Int J Life Cycle Assess (2017) 22:832–837
DOI 10.1007/s11367-017-1267-1

CONFERENCE REPORT

How can LCA support the circular economy?—63rd discussion forum on life cycle assessment, Zurich, Switzerland, November 30, 2016

Melanie Haupt[1] · **Mischa Zschokke**[2]

Received: 23 December 2016 / Accepted: 18 January 2017 / Published online: 2 February 2017

1 Introduction and overview

The concept of circular economy (CE) conceives of a production and consumption system with minimal losses of materials and energy through extensive reuse, recycling and recovery (Ellen MacArthur Foundation 2013; European Environment Agency 2014) and is gaining popularity in Europe and elsewhere. Both the recycling of waste and a recycling friendly eco-design are components of CE. In previous studies, however, life cycle assessment has shown that closed loops are not always favourable from an environmental point of view (Laner and Rechberger 2007; Humbert et al. 2009; Geyer et al. 2015). Nevertheless, political initiatives focus on the path towards CE without the use of life cycle assessment (LCA) to evaluate actions and targets. The Swiss LCA Discussion Forum is a platform for the exchange between industry, consulting companies and LCA scientists. The 63rd Swiss LCA Discussion Forum aimed at discussing the following leading questions with representatives from academia, institutional representatives and visionaries: (i) How can LCA support the creation of a circular economy? (ii) How shall substituted materials and products be accounted for, who can claim the benefit, and how is resource quality taken into consideration? (iii) How can wastes and resources be managed to minimise their environmental impacts? To set the stage at the discussion forum, the CE concepts and the political aspects were presented. The following presentations focused on factors relevant for consideration when evaluating the benefits of a CE, such as waste and resource quality aspects and their influence on the recycling system, as well as product quality. Based on these presentations, a panel discussion tackled the leading questions above. Finally, six case studies on CE were shown, highlighting key findings and methodological issues when LCA is used as a tool to assess CE.

The presentations from the DF-63 are available for download (www.lcaforum.ch), and the video recordings can be watched online (http://www.video.ethz.ch/events/lca/2016/autumn.html).

✉ Melanie Haupt
haupt@ifu.baug.ethz.ch

[1] ETH Zurich, Institute of Environmental Engineering, John-von-Neumann-Weg 9, 8093 Zürich, Switzerland

[2] Carbotech AG, Gasometerstrasse 9, 8005 Zürich, Switzerland

2 Concepts, policy and politics

Anders Gautschi (head of consumption and products section at Federal Office of the Environment (FOEN)) presented the position of CE in Swiss environmental policy. While often the resource optimisation in the disposal phase is targeted by CE, the FOEN sees the need to move towards a more circular economy also in the food, living and mobility sectors as these are the three main contributors to the environmental impact of Switzerland. Planned activities of the FOEN include waste prevention strategies (mainly regarding food waste and packaging), minimisation of the need for loops by substitutes and better materials, increased life time of products, eco-design, process optimisation, the phasing out of hazardous substances like heavy metals and persistent organic pollutants, and enhancement of the recycling and thermal valorisation of occurring wastes. After the failed amendment of the Federal Act on the Protection of the Environment (USG 2016) and the failed popular vote on the green economy initiative of the green party, the legal basis for CE actions in Switzerland is given in the technical ordnance on avoidance and disposal of waste (VVEA 2016). Gautschi stressed the point that the need for action is not questioned from any stakeholder, but that voluntary actions are politically preferred. Therefore, the foci for the next years include not only an increase of the knowledge base but also the support of voluntary actions. Another important field highlighted is the support of green public procurement by a procurement advisory service and institutional exchanges with stakeholders (such as cantons, municipalities and the EU).

