The International Journal of Life Cycle Assessment (2021) 26:215–220
https://doi.org/10.1007/s11367-020-01856-z

LIFE CYCLE SUSTAINABILITY ASSESSMENT

# Using life cycle assessment to achieve a circular economy

Claudia Peña[1] · Bárbara Civit[2] · Alejandro Gallego-Schmid[3] · Angela Druckman[4] · Armando Caldeira- Pires[5] · Bo Weidema[6] · Eric Mieras[7] · Feng Wang[8] · Jim Fava[9] · Llorenç Milà i Canals[8] · Mauro Cordella[10] · Peter Arbuckle[11] · Sonia Valdivia[12] · Sophie Fallaha[13] · Wladmir Motta[14]

Received: 30 November 2020 / Accepted: 13 December 2020 / Published online: 25 January 2021
© The Author(s), under exclusive licence to Springer-Verlag GmbH, DE part of Springer Nature 2021

**Abstract**
The current global interest in circular economy (CE) opens an opportunity to make society's consumption and production patterns more resource efficient and sustainable. However, such growing interest calls for precaution as well, as there is yet no harmonised method to assess whether a specific CE strategy contributes towards sustainable consumption and production. Life cycle assessment (LCA) is very well suited to assess the sustainability impacts of CE strategies. This position paper of the Life Cycle Initiative (hosted by UNEP) provides an LCA perspective on the development, adoption, and implementation of CE, while pointing out strengths and challenges in LCA as an assessment methodology for CE strategies.

**Keywords** Circular economy · Circularity · Life cycle assessment · Complementary methodologies

## 1 Background

According to the Global Resources Outlook, the use of natural resources has more than tripled since 1970 and continues to grow; climate change and health impacts linked to extraction and production of metals doubled between the years 2000 and 2015, and 90% of the impacts associated with water consumption and biodiversity are related to resource extraction and processing (UNEP IRP 2019). A greater commitment by the private sector has been already encouraged back in the year 2000 (UN Global Ministerial Environment Forum, Malmö) to strengthen the environmental accountability, and "this approach must be linked with the development of cleaner and more resource-efficient technologies for a life-cycle economy." UN (2012) recognises "the importance of adopting a life cycle approach and of further development and implementation of policies for resource efficiency and environmentally sound waste management," and we all need as society to step up our action and ambition to influence decisions that shift human development to sustainability, faster, and more efficiently (LCI 2020).

The circular economy (CE) concept was originally coined and defined by Pearce and Turner (1990) as an economy where wastes are recycled into resources, either through a technological feedback mechanism or through a natural ecosystem feedback mechanism, so that the stock of resources is constant or increasing over time. More recent usage stresses that this aim might also be achieved by keeping products, components, and materials at their highest level of utility and value for as long as possible, designing out waste and pollution and regenerating natural systems (EMF 2012; UNEP 2020a). Being regenerative by design, as opposed to the "take-make-dispose" linear model, CE strategies aim to preserve natural, manufactured, human, and social assets (EMF 2015). CE is gaining more and more attention

Communicated by Matthias Finkbeiner.

✉ Claudia Peña
cpena@addere.cl

1 ADDERE Research & Technology, Santiago, Chile
2 National Technological University, Mendoza, Argentina
3 University of Manchester, Manchester, UK
4 University of Surrey, Guildford, UK
5 University of Brasilia, Brasilia, Brazil
6 Aalborg University, Aalborg, Denmark
7 PRé, Amersfoort, The Netherlands
8 UNEP, Paris, France
9 Anthesis Group, Puntarenas, Costa Rica
10 European Commission (JRC), Seville, Spain
11 USDA, Beltsville, MD, USA
12 World Resource Forum, St. Gallen, Switzerland
13 CIRAIG Polytechnique Montreal, Montréal, Canada
14 CEFET-RJ, Rio de Janeiro, Brazil

worldwide as a way to advance efficiently towards sustainable consumption and production patterns (UNEA 4/Res.1) and contribute to achieving the sustainable development goals SDGs (UNIDO 2017a). However, most definitions of CE highlight economic prosperity as their primary objective, followed by environmental quality, and its impact on social equity and future generations is rarely mentioned (Kirchherr et al. 2017).

