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# Recycling, reuse, and circular economy: a challenge for ecotoxicological research

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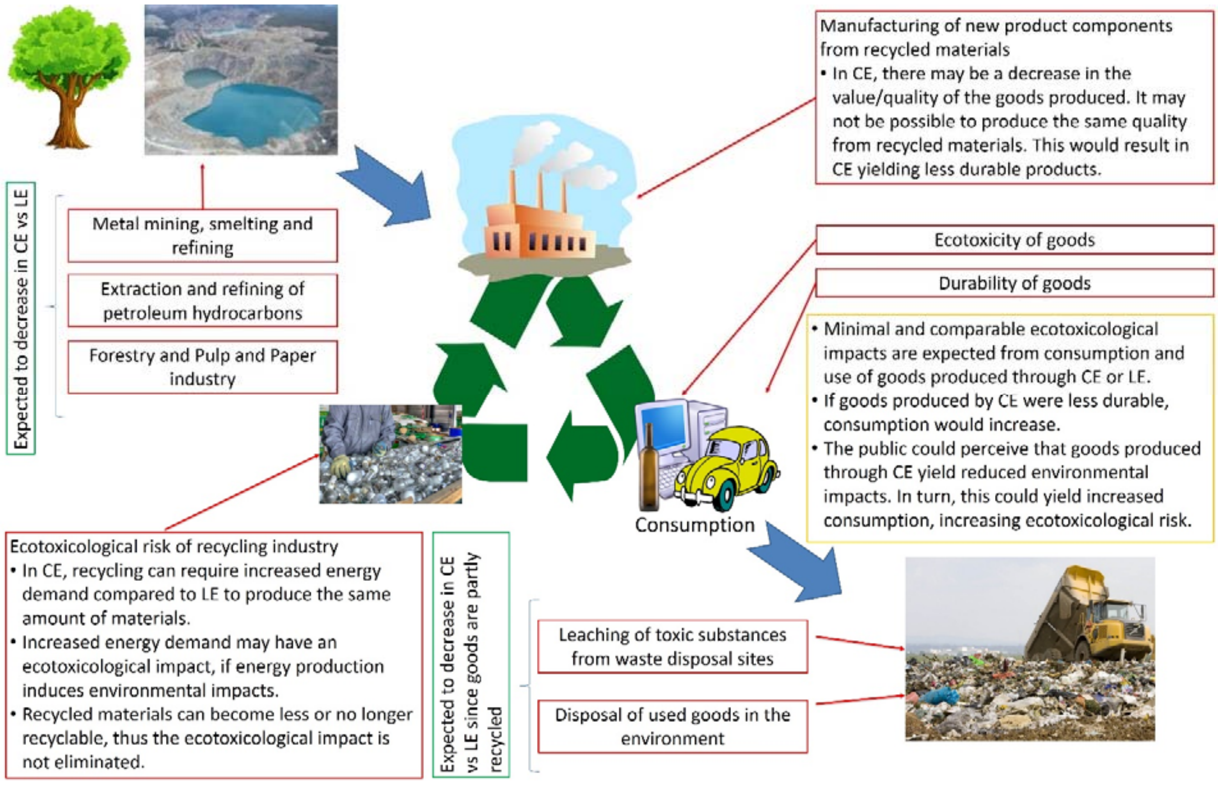
The continuously growing global population, a scarcity of fossil fuels, diminishing supplies of raw materials and metals, climate change, biodiversity decline, poor water quality and social concerns will require changes in production, consumption and mobility in modern society. To address this challenge, the concept of a circular economy (CE), including recycling and reuse, appears to be a promising path forward. Circular economy is an emerging concept aiming to move away from the traditional “take-make-dispose” approach and to decouple economic growth from natural resource consumption, allowing a societal evolution towards a sustainable future (Geissdoerfer et al., 2017; WBCSD, 2018).

However, despite important promises and expectations, questions about the environmental implications of the CE and its comparison with the linear economy (LE) have not yet been explicitly addressed (Fig. 1). The literature consulted indicates that to be realistic, the CE aims to reduce, rather than eliminate, environmental impacts. In a perfectly CE, no new resource would be exploited to produce goods. All raw materials would come from recycled goods. To date, there is no example of a single product that is truly 100% recyclable. Thus, CE is an idealistic view, since it would imply that (i) 100% of product components can be recycled; (ii) the recycling process returns the original compounds to their full quality and properties; and (iii) global consumption does not increase.



