects of CE (Kristensen and Mosgaard, 2020). Corona et al. (2019) indicate that such variety could be attributed to the lack of a common definition of CE, which inconsistently accounts for the environmental, economic, and social dimensions (Kirchherr et al., 2017). This has led to the development of a large number of metrics that measure progress and evaluate efforts to achieve the CE that can often be disproportional to the processes and scale of measurement and misleading (Moraga et al., 2019).

Discussion

Monitoring the transition to a circular economy and evaluating its sustainability and potential to align with new policies and trends necessitates a multiscalar analysis which requires a set of multilevel metrics. The classification of metrics into the macro, meso and micro scales of CE implementation, although useful for monitoring at higher level, can lead to a distorted depiction of the system's ability to become more circular and disaggregation of efforts to monitor and evaluate the transition to a sustainable CE. As suggested by Alaerts et al. (2019), the transition to CE is cross-sectorial and is thus expected to have multidimensional impacts.

In line with this, mass-based metrics may not encompass all aspects that should be monitored and evaluated for making a sustainable transition to CE but is essential in providing the baseline analysis of the system. This baseline analysis can lead to the development and management of metrics that measure the scale of input and output flows and which can be further developed to include environmental, economic, social, and technical indicators across all scales (meso level) and for specific materials, components, and products (micro level) (Iacovidou et al., 2017a; Mayer et al., 2019). Integrating the macro-, meso-, and micro-level metrics with the corresponding implementation scales of the CE can be succeeded by a view of linking the production, consumption, and management (PCM) stages of resources and wastes flows in a specific geographical context. In this way, the monitoring and evaluation method used should be able to account for the pertinent processes and stakeholders involved in that particular system, critical elements for enabling transitions to CE.

We suggest that the monitoring and evaluation processes for achieving a CE should be context specific, with the macro, meso, and micro scales of implementation referring to geographical context, thus representing system boundaries, and that the material, component, and product be the central force at all scales. Figure 13.1 presents our approach to monitoring and evaluation of sustainable CE transitions.

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Figure 13.1 Depiction of the macro, meso, and micro scales as system boundaries within which we have production-consumption-management. The processes and stakeholders involved in PCM stages can be inside or outside the micro-level boundaries, depending on the material, component, and product system(s) under analysis.

As depicted in Figure 13.1, at the micro scale, we have the PCM activities implemented at the local authority, municipality, or regional level. The analysis on such activities can then be expanded at the meso scale, referring to province, sub-national, or national levels, while the macro scale describes PCM activities implemented at multinational or global level. The scale is thus defined by the grade of complexity attributed to the PCM processes involved within each system boundary. In each scale, all sustainability aspects (i.e., environment, social, economic, and technical considerations) are casually taken into account in order to analyse the achievements of CE from a holistic perspective. Thus, the metrics selected and/or developed to monitor and evaluate progress in each scale are multidimensional and evaluated simultaneously, without prioritisation of any of the processes involved in the PCM system. The MFA is a prerequisite in our approach, as it facilitates the mapping of all processes involved within the system and supports the identification of the stakeholders directly involved in the system (Iacovidou et al., 2017b). The implementation of CE activities depend on the stakeholders' values, interests, and behaviour; thus, they represent a key element in the monitoring and evaluation processes.

Based on our approach, the classification of metrics in the macro, meso, and micro scales is independent of the material, components, products, and functionality. The selection and/or development of metrics depends on the targets and objectives for achieving CE at each scale and can be used for monitoring and assessing progress in meeting the targets. This way, metrics remain simple, transparent, and easy to measure, and can be both system and stakeholder specific, which is key in assessing the sustainability potential of resource recovery from waste. This approach follows the rationale of evaluating the 'complex value' of materials, components, and products, that is, the holistic sum of their environmental, economic, social, and technical benefits and impacts across the system, from their production to their end-of-life management. This is further described in the newly developed complex value optimisation for resource recovery (CVORR) approach (Iacovidou, Millward-Hopkins et al., 2017; Iacovidou, Velis et al., 2017). CVORR supports understanding of how the various policy interventions, current and planned, need to be coordinated to deliver the desired outcomes, key in monitoring and evaluating progress towards achieving the CE.

Conclusions

The circularity of materials, components, and products in resource recovery systems is not necessarily sustainable. Understanding the the processes and stakeholders involved in production, consumption, and management of materials, components, and products and is therefore necessary to assessing and monitoring progress towards transitions to circular economies. Up until now, progress has been slow due to the fragmented nature of the resource and waste management systems and the lack of coordination between all stakeholders involved. Adopting a whole-systems approach to selecting and/or developing the metrics needed for assessing and monitoring progress in the resource recovery system's performance and sustainability can help us rationalise and select the targets, measures, and interventions that are best suited to achieving the sustainable crcularity goal.

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