Dale Walker (project manager at the Ellen MacArthur Foundation) presented the CE concepts of the Ellen MacArthur Foundation, which defines CE as a new systemic model that is regenerative and restorative by intent and design. The Foundation's CE model aims at decoupling economic growth and the consumption of finite resources by keeping products, components and material at their highest utility and value at all times and base them, where possible, on renewable resources. There is, however, no set definition of the concept of CE. Currently, a linear economic model dominates the global economy, which was largely successful for a long time and for many people. Recently, a number of systemic issues have led to the conclusion that we are at the end of the road for this system model. One of these issues is the chronically high waste level, which also results in a loss of value from materials being lost in waste. The butterfly diagram from the Ellen MacArthur Foundation shows a new system model for an economy split into a biological and a technical cycle and highlights the biological cycle as being representative for goods which are consumed (e.g. food) while the materials which are used are represented in the technological cycle (e.g. washing machine). A recently finished study shows a potential macro-economic benefit of 1.8 trillion euros when the CE concept is applied (Ellen MacArthur Foundation 2015). No externalities were considered in the study, but decreasing environmental impacts and increasing jobs opportunities are expected. Concluding the presentation, four building blocks to increasing circularity in product systems were presented: (i) increased circular design and production, (ii) creation of new business models (moving from ownerships to sharing and community based systems), (iii) installation of reversed cycles and (iv) stimulation of enablers and favourable system conditions.

Urs Schenker (senior sustainability specialist at Nestlé) started by presenting a report on CE concepts done by CIRAIG (2015). A mapping of different CE concepts and tools (Fig. 1) highlights that LCA is a tool while CE is seen as a philosophy covering society and the global economy. There are substantial differences in CE definitions focusing on efficiency increases and CE concepts targeting the effectiveness of a system. The study highlights the lack of social issues and equity, other than job creation, in most models. Although it is not based on new ideas, the concepts of CE successfully link previous thoughts and ideas to an encompassing framework that is understood as an answer to resource scarcity. Nestlé itself acknowledged CE as a conceptual framework but also realised that there are potential, unintended side effects. Within Nestlé, the target is not to reach circularity, but to reduce environmental impacts based on LCA. Contradictions between CE and LCA were also confirmed for packaging (lighter material was environmentally preferable but not necessarily circular, Humbert et al. (2009)), for biodegradable packaging (preferable in CE, but not always leading to lower environmental impacts), for reusable packaging (transport can lead to low LCA performance) and for energy recovery (preferable in LCA but not beneficial according to CE). In general, packaging itself should never be investigated in isolation as only a minor share of the environmental impact of consumption are stemming from the packaging. An optimal packaging is not only environmentally sound but also protects the product and prevents the production of food waste due to under-packaging (EUROPEN 2009).

3 Measuring the circularity with LCA

Thomas Astrup (professor at Technical University of Denmark) presented a study on the importance of rebound effects when assessing food waste prevention using life cycle costing (LCC) (Martinez-Sanchez et al. 2015; Martinez-Sanchez et al. 2016). While food waste prevention may support the CE, only a few studies have included consistent assessment of indirect and rebound effects. Indirect income effects may be caused by monetary savings associated food waste prevention (assuming all savings are spent on something other than food). While providing significant welfare economic benefits in society, the environmental impacts caused by increased marginal consumption may also increase global warming impacts. This may lead to the conclusion that food waste prevention might not result in environmental benefits; however, assuming alternative consumption patterns may potentially result in slightly improved environmental performance (Martinez-Sanchez et al. 2016). Considerable uncertainties are associated with definitions of income effects and the marginal consumption which may result in relative large variations in indirect effects (Martinez-Sanchez et al. 2016). The study highlights that LCAs of waste prevention and CE solutions may need to address economic consequences and rebound effects.