Life cycle assessment (LCA) is a standardised (ISO 14,040–14,044:2006) and science-based methodology for assessing the impacts associated with the life cycle of a product or service, which can help understand the environmental implications of CE strategies. When applying a comprehensive set of impact categories, the LCA can also bring a holistic perspective into decision-making not only focusing on the biophysical environment but also the social and economic environment affected by a decision. The methodological developments associated to LCA allow addressing the product system by analysing its many elements and interactions through an interdisciplinary approach (Zamagni et al. 2013). A good example of this are the guidelines published by the Life Cycle Initiative such as the Guidelines on social LCA (S-LCA) in 2009 (UNEP 2009), which are currently being updated. Also, the concept of the Life Cycle Sustainability Assessment (LCSA) (Kloepffer 2008; Finkbeiner et al. 2010) finally led to the publication of the Framework on LCSA (UNEP 2011; Valdivia et al. 2013).

**Complementing Material Circularity Indicators (MCI) with LCA:**

Managing tire end of life is a complex problem because tires are heavy, bulky, and partially made of non-renewable resources, primarily black carbon and steel. Tires accumulated in garbage piles or landfills can pose fire-related problems and health risks. The tire industry has been looking for recovery outlets for tire materials. One of the strategies in a circular frame management is to recycle tires in a closed loop system to ensure the sustainability of the tire industry. Michelin carried out a study in two settings: the Brazilian and the EU context. The authors applied LCA and MCI to assess the potential of used tire management strategies to (1) avoid burden shifting, and (2) improve material circularity. The results of both case studies provide a good insight for tire manufacturers on how to manage used tires to better contribute to the CE objective. The study reveals that MCI is relevant to support circular design to preserve the specific materials that make up the product. But LCA provides a complementary perspective on a broader scope in terms of system boundaries and complementary indicators needed to measure the pressure on pollution–thus helping to avoid burden shifting. (Lonca et al, 2018).

LCSA refers to the evaluation of all environmental, social and economic negative impacts and benefits in decision-making processes towards more sustainable products throughout their life cycle (UNEP 2011). This broad approach is especially valuable as a complementary analysis for CE. Thus, LCA can support evaluating and comparing the most promising CE strategies and options for improving the environmental performance of society's consumption and production patterns. Furthermore, the transition to the CE has direct linkages to international trade and may lead to structural changes in the economy, which in turn may impact on trade flows of primary and secondary resources (OECD 2018).

LCA and LCSA provide a comprehensive and systematic basis for ensuring that the impacts of both the upstream primary resources, which are often linked to emerging economies (UNIDO 2017b), and the downstream components of value chains are truly integrated into the CE analysis. Overall, LCA allows to understand and evaluate whether the claimed environmental benefits of CE solutions can be achieved and to what extent, and which are the most critical processes and aspects that needs to be properly managed.

## 2 Purpose of this position paper

This paper aims to clarify the potentialities of LCA and the need of its coherent application in the development, adoption, and implementation of CE worldwide to advance more effectively and efficiently towards environmental sustainability.

This paper defines the conceptual relationship between CE and LCA and recommends further steps. Finally, it also points out the limitations of LCA in the context of CE and lists issues to be addressed in order to better support the implementation of CE with LCA information, models, and results.

## 3 Circular economy

The rapid increase in interest for CE calls for precaution, as there is as yet no harmonised methodology or framework to assess whether a specific CE strategy fulfils the requirement of reducing environmental and social impacts. Furthermore, socio-economic impacts are not always adequately considered in CE projects. Some CE strategies could lead to significant spill over effects between the social and environmental aspects.

Also, there is a growing concern among CE practitioners regarding the definition and implementation of concepts and methods—for example regarding CE indicators and assessing material efficiency aspects, such as durability, reparability, recyclability, and dissipative use of materials. Consequently, CE strategies must be designed and implemented with a view to potential upstream and downstream impacts, as well as trade-offs of impacts from one resource or impact area to another. Without such vigilance, CE strategies could lead to less efficient or inappropriate solutions.

Currently, different metrics can be found in the literature describing overall product circularity (Moraga et al. 2019). They are all quite different from being demanding or simple with regard to calculation complexity and subjective or objective with regard to evaluation. There is an urgent need to find common ground for practical use in circularity.

In this context, a new ISO Technical Committee (TC323) on CE has been established, with the objective to develop requirements, structure, and guidelines and to support tools related to the implementation of CE strategies. ISO TC323 highlights that particular aspects of CE are already covered by existing standards of the ISO TC207, such as LCA and especially eco-design. However, explicit and clear guidance has not yet been established on how LCA and LCA-based methodologies can provide a holistic view and a consistent methodological basis for assessing the sustainability of CE solutions.

## 4 Assessment needs in circular economy

The CE is both a new challenge and an opportunity to continue industrialisation in a sustainable way, through inclusive CE strategies for global transition considering the needs of all economies involved (developing, emerging, developed). LCA-based tools can ensure the inclusion of the environmental, social and economic impacts of different CE strategies, which will often involve different consequences in emerging vis-à-vis developed economies. Ignoring such holistic perspective and differences could lead to negative outcomes in different parts of the global value chains.

