The actual goals and limits of circular economy – a critical perspective

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Abstract

In order to avoid exaggerated expectations and hopes and to give a realistic picture of the limits and possibilities of circular economy, this paper deliberately adopts a critical perspective. The idea of circular economy is an important meta-strategy for sustainable development. Its thermodynamic limits explain why it must be seen as a means and not an end. However, in policy and standardisation, proxies are chosen as indicators that almost exclusively focus on circularity. There is a lack of indicators and analysis methods that also take into account the overarching goals of a circular economy and check whether a measure contributes to these goals. Concerning the environmental goals, life cycle assessment would be an appropriate approach.

Introduction

How do we achieve sustainable development? This question alone could fill volumes, yet it remains unsatisfactorily answered from a practical standpoint. Every year, we seem to move further away from the goal of a sustainable state for our planet, rather than closer to it.

In theory, there are three paths to sustainable development: efficiency, sufficiency, and consistency (Huber 1996, 2000). Consistency is the most promising, as it best balances ecological and social aspects, but it is also the most complex and time-intensive (Schmidt 2008; Rudolf and Schmidt 2024). It involves two key strategies: transitioning to solely renewable energy ("energy transition") and embracing a circular economy (CE). The latter shifts away from the linear "take make dispose" model and aims at conserving resources and minimizing waste by cycling and re-using materials within the technosphere as long and often as possible.

The very concept of waste –inevitable outcome of the linear economy - is interesting. Largely a modern phenomenon, in Johann Heinrich Zedler's 1732 encyclopedia, the German term for waste ('Abfall') was only linked to mining, referring to low-grade ores (Kuchenbuch 1989). Earlier societies had little waste, as scarcity was the norm and all usable materials were repurposed. Even Georgius Agricola's 1556 "De Re Metallica" described the beneficial use of mining residues such as fly ash (Albrecht 2001). The modern notion of waste emerged later, encompassing residues from manual or industrial production and food decay. Even in the time of scarcity between the two world wars of the 20th century, Germany was closer to a circular economy than today: Recycling concepts even existed at that time for cleaning wool in steelworks (Schmidt & Görlach 2010). Today, waste is a constant companion of consumerism: people remain in a cycle of throwing away and buying new things; actions that seem to have become just two sides of one and the same thing. Nature, however, operates in material cycles, making the circular economy a prime consistency strategy, emulating natural systems. Thus, in a circular economy context, should we still talk about waste, or rather, (secondary) raw materials? Ideally, 'waste' disposal transforms into a new 'raw material' supply.

Yet, we are far from this ideal. The Circularity Report reveals that a mere 7.2% of material inputs are recycled globally (Fraser et al. 2023), with Germany at a 13% "circular material use rate" (Eurostat 2023). Projections show that even for materials like steel or aluminium, recycling rates will only reach 60-70% by the next century's turn, still necessitating significant primary material extraction (Van de

Voet et al. 2019). Global demand, fueled by a growing population, many of whom live in material poverty, poses a significant hurdle to a global circular economy, even with optimal recycling (Van de Voet et al. assumed an optimistic 90% recovery rate for steel and aluminium).

Review of common premises

But is a 100% circular economy theoretically feasible or even desirable? This has been a contentious debate (Georgescu-Roegen 1979, Ayres 1999, Craig 2001, Baumgärtner et al. 2003, Lems et al. 2004). The popular notion of "closing the loop" stems from three premises:

a) We need a circular economy because the earth is finite and sooner or later we will run out of raw materials.
b) Recycling is always better for the environment than primary extraction from mining.
c) Nature demonstrates the possibility of 100% recycling.

All three assumptions must be critically scrutinised today. Regarding a), the earth, while limited, possesses vast quantities of chemical elements and, in particular, metals (Schmidt 2021). There are geological estimates of raw material resources that are several orders of magnitude higher than those currently discussed in public arguments (Arndt et al. 2017). A genuine geological shortage is therefore not to be expected in the foreseeable future.