Cornelia Stettler (project manager at Carbotech AG) presented insights from more than 25 years experience in LCA of waste management systems and eco-design projects. Often results showed that the secondary production induces less environmental impacts than primary production. These studies, however, are not suitable to answer the general question on the environmental benefit from recycling as highlighted by a study comparing 57 beverage packaging options where the environmentally best option was not the most circular one (Kägi and Dinkel 2014). An inquiry on the relevance of contributions to a sustainable

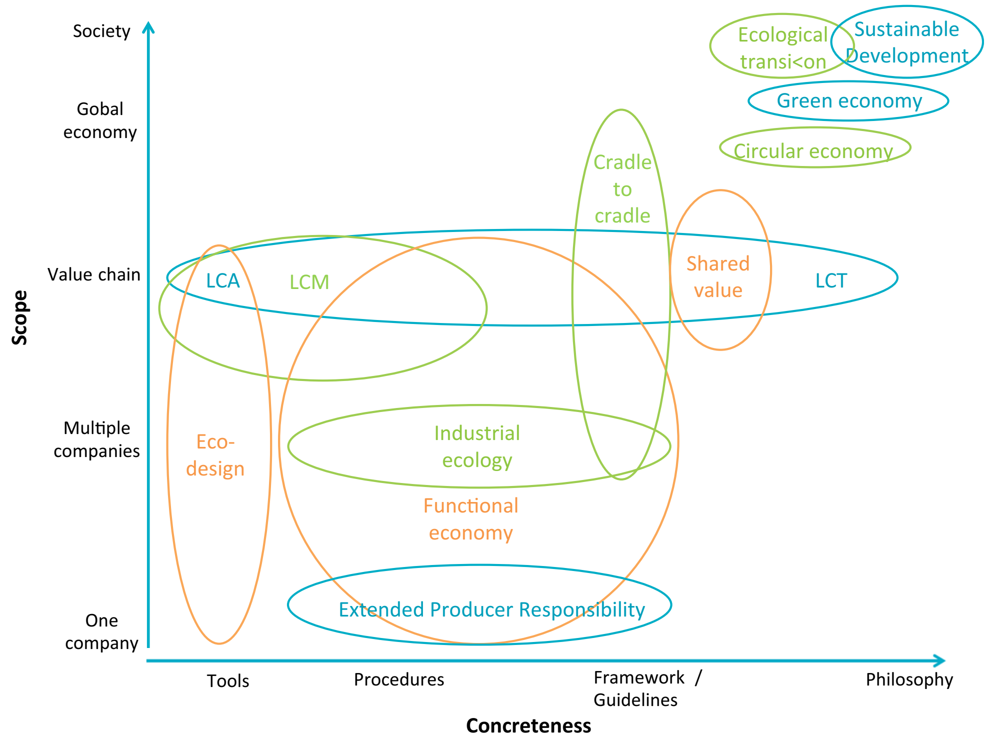

Fig. 1 Map of tools and concepts based on their scope and concreteness. *LCA* life cycle assessment, *LCT* life cycle thinking, *LCM* life cycle management (CIRAIG 2015)

environment shows that consumers consider recycling as one of their main contributions. However, environmental impacts from consumption are known to arise from living, mobility and food while the overall impact from waste management is minimal.

David Laner (senior researcher at Technische Universität Wien) started the presentation by highlighting the fact that already many materials are recycled. As material stocks and consumptions, however, are further increased, the demand cannot be covered from secondary resources alone. This would also not be favourable in a steady state, as contaminants need to be directed to final sinks (e.g. heavy metals and organic pollutants). The case study about paper highlights that chemicals from inks, solvents, pigments, and pesticides are also recycled and therefore transferred from primary to secondary applications. The flows were investigated using a dynamic material and substance flow analyses for paper and the chosen chemicals, respectively, and for three different strategies (Pivnenko et al. 2016). Results show that the optimisation of collection schemes (collecting the right fractions) can result in 5–19% reduction of the chosen chemical and a doubling of the removal rate of fibres leads to a reduction between 9 and 80%, depending on the chemical. Phasing out the chemicals would lead to a 100% reduction in 13 to 31 years. A trade-off between quality and quantity arises when moving towards a circular paper management. There is currently, however, no LCA methodology that would allow for taking into account the recycling of contaminants and, therefore, methodological developments in LCA are needed when applying it to assess and optimise the performance of a waste management system.