Manufacturing of new product components from recycled materials

- In CE, there may be a decrease in the value/quality of the goods produced. It may not be possible to produce the same quality from recycled materials. This would result in CE yielding less durable products.

- Minimal and comparable ecotoxicological impacts are expected from consumption and use of goods produced through CE or LE.
- If goods produced by CE were less durable, consumption would increase.
- The public could perceive that goods produced through CE yield reduced environmental impacts. In turn, this could yield increased consumption, increasing ecotoxicological risk.

Ecotoxicological risk of recycling industry

- In CE, recycling can require increased energy demand compared to LE to produce the same amount of materials.
- Increased energy demand may have an ecotoxicological impact, if energy production induces environmental impacts.
- Recycled materials can become less or no longer recyclable, thus the ecotoxicological impact is not eliminated.

**Figure 1.** Summary of the ecotoxicological implications of the circular economy (CE) versus the linear economy (LE) and the potential risks. The figure presents the comparative advantages and disadvantages of each, as well as the potential ecotoxicological risks with respect to the desirable achievement of sustainability in the cycling of trace metals and other natural resources, from processing, use by industry and consumers, to disposal. Increased sustainability achieves minimization of environmental impacts.

At present “the large majority of recycling actually constitutes ‘downcycling’ because the recycling process reduces the quality of the materials, making them suitable for use only in lower value applications. Some materials still end up eventually in landfills or incinerators. Their lifespan has been prolonged, but their status as resources has not been maintained” (Braungart et al., 2007). Current technologies allow the use of recycled materials to produce other materials of lower value or with no recycling potential. Furthermore, the presence of toxic substances in different materials will “make recycling more difficult and present new, unexpected exposure situations, for example, if contaminated recycled materials get used in products not originally foreseen” (DG-EC, 2017; Bodar et al., 2018). Examples of such problematic substances include dioxin-like chemicals in toys (Petrlik et al., 2018), flame-retardants found in thermos cups and plastic tableware produced from recycled plastics (Gu et al., 2017, Pivnenko et al., 2017), and xenobiotic residues in paper food packing materials produced from recycled pulp (Vapenka et al., 2016). Other well-known examples include polychlorobiphenyls (PCBs, Rodenburg et al. 2015), lead, cadmium (Whitt et al. 2013) and some fluorinated substances (Herzke et al., 2012), which are contained in various materials destined for recycling/reuse. These could subsequently be incorporated into new products, and thus continue to circulate in the CE material streams. Despite their “dilution” in materials that do not contain toxic substances, such substances can continue to cause problems through service life exposure, end-of-waste status, management and recycling once the products become waste (DG-EC, 2017). For example, a modelling study reported that the decontamination of a recycled waste stream might take centuries, even after the input of those substances into manufactured articles has ended (Pivnenko et al., 2016).

The need to consider the risk management of toxic substances from a CE perspective and to adapt it to address explicitly the reuse and re-entrance of hazardous substances into material streams has only recently been highlighted (Bodar et al., 2018). To date insufficient attention has been paid to hazardous substances present in materials for recycling and to end-of-waste. For example, metals are relatively easily recycled; depending on their form, they may be recycled with no loss of quality or properties. However, once incorporated into alloys, metals become much less recyclable. Izatt et al. (2014) comprehensively reviewed challenges in achieving metal sustainability in high-tech society, including environmental aspects of metal use, contamination of soil, air and water, human and environmental health. Despite the significant ongoing efforts carried out in the pursuit of solutions to environmental and health hazards from the products and mining wastes, there are still knowledge and technological gaps limiting the sustainability of metal production from mining and recycling industries (UNEP, 2013). The environmental sustainability of metal recycling and reuse and their circular economy remains to be demonstrated.

