Journal of Circular Economy
https://doi.org/10.55845/WNHN7338 Volume 1, Issue 1

**Perspective**

# On Circularity, Complexity and (Elements of) Hope

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Handling Editor: Andrea Urbinati

Received: 29.11.2022 / Accepted: 16.12.2022

## Abstract

A truly sustainable circular economy is more than just recycling, making it a complex matter. We argue that reducing complexity will ease the path to circular economy. Complexity reduction potential lies in lower material diversity, increasing accessibility and intuitive use for consumers, as well as simplifying business operations.

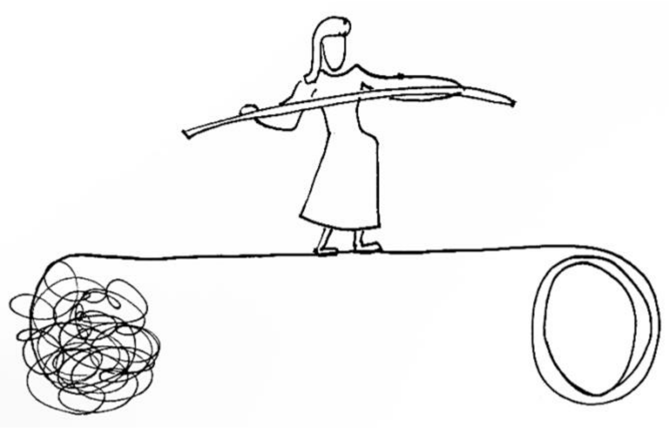

*Figure 1 – Easing the path to circular economy by reducing complexity (Source: own illustration)*

**Keywords:** Industrial Sustainability; Barriers; Enablers; Closed-Loop Supply Chain; Business Model Innovation; Circular Ecosystems; Material Diversity; Biomimicry

## 1. INTRODUCTION

Taking nature as an example: Powered by the sun, biomass is built up, feeding a large number of organisms, which ultimately become raw materials for new cycles. The entire ecosystem is based on only few, but abundant chemical elements, none of which is lost irrecoverably. In contrast, modern society sources chemical elements across the periodic table (Zepf et al., 2014), most through mining from finite deposits. With the help of fossil energy—itself a finite resource—materials are put into products and only a fraction is given a second life (Circle economy, 2021). Most materials end up finely

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dispersed in the environment, for example through incineration, corrosion and abrasion, or are mixed in a way that makes recovery practically impossible.

A circular economy propagates becoming part of nature through bio-based materials, and imitating nature by closing material cycles—that is to circulate products, components and materials. Product manufacture shall become independent of finite material resources and reduce negative impacts on the environment caused by extraction and waste disposal (Desing, Brunner, et al., 2020). Companies see market opportunities and governments a way to decouple economic growth from increasing environmental impacts and resource consumption.

To some extent, this is wishful thinking. Increasingly closed material cycles require more and more energy, itself a limited resource (Desing et al., 2019). And filling new stocks—like batteries or solar panels—requires primary inputs inevitably. Bio-based materials in technical products often become incompatible with the biosphere (e.g. ink on paper, coatings on wood), thus breaking cycles. As man-made materials already exceed all living biomass (Elhacham et al., 2020) and biodiversity is in a deep crisis (Ceballos et al., 2020), bio-based material's contribution could at best be small. On our limited planet, growth in physical entities can never be indefinite (Murphy, 2022). Still, circularity is an essential concept and the biosphere a valuable blueprint for living well within the limits of our planet. This may be achieved, however, only if circularity is implemented with the objectives of maximizing sustainability and wellbeing (as opposed to maximizing circularity) (Desing, Brunner, et al., 2020) and reducing ecological risks (Desing, 2021; Desing & Widmer, 2021).

We suggest to discuss if reducing complexity facilitates the implementation of circular economy. We see three areas with complexity reduction potential: A) material diversity, B) the customers' role in the value chain, and C) long-term relations within circular value chains. In the following we shortly discuss the three areas

## 2. OPTIMIZING MATERIAL CIRCULARITY

Proponents of the circular economy often propagate a waste hierarchy, preferring waste avoidance over recycling. While this sounds plausible, it is not always beneficial for the environment. Consider a gas heating system. Replacing it immediately with a heat pump is much better environmentally, despite wasting a functional product prematurely to recover its materials (Hummen & Desing, 2021). This is true for all circular strategies: because they not only avoid but also cause impacts, there are optimal levels of circularity. Decisive factors for environmental impacts are the quantities of materials cycled, how fast they circulate, how small losses are, and what energy is used to power cycles (Schäfer, 2021). Additionally, there are substances—such as flame retardants in insulation materials (Wiprächtiger et al., 2020) or mercury in electronics (United Nations Environment Programme, 2019)—that should not be circulated due to risks to humans and ecosystems (Kral et al., 2013). Every product has a different optimal circular strategy and point of replacement, i.e. circularity has to be optimized for minimum impacts, not maximized in terms of circulated material mass (Blum et al., 2020)!