Melanie Haupt (PhD student at ETH Zurich) started by presenting a study on indicators used to measure the circularity of a waste management system. By doing a material flow analysis of the Swiss waste management system with detailed case studies on municipal solid waste fractions, collection and recycling rates could be calculated and compared (Haupt et al. 2016a). The study highlights that by using collection rates, as it is currently done in Switzerland and also in other countries, the circularity of a system cannot be measured. Instead, the improvement potential is hidden as recycling processes are not taken into account when measuring the efficiency of the system. The quality of collected fractions cannot only influence the available material for secondary production from open- or closed-loop recycling but can also influence the recycling process. This effect was shown for the case study of ferrous metal (Haupt et al. 2016b). When steel is recycled after a thermal incineration process, 20–40% more electricity is needed in the recycling process compared to source segregated and detinned ferrous scrap. The study shows that copper is increasingly incorporated into the recycling process if the material undergoes an incineration process, therefore highlighting the need for a final sink for these contaminants. Considering all environmental issues related to circularity and the limited use of collection rates as indicators for circular economy, the use of LCA is strongly recommended.

4 Case studies

In six short presentations, a variety of topics in the field of CE and LCA were discussed. Sonia Validivia (program manager at the World Resource Forum) presented insights on urban mining in circular economy with a focus on developing countries. She highlighted five guidance principles for sustainable resource management: (i) enabling safe, healthy and equitable working conditions, (ii) building and strengthening local community relations and resilience, (iii) conserving and protecting the environment and natural resources, (iv) improving recovery of secondary metals and (v) implementing a sustainable management approach (Valdivia et al. 2016). Raphael Fasko (project manager at Rytec AG) questioned why the already existing examples of business models following the CE approach have not yet been scaled up. The reason was found in the currently predominant sales model, where economic benefits are based on value creation of sales. It therefore does not make sense economically to invest in circular design as the added value does not come back to the producer. By shifting the ownership of the resources, circular business models such as rental, leasing, or product-as-a-service models were identified. Examples include the carpet producer Desso, who lends carpet, and Philips, who sells light as a service. Currently, the project continues to map the trade-offs between circularity and environmental performance, the latter being measured by LCA. The use of LCA is also supported by Mélanie Guiton (R&T associate at the Luxembourg Institute of Technology), who states that consequential LCA should be used to quantify the environmental impacts of the implementation of a circular system. The case study on linoleum concludes that consequential LCA is of particular interest when the transition towards a circular model includes significant technical variations and therefore leads to large changes at a system level. Monia Niero (postdoctoral researcher at the Technical University of Denmark) investigated the effect of the circular use of aluminium cans based on LCA, but by developing an approach to take into account multiple recycling loops. In the study presented, the development of the concentration of alloying elements is modelled to investigate the numbers of cycles that aluminium cans be recycled in a closed loop (Niero and Olsen 2016). The LCA revealed that a closed-loop recycling for used beverage cans can result in lower climate change impacts than the recycling of cans with mixed aluminium packaging scrap. The resulting suggestion is to include the idea of multiple co-functions in the functional unit definition. Lucia Rigamonti (senior researcher at Politecnico di Milano) further recommended the use of a replacement coefficient also taking into account the quality and the market availability when evaluating the substitution benefits (publication submitted[1]). Highlighting the need for a market for recyclables, René Itten (research associate at Zurich University of Applied Sciences) presented the ongoing project Sharebox, which focuses on the creation of an industrial symbiotic exchange of resources. Challenges for an industrial symbiosis are the information flow and the knowledge of opportunities, the lack of a secure platform and inadequate resource information related to contamination, availability and classification.