On the other hand, at local and national levels, some emerging economies already circulate material and resources more than within many developed economies, since materials and resources are less available or less abundant in supply, and therefore used for a longer amount of time. The importance of the informal reuse and recycling sectors illustrates that behaviour. LCA and LCA-based methodologies can help emerging economies as well as developed countries to advance towards sustainable circular economies, where circularity provides wealth in a resource efficient manner without rerouting via a linear economy.

Decision-making on CE strategies often asks questions that can be answered by application of LCA and its related methodologies, providing insight into trade-offs of impacts between for instance water use, energy, carbon, material use, and recycled content and also considering social and economic impacts. Here are a few examples:

- Planning to move towards a goal of 100% recycled content in a product needs to consider the impacts of energy, water and material use of obtaining and using the recycled materials in a safe way (i.e. free from toxic substances built-up from previous cycles).
- Banning the use of single-use plastic products should simultaneously consider the economic, environmental and social impacts of alternatives (such as paper, cotton or durable plastic bags), throughout the life cycle of products (UNEP 2020b). The sustainability impact assessment needs to cover all major environmental impact categories such as climate change, water footprint, land-use and biodiversity impacts from litter in the environment, as well as resource depletion, drinking water coverage, sanitation coverage, minimum wage per month, among other social and economic impacts (Wulf et al. 2018).
- Moving to local production, which involves working with near providers and using less transport to bring materials to the facilities, needs to consider how it would affect the quality and impacts of key products from local sources, as well as the socio-economic impacts on the original supplier countries.

## 5 Underpinning of circular economy strategies through LCA

LCA is a crucial assessment methodology to inform and improve CE strategies by comparing them in terms of sustainable performance. Even if the methodology is standardised (ISO 14,040–14,044: 2006), further requirements must be set to ensure comparability between LCA studies.

The same strict principles must apply to compare CE strategies based on LCA. A concrete example of this is the CE strategy of the energy company Enel (EU 2019), which uses LCA to measure the circularity of products and their environmental impacts, and to engage suppliers in improving their performance, to then communicating it through environmental product declarations.

**Using LCA to measure products' circularity and engaging suppliers in improving their performance:**

Enel defined a set of parameters and indicators used to quantify the circularity of products and projects, based on the benefits of reducing virgin materials consumption. Its target is to objectively quantify, certify and communicate impact over the whole supply life cycle (water consumption, $CO_2$ emissions, impact on soil, etc.). This allowed Enel to measure the impact of its own business on the world's natural resources and then mitigate it, and it also allowed suppliers to be involved in an activity that checks the eco-efficiency of the production cycle and have references for establishing improvement actions. In 2018 the company launched the CE Initiative for Supplier Engagement, for which suppliers are requested to conduct LCA of relevant products and certify their results through an Environmental Product Declaration (EPD: ISO 14025) to support decision-making. The project aims to quantify, evaluate and validate environmental KPIs deriving from the manufacturing cycle of the product. In a first wave the CE Initiative involved five main products of its supply chain, and in a second wave will add seven products more. Enel seeks in this way to be able to measure and evaluate its own sustainability performance and identify opportunities for co-innovation with its suppliers, to improve circularity throughout the supply chain in what represents more than 60% of the acquisition of assets of the company.

LCA helps to evaluate different strategies related to material efficiency to advance in the transition towards a circular economy (Cordella et al. 2020). It can highlight situations where CE projects may be too narrowly focussed on the "circularity" of a specific resource, and not appear as the best choice in a broader assessment. In the context of product lifetime extension policies, LCA could also help determine the best options. For instance, in the case of intensive energy-using products, identifying the good balance between the desired lifetime extension and the pace of technological improvement in the area of energy efficiency (Gallego-Schmid et al. 2016).

## 6 Bridging perspectives on resources and impacts

In broad terms, it can be highlighted that:

- CE prioritizes the continued use of resources. This implies maintaining the highest level of utility of materials through recycling, either within the economy, typically through a network of industrial sectors, or in natural ecosystem processes, and may involve extending the lifetime of products to minimize the need for wasteful recycling activities.
- Methodologies and frameworks for the CE and the circularity assessment indicators are in development and aim mainly at augmenting the perceived value by increasing the utility value of resources within the economy.
- LCA can be used to measure and assess the environmental and social performance of a defined system in a circular economy, to ensure the optimal decision-making.
- LCA is a well established and standardized methodology adopted by industry worldwide, which allows characterizing the environmental performance of product system, not only in relation to impact associated to resource use, but to the whole range of impact categories relevant through the life cycle of the product.