Furthermore, recycling itself can generate diverse impacts from energy consumption to gas emission and use of chemicals. For example, in the case of metal recovery, alternative methods (pyrometallurgy vs. hydrometallurgy) yield different environmental impacts, which need to be thoroughly evaluated and benchmarked (BRGM, 2017). In the particular case of mining activities and mining waste management, ecotoxicity assessment could play a key role in the development of tools (based on Life Cycle Analysis (LCA) approaches) that allow the selection of best management practices (BRGM, 2017). Other products such as paper, derivatives (e.g. cardboard) and laminates are even more complex to investigate from an ecotoxicological perspective. The source of new fibres influences the relative ecological advantages of paper recycling. For instance, harvesting wood from natural forests for paper production yields environmental impacts from fossil fuel combustion by relevant machinery that are presumably larger than those from harvesting cultivated trees and plantations of fibrous plants, which also serve as a carbon sink. In the textile industry, the production of synthetic fibres requires a range of manufacturing stages during which the environment is put under strain by effluent discharges, energy requirements and emissions of volatile organic compounds. The above examples illustrate the tight relationship between environmental safety and sustainability in the context of CE.

Clearly, the evolution from a linear to a circular economy will result in changes in the quantities of contaminants released into the environment, as well as in the appearance of possible new risks associated with the high complexity of recycled modern goods. This reasoning is built into LCA, which includes an evaluation of environmental impacts, but also takes into account many other factors. An integration of the criticality of raw materials into Life Cycle Sustainability Assessments was proposed as a multi-dimensional approach going beyond the environmental LCA approach (Drielsma et al., 2016). LCA of metal-containing products attempts to include metal speciation and ecotoxicity (Tromson et al., 2017; Dong et al., 2014; Haye et al., 2007; Huijbregts et al., 2000). However, the existing methodologies of the life cycle impact assessment possess some limitations of toxicity characterization (Gust et al., 2016). Thus, the incorporation in the Adverse Outcome Pathways concept into the toxicity characterization within the LCA was suggested as a possible way to overcome the existing limitations. A novel scheme describing how to decide whether an additional risk assessment is necessary with regard to the re-use of materials containing hazardous substances has been proposed (Bodar et al., 2018), including assessment of substances of high concern in both waste and product phases.

Despite the above-mentioned recent scientific developments, some questions remain regarding the potential environmental and human health benefits and risks of the CE and how these differ from the LE. Two key research questions challenging modern ecotoxicology in the context of the CE need to be urgently addressed: (i) How efficient are CE approaches in the reduction of pollutant emissions into the atmosphere and their release into terrestrial and aquatic habitats? and (ii) How will the expected reduction of pollutant emissions and releases translate into improved environmental quality and human well-being?

The implementation of CE requires public support, which in turn requires rigorous scientific studies to investigate its environmental and economic benefits. This involves mobilizing social scientists to study the perception of risks and benefits associated with the CE by stakeholders, including consumers. Environmental science and pollution research should prioritize investigations at the interface of CE and ecotoxicology, addressing the implications of the CE for the environment via an interdisciplinary, issue-driven approach involving science, policy and industry. Similarly, governments and agencies involved in CE implementation should include consideration of ecotoxicology to instruct stakeholders about its advantages for environmental protection. Improving communication and collaboration among environmental scientists, industry and policymakers to adopt measures allowing the assessment of the efficiency of CE in reducing environmental impacts is the key to moving towards the adoption of appropriate environmental regulations for the development of a sustainable CE.

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## References

Bodar, C., J. Spijker, J. Lijzen, S. Waaijers-van der Loop, R. Luit, E. Heugens, M. Janssen, P. Wassenaar, T. Traas (2018) Risk management of hazardous substances in a circular economy. *J Environ Manag* 212: 108-114.

Braungart M., McDonough W., Bollinger A. (2007) Cradle-to-cradle design: creating healthy emissions – a strategy for eco-effective product and system design. *J Cleaner Prod* 15:1337-1348.

BRGM-French Geological Survey (2017) http://www.brgm.eu

Dong Y., Gandhi N., Hauschild M.Z. (2014) Development of comparative toxicity potentials of 14 cationic metals in freshwater. *Chemosphere* 112, 26-33.

DG-EC (2017) Directorate-General for Environment Sustainable Chemicals "Study for the strategy for a non-toxic environment of the 7th Environment Action Programme".