5 Discussion

In a panel discussion with Thomas Astrup (Danish Technical University), Raphael Fasko (Rytec AG), Stefanie Hellweg (ETH Zurich), David Laner (TU Wien) and Dale Walker (Ellen MacArthur Foundation), the use of LCA in the concept of CE, the political focus on the CE concept and the risk of contaminants in recycling were analysed. The panellists agreed that CE is a philosophy describing an optimal system model that can be adapted from a single company (micro level) but also in value chains, or in the global economy (macro level). Taking into account the resource limitations of the planet, the concept describes an economy that is entirely circular. The feasibility of a closed-loop economy, however, is still unknown. In principal, there was largely agreement that LCA and other assessment tools should be used to evaluate options for CE solutions to ensure a positive balance of efforts and benefits in both new product designs and increased recycling. In the presentations at the forum, several examples on a micro level showed that the most circular option was not necessarily the environmentally preferable option. This leads to contradicting conclusions when applying LCA or CE principles. Walker highlighted that current LCAs are still based on today's energy mix and material management, which will likely shift if a systemic change towards a circular economy takes place. For example, if the energy mix is completely renewable, the increased energy need in recycling processes might not be limiting the environmental benefit from recycling. When evaluating solutions using LCA, therefore, studies on a micro level should also include the changed system configurations on a macro level. Although LCA is currently mostly applied on small-scale problems, several applications show its use also on a societal level (e.g. LCAs on whole economies based on input-output statistics (Tukker

[1] Rigamonti, L., M. Niero, M. Haupt, M. Grosso, J. Judl, K. Manninen, and L. Zampori (2017) Advancing the knowledge on the modelling of primary material substitution in waste-management-oriented LCA. In Submission.

and Jansen 2006)). The problem of a macro-level LCA lies in the uncertainties related to large system changes.

Applying LCA in the field of CE, methodological questions related to material quality arise. It is still unclear how to account for multiple material uses with changing material qualities. The exclusion of contaminants, for example, is a key issue when moving from a waste to a resource management approach: During the use phase, but also during production and collection, contaminants enter the material cycle. To keep a material in the technological circle, contaminants need to be separated and directed to final sinks. The methodology to assess contaminants that are kept in the material streams during recycling needs to be further developed. In addition, risk assessment might be needed to assess the danger from impurities. Risk assessment is therefore an additional tool that could be applied when evaluating CE concepts.

6 Conclusions

The following conclusions were drawn from the studies presented and available literature by the authors and were presented as wrap-up at the forum.

LCA is a comprehensive tool to assess the environmental impacts of products, end-of-life treatments and also economies at the level of society. LCA is therefore a tool that is suitable to assess the environmental performance of circular product designs but also large-scale changes, for example the movement towards a more circular economy. The ultimate goal to lower environmental impacts is common to LCA and the CE concept. In cases where LCA results contradict the CE ideas, as shown in the presentation examples, the circularity should not be enforced. It is crucial, however, to also assess systemic changes, such as the restructuring of the energy sector for future system evaluations.

CE has been largely discussed on a political level and actions were initiated, e.g. the formulation of the Action Plan on Circular Economy (EC 2015) in the European Union. The formulated measures, however, mostly target waste management and are not oriented towards the societal change necessary to move towards CE. Except for recycling rates (mostly describing a collection rate, Haupt et al. (2016a)), the political measures also lack indicators to formulate targets. As seen in the presentations, however, an increased recycling rate does not necessarily lead to a better environmental performance. If targets within CE concepts would be defined based on the environmental performance, LCA could be applied to measure the progress on a company but also societal level.

The ideas behind CE are not new, but CE links various concepts to a framework which seems attractive for many. Previous initiatives such as the pollution prevention revolution in the USA were based on similar motivation and failed, partly because of industries resistance but also as local environmental problems were in the focus (Hirschhorn 1997). CE is a globally wide-spread concept which addresses large-scale problems such as resource availability and monetary values lost. CE is in the focus of industry, academia and policy and has the potential to initiate a paradigm shift. Solutions presented within the CE concept, therefore, should be carefully assessed for their environmental performance.