CE focuses on maintaining (preserving and increasing) resource values for the economy. In doing that CE considers also different levels of application: at the macro level, it focuses on material exchanges between the economy and the environment, and also internationally; at the structural or meso level, the emphasis is on material flows in industrial systems, distinguishing not only categories of materials but also sectors and industrial branches; at the micro or business level, it focus on firms and their products. LCA focuses mainly on product level and on all the impacts associated to the product life cycle, i.e. not only on the impacts related to the use of materials and resources but on all those impacts that can be relevant for a product category.

CE strategies often assume that it is always good to keep individual resources within the economy, either in use for as long as possible, or through cycling loops in technical or biological cycles. On the other hand, LCA and related approaches do not advocate for any specific strategy, but simply provide an assessment framework to understand the environmental, social, and economic implications of different options to deliver a function or service. In this way, LCA and its related approaches may serve as the science-based methodology to assess the benefits or otherwise of specific CE strategies, and also the occasions where keeping the resources within the economy for longer may actually be counter-productive (e.g. due to the costs of removing toxic substances contaminating such resources).

## 7 Conclusion: position and recommendations of the Life Cycle Initiative

The Life Cycle Initiative promotes the use of LCA and related approaches as a methodology and framework to build more consistent and robust CE strategies that consider potential upstream and downstream impacts and encompass all relevant resources and impact categories, leading to better decisions for sustainability.

The current global interest in CE opens an opportunity to make society's consumption and production patterns more resource-efficient. Assessing CE strategies requires addressing the technical and scientific challenges involved across the life cycle of such strategies, as well as the broader implications for the sustainability of both emerging and developed economies.

The Life Cycle Initiative encourages LCA professionals to address the technical and scientific shortcomings involved in the assessment of CE projects, notably:

- Consistent accounting for changes in stocks of resources that respect mass balance principles.
- Consistent modelling of open recycling loops.
- The inclusion of all relevant resources and impacts, i.e. a full environmental, social and economy-wide (LCSA) perspective.
- Transparency of assumptions, reliability of data, and critical interpretation of results and trade-offs between a globally agreed number of impact categories, e.g. through valuation, as suggested in ISO 14,008.

Specifically, the Life Cycle Initiative aims to contribute to:

- Consensus building within the LCA community on terminology related to CE;
- Resolve the technical and scientific challenges to advance in the implementation of LCA in the assessment of CE projects;
- Assessment methodology and metrics for CE, starting from the recognition of historical limitations in the way LCA models raw materials and resource considerations (which often take the linear economy as the frame of reference);
- Global and regional CE fora, particularly within the technical working groups of the ISO/TC 323 on CE;
- Promote the application of LCA in assessing and planning CE projects, i.e. involving the LCA community in designing the approach, monitoring and evaluation, as well as in data collection and assessment of CE strategies.

**Acknowledgements** The Life Cycle Initiatives acknowledges the reviewers who were part of the internal review process of this paper: Sven-Olöf Ryding, IVL, Sweden; Alessandra Zamagni, Ecoinnovazione, Italy; Raul Carlsson, RISE, Sweden; Tatiana Vakhitova, Ansys Granta Materials, UK; and Atta Ajayebi, University of Exeter, UK.

## References

Cordella M, Alfieri F, Sanfelix J et al (2020) Improving material efficiency in the life cycle of products: a review of EU Ecolabel criteria. Int J Life Cycle Assess 25:921–935. https://doi.org/10.1007/s11367-019-01608-8

EMF (Ellen MacArthur Foundation) (2012) from: www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf. Accessed May 2020

EMF (Ellen MacArthur Foundation) (2015) Towards a circular economy: business rationale for an accelerated Transition. www.ellenmacarthurfoundation.org/assets/downloads/TCE_Ellen-MacArthur-Foundation_9-Dec-2015.pdf. Accessed April 2020

EU (European Union) (2019) About: Good practices, Getting suppliers involved to better assess circularity throughout the value chain: a project by Enel. https://circulareconomy.europa.eu/platform/en/good-practices/getting-suppliers-involved-better-assess-circularity-throughout-value-chain-project-enel. Accessed May 2020

Finkbeiner M, Schau EM, Lehmann A, Traverso M (2010) Towards life cycle sustainability assessment sustainability 2(10):3309–3322. https://doi.org/10.3390/su2103309

Gallego-Schmid A, Mendoza JMF, Jeswani HK, Azapagic A (2016) Life cycle environmental impacts of vacuum cleaners and the effects of European regulation. Sci Total Environ 559:192–203. https://doi.org/10.1016/j.scitotenv.2016.03.149