Along every material cycle, losses (a form of waste) occur inevitably: be it during manufacture, use, collection, sorting or processing. Losses can be reduced through optimizing processes or cleaning contaminated wastes with the help of additional energy. Consequently, a sustainable circular economy will continue to require primary resources and disposal options for unavoidable waste (Kral et al., 2013). Impacts on planetary boundaries limit thereby both the availability of materials (Desing, Braun, et al., 2020) and energy (Desing et al., 2019). Theoretically, fully closed cycles would require infinite energy. Nature comes close to it by reducing material complexity (all organisms process the same, abundant elements C, H, O, N, P and a few others) and transferring matter between huge inactive reservoirs with the help of abundant solar energy (Ayres, 1999). Similarly, technical cycles have to be primarily driven by solar energy harvested on the already sealed surface of the built environment, the by far largest and most accessible potential within planetary boundaries (Desing et al., 2019). Furthermore, less material complexity in products and the entire socio-economic metabolism helps increasing circularity and reducing primary inputs and losses, because collection, separation and processing become easier. Abundant elements—such as H, C, O, Al, Si, Fe; similar to those used by nature—are readily available in large, distributed inactive stocks, whereas rare and critical materials can only be extracted in special locations with extra efforts to keep them in the loop. Consequently, mimicking nature by building society's metabolism increasingly on abundant "elements of hope" (Diederen, 2010) should become a central strategy for a sustainable circular economy. Atmospheric carbon is a good example (Desing, 2022): we need to remove it from the atmosphere anyway, so why not make useful products out of it and replace current impactful materials?

## 3. CHANGING ROLE OF CUSTOMERS: FROM KINGS TO SERVANTS

Like in nature, all actors in circular supply chains are customers and suppliers: using and processing materials (products), not leaving waste but nutrition behind. Actors are dependent on each other and the availability of resources. In such a setting, customers—as in the classical understanding of consumers of products and services offered by industry—have responsibility and are integral parts of a bigger system, requiring a shift away from the “customer is king” paradigm. Counter to the current focus in literature on how customer behavior and preferences influence the emergence of circular business models (Gomes et al., 2022; Mostaghel & Chirumalla, 2021), the integral functions of customers need investigation (Milios, 2022) especially in regard to help reducing complexity in circular systems.

Products and services for such costumers need to be designed in a way that is intuitively good for the bigger ecosystem, i.e. reducing complexity of the intended use. For example, the furniture company that delivers a sofa is taking back the old sofa: avoiding complex decisions for the customer on how and where to dispose the old sofa and incentivizing the manufacturer to reduce product complexity facilitating easy re-use of materials and components. Car companies offer long-term rentals and car-sharing options including services, energy and insurance, which is incentivizing them to build energy-efficient, durable, repairable cars (all facilitated by less complex cars designs) and makes car ownership unattractive. Or an optimized collection–point network for PET bottles, minimizing $CO_2$ emissions for transportation and maximizing accessibility (i.e. reducing the complexity for customers to return bottles) and consequently the amount of returned bottles (Haupt et al., 2018).

## 4. LONG-TERM THINKING TO REDUCE COMPLEXITY

Natural cycles function way beyond the lifetime of individuals. Similarly, implementing material cycles in the economy also requires long-term and integrative thinking. Buildings and infrastructures, for example, hold materials for many decades and should then be able to become parts of new cycles. This requires a paradigm shift, transcending thinking in quarterly financial periods to long-term thinking in (several) generations. Besides reducing material complexity (in buildings for example with flexible and adoptable structures or mono-materials), material cycles require collaborations too: one actor's products are another's feed, with future inputs directly depending on today's operations of all actors in the circular supply chain. Finding stable partner networks ("circular ecosystems" (Takacs et al., 2020)) or vertically integrating parts of the circular supply chain reduces uncertainties from volatile markets as well as the complexity of dealing with changing suppliers and customers. Reducing the barriers for establishing such networks in the policy landscape can greatly incentivize this change. But: companies do not have to wait for legislature paving the way. Circularity can already be profitable today, as demonstrated in second-hand stores, reusable packaging, or "product as a service" models. A change in business model, however, has to go hand in hand with the circular design of products and services (Desing et al., 2021; Lama et al., 2022).

## 5. CONCLUSION

Making increasing circularity manageable and implementable, requires to reduce complexity in materials—fewer, but purer and more abundant materials are easier to handle and circulate with less energy—and operations. The latter can be achieved (i) by establishing long-term collaborations, ease of access and use; and (ii) by increasing complexity in linear, fossil-based operations—incentivizing change over persistence. Research can contribute easy-to-use tools, processes and materials for optimizing circularity; companies need to think and act collaboratively; and society can incentivize change towards a hopeful, circular and fossil-free future

## DECLARATIONS

**Competing interests** The author declares no competing interests.

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