The role of life cycle assessment to measure progress towards the circular economy

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Abstract

The circular economy (CE), as opposed to the current linear economy, is seen as a sustainable economic system where the economic growth is decoupled from the resources use, through the reduction and recirculation of natural resources. In the shift towards the CE, quantifying the circularity of products and services (or their contribution to the CE) is crucial in designing policies and business strategies, and prioritizing sustainable solutions based on evidence. This study explores the role of Life Cycle Assessment (LCA) in assessing the circularity of products and services. A review was made on current LCA case studies assessing progress in the CE, attending to the following aspects: the goal of the studies, the modelling and allocation approaches, the assessment methods used, and their alignment with the CE goals. The results indicate that LCA is one of the most used and comprehensive tools to assess CE. However, the multifunctional and multidimensional nature of the CE strategies impose methodological challenges that are still not solved.

Keywords: Circular economy, LCA, circularity, methodologies, review, sustainability

1. Introduction

The circular economy (CE) is seen as a sustainable economic system where the economic growth is decoupled from resources use. This is achieved through the reduction and recirculation of natural resources at the end-of-life (EoL) of products and services. The shift from a linear economy to a CE as an essential step to achieve sustainable development (European Commission, 2015). It is necessary to recirculate and minimize the use of natural resources in order to overcome current environmental and societal challenges, such as resource scarcity or climate change.

In practice, different circular strategies have been proposed as a way to move from a linear economy to a CE. These strategies are usually integrated in the R-strategies framework, ranging from refusing and reducing consumption of resources, to recycling and recovering of waste (Potting et al., 2017). Quantifying the sustainability of such strategies for products and services is crucial for a successful transition to a circular economy. Furthermore, the nature of circular strategies require the use of metrics that are able to model and represent the complexities of multiple cycles (multifunctionality) and the consequences of material downcycling. However, most of the published circularity metrics have a sole focus on measuring to what extent materials' cycles are closed. Such approach overlooks what really matters: the length of the loops and their sustainability performance.

This study aims at reviewing the recent role of the Life Cycle Assessment (LCA) methodology in assessing progress towards the CE, while providing recommendations to deal with the main methodologic challenges.

2. Methodology

In order to explore how the scientific community is responding to key methodological issues regarding measuring and assessing circularity, a literature review was conducted in August 2018 using the Web Of Science Core Collection search engine. The search was focused in English scientific articles or book chapters published from 2008 to August 2018, and was performed by including different combinations of the words *measur**, *quantif**, *circular economy*, and *life cycle assessment*. The search obtained 259 results, which were reduced to 66 after a screening process. The discarded 197 articles did not directly address the issue of measuring circularity in a quantitative way, or presented high similarity with articles already included. The LCA case studies found within the relevant articles were analyzed considering the following methodological aspects: goal of the study, multifunctionality and allocation, assessment method, modelling approach, and alignment with the CE goals.

3. Results

Due to its versatility and maturity, LCA is one of the most applied tools to quantify and evaluate the benefits/impacts of CE strategies. This review found 48 articles measuring the circularity of products or services, of which 22 cases used LCA or proposed new LCA-based indicators to assess the impacts of circular products or strategies.

***Goal*:** 42% of the reviewed LCA case studies were aimed at estimating the benefits of circular strategies with respect to linear alternatives, 37% aimed at choosing the best option between different circular strategies, and 21% at finding points of improvement for the design of circular products or systems. The analyzed systems included food products, waste management systems,

consumers products, materials, industrial clusters and energy sectors.

Multifunctionality: Products or services with open-loop recycling processes are subject to the "multifunctionality problem". Most of the reviewed case studies solved it with a system expansion approach (mostly expansion by substitution, 61 % of the cases), followed by a cut-off approach (17%). One study applied the Product Environmental Footprint EoL formula, and the remaining studies did not specify the applied approach. Quality loss in recycled materials was seldom addressed (only in 5 studies). The approach chosen to solve multifunctionality greatly affected the robustness and validity of the results. Good practices were identified in case studies that enlarged the system to consider upstream impacts, and used a functional unit reflecting the function of the downstream, secondary product. Such an approach puts the focus of the assessment in the quality of the recovered material, which is key for the success of the CE.

Assessment method: A big variation on impact categories and assessment methods was found in the case studies. The most applied methods and categories were based on the ILCD recommendations (six case studies), followed by the ReCiPe method (four case studies), and single-issue assessments such as climate change and cumulative energy or exergy demand (three case studies). Additionally, this review found four CE assessment indicators developed from the LCA methodology: the eco-efficiency index (EEI), the eco-efficiency value ratio (EVR), the global resource indicator (GRI) and the circular performance indicator (CPI). The EVR (Scheepens et al., 2016) and the EEI (Laso et al., 2018a) rely on monetization techniques to integrate both environmental and economic criteria. The former represents the ratio of environmental burden to the value added of the analyzed product, and uses marginal prevention costs to monetize environmental externalities. The second estimates environmental impacts in physical units (with an endpoint indicator derived from ReCiPe), and the monetization takes place as a final weighted step. The GRI (Adibi et al., 2017) is a new midpoint characterization indicator to assess the impacts of resource use, based on the scarcity, geopolitical availability and recyclability of resources. The CPI is based on an exergy analysis (Huysman et al., 2017), and is defined as the ratio of the environmental benefit obtained from a waste treatment option over the ideal potential environmental benefit considering the material quality.

Modelling approach: Consequential approaches are more suitable to measure progress into the CE because of their ability to model at the system level. However, the consequential LCA approach was not applied by any case study, although it was encouraged by some authors.

CE goals alignment: A major challenge encountered in the reviewed metrics was related to the full representation of the CE concept. The CE is seen as a promising way to produce and consume in a sustainable way. Even if the focus of a particular intervention is to increase the material circularity of a system, such circularity should also be sustainable for the environment, economy and society. An advantage of LCA studies with respect to other CE metrics found in the literature is the assessment of, not only the reduced use of resources, but also the reduction in other environmental impacts. However, some studies did not assess a representative range of impact categories. Additionally, the economic and societal dimensions of sustainability were barely addressed (only three LCA case studies included economic indicators in their studies).

Measuring sustainability effects in the CE can be carried out considering different perspectives: focusing on the burdens of strategies (emissions or resource use), or on the value/benefits of such strategies (extended duration or value added). LCA is typically focused on the burdens of strategies. Some authors argue that the key point of CE is to keep resources within the economy, hence, value based metrics should be preferred. Still, some LCA studies were able to show the benefits of applying circular strategies by including economic value added indicators, and providing the reduced impacts when compared to linear alternatives.

4. Conclusions

The LCA methodology is currently one of the main and most comprehensive tools used to assess the progress of the CE for products and services. However, the multifunctional and multidimensional nature of the CE strategies impose methodological challenges that are still not consensually solved by the LCA community. Major challenges are related to the allocation approach for open-loop recycling, the consideration of a systemic perspective, and the inclusion of economic and social value added measurements.

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