ISO 14040:2006a Environmental management — Life cycle assessment — Principles and framework

ISO 14044:2006b Environmental management — Life cycle assessment — Requirements and guidelines

ISO 14025:2006 Environmental labels and declarations — Type III environmental declarations — Principles and procedures

LCI (Life Cycle Initiative) (2020) LC Net Newsletter February 2020. LC Net: bimonthly newsletter of the LCI. www.lifecycleinitiative.org/?mailpoet_router&endpoint=view_in_browser&action=view&data=WzQsImM5ZjQ0NWU5OTNjNiIsMCwwLDAsMV0. Accessed April 2020

Kirchherr J, Reike D, Hekkert M (2017) Conceptualising the circular economy: An analysis of 114 definitions. Resour Conserv Recycl 127:221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kloepffer W (2008) Life cycle sustainability assessment of products. Int J Life Cycle Assess 13:89. https://doi.org/10.1065/lca2008.02.376

Moraga G, Huysveld S, Mathieux F, Blengini GA, Alaerts L, Van Acker K, de Meester S, Dewulf J (2019) Circular economy indicators: what do they measure? Resour Conserv Recycl 146:452–461. https://doi.org/10.1016/j.resconrec.2019.03.045

OECD (Organisation for Economic Cooperation and Development) (2018) International Trade and the Transition to a Circular Economy. www.oecd.org/environment/waste/policy-highlights-international-trade-and-the-transition-to-a-circular-economy.pdf. Accessed April 2020

Pearce DW, Turner PK (1990) The economics of natural resources and the environment. Harvester Wheatsheaf, Hemel Hempstead

UNEP (2020a) Circularity Platform. https://buildingcircularity.org/ Accessed June 2020

UNEP (2020b) Single-use plastic bags and their alternatives: recommendations from Life Cycle Assessments. https://www.lifecycleinitiative.org/wp-content/uploads/2020/04/Single-use-plastic-bags-and-alternatives-Recommendations-from-LCA-final.pdf. Accessed May 2020

UNEP (2011) Towards a Life Cycle Sustainability Assessment. Making informed choices on products. https://www.lifecycleinitiative.org/wp-content/uploads/2012/12/2011%20-%20Towards%20LCSA.pdf. Accessed June 2020

UNEP (2009) Guidelines for Social LCA of Products. https://www.lifecycleinitiative.org/wp-content/uploads/2012/12/2009%20-%20Guidelines%20for%20sLCA%20-%20EN.pdf. Accessed April 2020

UNEP IRP (UNEP International Resource Panel) (2019) Global Resources Outlook. https://www.resourcepanel.org/reports/global-resources-outlook. Accessed May 2020

UNIDO (United Nations Development Organization) (2017a) Circular Economy. https://www.unido.org/sites/default/files/2017-07/Circular_Economy_UNIDO_0.pdf. Accessed March 2020

UNIDO (United Nation Development Program) (2017b) About: The circular economy: getting the best out of Latin America. https://www.unido.org/stories/circular-economy-getting-best-out-latin-america. Accessed April 2020

UN (United Nation Organization) (2012) The future we want—outcome document. https://sustainabledevelopment.un.org/futurewewant.html. Accessed May 2020

UN (United Nation Organization) (2000) Global Ministerial Environment Forum, Malmö. https://unep.ch/natcom/assets/milestones/malmo_declaration.PDF. Accessed April 2020

UNEA 4/Res.1. Resolution adopted by the United Nations Environment Assembly on 15 March 2019 http://wedocs.unep.org/bitstream/handle/20.500.11822/28517/English.pdf?sequence=3&isAllowed=y. Accessed May 2020

Valdivia S, Ugaya C, Hildenbrand J, Traverso M, Mazijn M, Sonnemann G (2013) A UNEP/SETAC approach towards a life cycle sustainability assessment—our contribution to Rio+20. The International Journal of Life Cycle Assessment 18(9):1673–1685. https://doi.org/10.1007/s11367-012-0529-1

Wulf C, Werker J, Zapp P, Schreiber A, Schlör H, Kuckshinrichs W (2018) Sustainable development goals as a guideline for indicator selection in Life Cycle Sustainability Assessment. Procedia CIRP 69:59–65. https://doi.org/10.1016/j.procir.2017.11.144

Zamagni A, Pesonen HL, Swarr T (2013) From LCA to Life Cycle Sustainability Assessment: concept, practice and future directions. The International Journal of Life Cycle Assessment 18(9):1637–1641. https://doi.org/10.1007/s11367-013-0648-3

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.