Acknowledgements The authors would like to thank the presenters for their contributions. Furthermore, ESU-services Ltd. and Quantis Switzerland are acknowledged for their financial and technical support during the organisation of the 63rd Discussion Forum on LCA. Melanie Haupt is grateful for the funding provided by the Swiss National Science Foundation (SNSF).

References

CIRAIG (2015) Circular economy: a critical literature review of concepts. ISBN 978-2-9815420-0-7. Polytechnique Montréal. Montréal, QC

EC (2015) Closing the loop—an EU action plan for the circular economy. European Commission, Brussels

Ellen MacArthur Foundation (2013) Towards the circular economy: Economic and business rationale for accelerated transition. Ellen MacArthur Foundation

Ellen MacArthur Foundation (2015) Growth within: a circular economy vision for a competitive Europe. Ellen MacArthur Foundation

European Environment Agency (2014) Signals: well-being and the environment—building a resource-efficient and circular economy in Europe Luxembourg. Publications Office of the European Union, Copenhagen, Denmark

EUROPEN (2009) Packaging in the sustainability agenda: a guide for corporate decision makers. Brussels, Belgium

Geyer R, Kuczenski B, Zink T, Henderson A (2015) Common misconceptions about recycling. J Ind Ecol 20(5):1010–1017

Haupt M, Vadenbo C, Hellweg S (2016a) Do we have the right performance indicators for the circular economy?—insight into the Swiss waste management system. J Ind Ecol. doi:10.1111/jiec.12506

Haupt M, Vadenbo C, Zeltner C, Hellweg S (2016b) Influence of input-scrap quality on the environmental impact of secondary steel production. J Ind Ecol. doi:10.1111/jiec.12439

Hirschhorn JS (1997) Why the pollution prevention revolution failed—and why it ultimately will succeed. P2: Pollution Prevention Review 7(1):11–31

Humbert S, Rossi V, Margni M et al (2009) Life cycle assessment of two baby food packaging alternatives: glass jars vs. plastic pots. Int J Life Cycle Assess 14:95–106

Kägi T, Dinkel F (2014) Ökobilanz Getränkeverpackungen - Gesamtbericht. Carbotech AG, Basel

Laner D, Rechberger H (2007) Treatment of cooling appliances: interrelations between environmental protection, resource conservation, and recovery rates. Resour Conserv Recycl 52:136–155

Martinez-Sanchez V, Kromann MA, Astrup TF (2015) Life cycle costing of waste management systems: overview, calculation principles and case studies. Waste Manag 36:343–355

Martinez-Sanchez V, Tonini D, Møller F, Astrup TF (2016) Life-cycle costing of food waste management in Denmark: importance of indirect effects. Environ Sci Technol 50:4513–4523

Niero M, Olsen SI (2016) Circular economy: to be or not to be in a closed product loop? A life cycle assessment of aluminium cans with inclusion of alloying elements. Resour Conserv Recycl 114:18–31

Pivnenko K, Laner D, Astrup TF (2016) Material cycles and chemicals: dynamic material flow analysis of contaminants in paper recycling. Environ Sci Technol 50(22):12302–12311

Tukker A, Jansen B (2006) Environmental impacts of products: a detailed review of studies. J Ind Ecol 10:159–182

USG (2016) Bundesgesetz über den Umweltschutz (Umweltschutzgesetz, USG). Bern, Switzerland

Valdivia S, Sureda M, Schluep M, Widmer R (2016) Guidance principles for the sustainable management of secondary metals. In: Proceedings of Electronics Goes Green 2016+. Berlin, Germany

VVEA (2016) Verordnung über die Vermeidung und die Entsorgung von Abfällen (Abfallverordnung, VVEA). Bern, Switzerland