However, more raw material deposits must be identified fo fulfill the rising demand. While the earth hasn't been fully explored yet, only easily accessible deposits are currently known (Wellmer et al. 2016). It is not the quantity of chemical elements itself that is a problem, but the available deposits with sufficient ore content to make mining profitable. The concentration of the metals or materials in the deposits is decisive in this regard. The lower the concentration, the greater the effort required - in physical terms (energy), in economic terms (costs) and in ecological terms (environmental pollution and greenhouse gas emissions). This dependency is predetermined by natural laws of thermodynamics (Faber et al. 1996). Additionally, potential conflicts in extraction areas exist, where valuable deposits may be inaccessible due to social, ecological, or political reasons.

The ore concentration and thus the thermodynamic laws also apply to premise b). Recycling also demands effort in terms of energy, entails costs and environmental impacts. While recycling some bulk metals may be cheaper than primary mining, this varies with conditions like collection effort, separation processes, and the quality of secondary materials. In this context, Allwood (2023) describes the technical challenges of recycling the most important materials in our society - steel, aluminium, cement, plastics, glass, paper and clothing - and comes to a rather disappointing conclusion: “The phrase ‘circular economy’ creates an attractive image of a beneficial loop of continuous material recycling without the harmful environmental impacts of new production. In fact, this chapter has shown that recycling is only one among the lower orders of a hierarchy of options for reducing those impacts, and the ‘circular economy’ is rarely if ever the key to doing so.”

The concentration of materials in products or waste significantly affects recycling efficiency: lower concentrations escalate energy usage, costs, and environmental impact. For instance, a typical mobile phone, weighing around 110 grams, contains just 0.3 grams of rare earths and a mere 17 milligrams of gold. This amounts to a metal value of only about 1 US dollar per phone (Bookhagen et al. 2020). When considering the global scale of mobile phones, the quantities of secondary raw materials in phones are substantial, yet the challenge lies in collecting and concentrating these materials. The concentration ratios in waste thus compete with those in primary deposits, which Schäfer (2021) has worked out well. In some cases, recycling can be more costly and environmentally detrimental than mining.

Concerning premise c): If there was enough energy, it would be possible to close the cycle of materials. Yes, in theory this could work, but the required energy levels would be prohibitively high. Metallurgist Markus Reuter once compared the attempt to the effort required to separate the milk from a cappuccino. Globally, the availability of energy in amounts that are both economically and ecologically viable is the primary limiting factor for a total recycling, a situation likely to persist for a long time. Moreover, there are intrinsic objections to the concept of "closing the loop". From a thermodynamic perspective, Ayres (1999) argues that even if any amount of energy (i.e., exergy = workable energy) were available, the entropy in the overall system would have to be distributed appropriately. In recycling, this involves creating what is termed 'inactive material stocks' – essentially, low-grade waste with high entropy, which would need to be substantial in size. Ayres argues that nature relies precisely on such inactive material stocks and that only a very small proportion of material is in circulation. Inactive stocks resulting from recycling can include slag, chemical residues, wastewater, emissions, and more, potentially not benefiting the environment. Ayres further noted that "one consequence of the second law of thermodynamics is that recycling can never be 100% efficient" (Ayres, 2004). Consequently, a fully closed-loop system is not feasible.

Circularity as an overall goal?

The problem of recycling is therefore basically the same as that of primary extraction from mining. Both processes are efficient at high concentrations, but at lower concentrations, they become unprofitable, demanding substantial energy and causing significant environmental pollution (Schäfer 2021). What does this imply? It suggests that circularity, especially from an environmental and climate protection standpoint, is not inherently beneficial. While this is true in many instances, it is not a universal rule. A detailed analysis and evaluation of each specific case is necessary. Most importantly, we need to ask ourselves the critical question: why do we pursue a circular economy? This introspection helps in aligning our actions with sustainability goals and especially with environmental goals.

If we look at the circular economy as a means of strengthening local supply security, in particular by reducing dependence on foreign raw materials, it certainly has its merits. However, we must confront two truths: First, a high rate of recycling for supply security might have adverse environmental and climate impacts, as previously mentioned. Second, we must consider what the circularity of a country's supply security actually entails. Can the same indicators be used as for the assessment from a climate protection perspective? Hardly. For climate protection, only the global emissions of a circular economy measure counts. For supply security, the crucial factor is the volume of goods (both primary and secondary materials) imported from economically unstable regions. Lately, this concern has been associated with countries like China and Russia, but in the future, it could extend to regions like Africa or even the USA.