Drielsma J.A., Allington R., Brady T., Guinée J., Hammarstrom J., Hummen T., Russell-Vaccari A., Schneider L., Sonnemann G., Weihed P. (2016) Abiotic Raw-Materials in Life Cycle Impact Assessments: An Emerging Consensus across Disciplines, *Resources* 5(1), 12.

Geissdoerfer M., Savaget P., Bocken N. M.P., Hultink E. J. (2017) The Circular Economy – A new sustainability paradigm? *J Cleaner Prod, 143*, 757-768.

Gust K.A., Collier Z.A., Mayo M.L., Stanley J.K., Gong P, Chappell M.A. (2016) Limitations of toxicity characterization in life cycle assessment: Can adverse outcome pathways provide a new foundation? *Integr Environ Ass Manag*, 12, 580–590.

Gu F., Guo J, Zhang W, Summers P.A., Hall P.H. (2017) From waste plastics to industrial raw materials: A life cycle assessment of mechanical plastic recycling practice based on a real-world case study, *Sci Total Environ*, 601–602, 1192-1207, 2017.

Haye S., Slaveykova V.I. Payet J. (2007) Terrestrial ecotoxicity and effect factors of metals in life cycle assessment (LCA) *Chemosphere* 68 (8), 1489-1496.

Herzke, D., Olsson, E., Posner, S. (2012) Perfluoroalkyl and polyfluoroalkyl substances (PFASs) in consumer products in Norway – A pilot study. *Chemosphere* 88: 980-987.

Huijbregts, M.A.J., Thissen, U., Guinee, J.B., Jager, T., Kalf, D., van de Meent, D., Ragas, A.M.J., Sleeswijk, A.W., Reijnders, L. (2000) Priority assessment of toxic substances in life cycle assessment. Part I: Calculation of toxicity potentials for 181 substances with the nested multi-media fate, exposure and effects model USES-LCA. *Chemosphere* 41, 541-573.

Izatt R.M., Izatt S.R., Bruening R.L., Izatt N.E., Moyer B.A.(2014) Challenges to achievement of metal sustainability in our high-tech society *Chem Soc Rev*, 43, 2451-2475.

Petrlik, J., Behnisch, P., Digangi, J., Strakova, J., Fernandez, M., Jensen, G.K. (2018). Toxic Soup: Dioxins in Plastic Toys. Technical Report 10.13140/RG.2.2.26295.98726.

Pivnenko K., Eriksen, M.K., Martín-Fernández, J.A., Eriksson, E., Astrup, T.F. (2016) Recycling of plastic waste: Presence of phthalates in plastics from households and industry, *Waste Manag*, 54, 44-52.

Pivnenko K., Granby K., Eriksson E., Astrup T.F. (2017) Recycling of plastic waste: Screening for brominated flame retardants (BFRs), *Waste Manag* 69:101-109.

Rodenburg, L. , Guo, J. and Christie, R. (2015), Polychlorinated biphenyls in pigments: inadvertent production and environmental significance. *Coloration Technol*, 131: 353-369.

Tromson, C., Bulle, C., Deschênes, L., 2017. Including the spatial variability of metal speciation in the effect factor in life cycle impact assessment: Limits of the equilibrium partitioning method. *Sci Total Environ* 581-582, 117-125.

UNEP (2013) Environmental Risks and Challenges of Anthropogenic Metals Flows and Cycles, A Report of the Working Group on the Global Metal Flows to the International Resource Panel. van der Voet, E.; Salminen, R.; Eckelman, M.; Mudd, G.; Norgate, T.; Hischier, R. pp 234.

Vápenka, L., Vavrouš, A., Votavová, L., Kejlová, K., Dobiáš, J., Sosnovcová, J. (2016) Contaminants in the paper-based food packaging materials used in the Czech Republic *J Food Nutr Res*, 55: 361-373

WBCSD (2018) World Business Council for Sustainable Development, Circular Economy Programme https://www.wbcsd.org/Programs/Circular-Economy, consulted November, 28 2018.

Whitt, M., Vorst, K., Brown, W., Baker, S., & Gorman, L. (2013). Survey of heavy metal contamination in recycled polyethylene terephthalate used for food packaging. *J Plastic Film & Sheeting*, 29, 163–173.