The effectiveness of a circular economy in terms of increasing supply security needs careful consideration, especially when waste and residual materials are shipped overseas for recycling, only to be re-imported into Europe. Hilgers et al. (2021) point out the problem of the lack of industrial infrastructure for comprehensive recycling: "The lack of smelters and refineries in Europe not only limits the recycling capacities for scrap, but also leads to a loss of expertise and innovation. The outsourcing of the industry to emerging countries leads to lower material efficiency and increased environmental pollution." The real gains for supply security and environment become questionable under such circumstances. For instance, the extended re-use of mobile phones or electric cars in Africa, often lauded for prolonging product life, might not contribute significantly to sustainability if these end up being recycled in places like the infamous Agbogbloshie landfill in Accra, Ghana under inhumane conditions that destroy health and the environment. Such scenarios highlight the complexities in assessing the true impact of circular economy practices, particularly when they cross international boundaries and involve varied environmental impacts.

This critical perspective on the circular economy is not novel but a recurring theme in scientific discourse (Harris et al. 2021). Korhonen et al. (2018a, 2018b) have cautioned that a robust scientific foundation is essential for the circular economy and that it should not be driven solely by selective practical examples. The influential presence of organizations like the Ellen MacArthur Foundation together with McKinsey, and the political momentum from the European Union have propelled the circular economy into a realm of unexpected dynamism. This rapid development sometimes leads to the oversight of careful and conscientious consideration of the broader implications and practicalities involved.

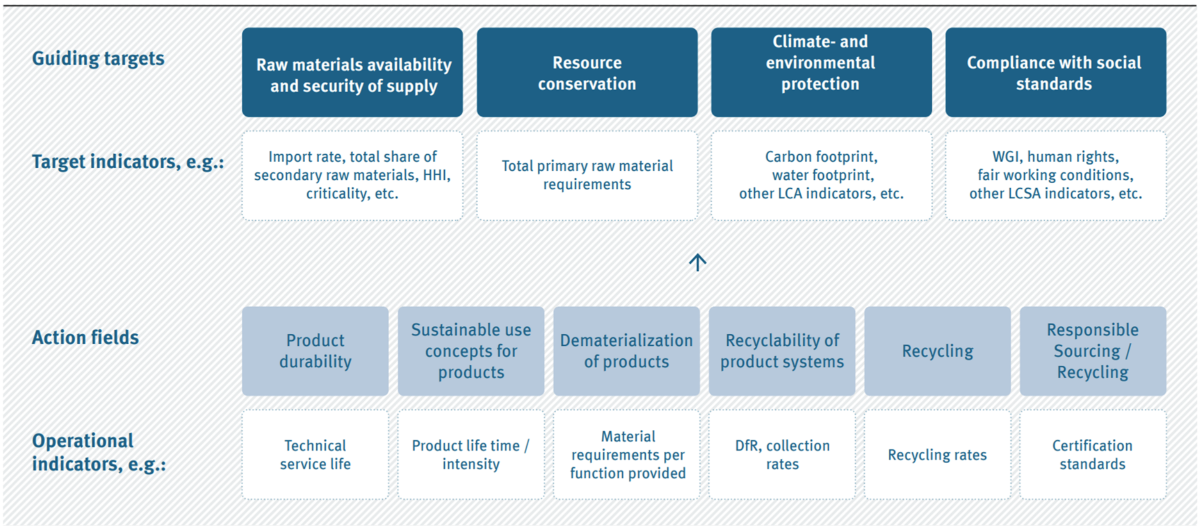

Figure 1: Schematic figure of a target hierarchy in the Circular Economy (CE) with guiding targets and a selection of fields of action and indicators. HHI: Herfindahl-Hirschman-Index; LC(S)A: Life Cycle (Sustainability) Assessment; WF: Water Footprint; WGI: World Governance Indicator; DfR: Design for Recycling. Source: UBA Resource Commission (2023).

In its latest statement, the Resource Commission of the German Federal Environment Agency emphasized that the circular economy should not be seen as an end in itself, but rather as a means to achieve broader goals (UBA Resource Commission 2023). In addition to environmental and climate protection, these guiding targets include security of supply, but also social aspects (refer to Figure 1). To truly assess the effectiveness of circular economy practices, it's essential to employ the right indicators that measure their impact on these overarching targets. So how does the circular economy contribute to social standards, climate protection or supply security? In the circular economy discourse, there is often an oversight in this critical evaluation, with circularity being used as a proxy for overall success. However, such an approach is only justifiable when the goals of circularity align closely with these broader objectives.

Lack of proper assessments and indicators

This fundamental critique extends to broader interpretations of the circular economy, which include aspects like prolonging product lifespans. Various studies demonstrate that product lifespan and reuse need nuanced consideration (Agrawal et al. 2012, Madsen 2015, Kjaer et al. 2016, Helms et al. 2023, Isenhour et al. 2023). For instance, the availability of shared resources like cars or electric leaf blowers could lead to their increased use over more sustainable options like bicycles or brooms. This highlights the need to evaluate the sharing economy not just on the basis of reducing ownership, but also on its actual impact on resource use and sustainability.

There exists a risk that political efforts in advancing the circular economy might focus on inappropriate indicators, particularly those related solely to circularity, such as recycling rates or recyclate quotas. While targeting these indicators may be effective in specific instances to motivate certain economic sectors towards greater circularity, it is crucial to continually assess whether these policy tools are truly yielding the intended outcomes. This means verifying if these measures are contributing effectively to the overarching goals. It is not enough to simply promote circular activities; their real-world impact on key targets like sustainability, environmental protection, and resource efficiency must be rigorously evaluated to ensure that policy actions align with long-term objectives.

An illustrative example of this approach is the upcoming 59000 series of standards from the International Standardization Organization (ISO), set to be endorsed under the broad category of 'Circular Economy'. The proposed standard ISO 59004 focuses on "Terminology, Principles and Guidance for Implementation", while ISO 59010 provides "Guidance on Business Models and Value Networks", and ISO 59020 centers on "Measuring and Assessing Circularity". Additionally, there are standards like ISO 59040, which introduces a "Product Circularity Data Sheet", and ISO 59014, which pertains to "Secondary Materials".

ISO 59004 notably includes sustainability as one of its key objectives. It defines the circular economy as "an economic system that employs a systemic approach to maintain a circular flow of resources, by recovering, retaining, or enhancing their value, all while contributing to sustainable development." However, a significant limitation arises with the 59000 series standards: they focus primarily on circularity metrics and do not mandate that circular economy measures directly contribute to sustainability goals. This becomes evident with ISO 59020, where the only mandatory indicators are the circular content of inflow and outflow. Other potentially crucial ecological metrics, such as energy use or water utilization, are merely optional. Thus, while the ISO 59000 series aims to preserve material economic value—a core aspect of circular economy—it falls short in providing a comprehensive framework for evaluating whether circular economy initiatives are effectively advancing sustainable development goals. This gap indicates a need for broader and more inclusive approaches that encapsulate both circularity and sustainability in a more integrated manner.

Nontheless, these standards form a framework that aids the global promotion and implementation of the circular economy, but miss an important opportunity to integrate with a comprehensive methodology ISO helped develop: Life Cycle Assessment (LCA) and its associated standards, ISO 14040 and 14044, along with its smaller sister of the LCA, the Product Carbon Footprint defined by ISO 14067. These methods provide a comprehensive evaluation of the environmental and climate impacts of economic systems across the entire product lifecycle, considering a wide range of ecological impact categories. The LCA is crucial for preventing misguided decisions that might simply shift environmental burdens within the value chain or create other unintended ecological consequences. Regrettably, the upcoming ISO 59020 standard only mentions LCA methods in passing, labeling them as "complementary methods" among various others. This represents a significant missed opportunity to enhance the circular economy framework with a well-established, holistic approach to environmental impact assessment.

Holistic approaches needed

LCA remains a robust foundation for evaluating circular economy measures. This method has been developed over decades by leading minds in industrial ecology and environmental science and has reached a high degree of maturity (Peña et al. 2021). Nevertheless, there are still open questions that need to be discussed. In the area of primary and secondary materials in particular, so called allocation of impacts is constantly being scrutinised (Schrijvers et al. 2016). Just as in economics, the allocation problem cannot be answered scientifically, but is always subject to an arbitrary determination based on certain assumptions or preferences. This subjectivity is openly acknowledged and discussed within the LCA community, allowing for its contextual and meaningful application. In contrast to the European Union's bureaucratic allocation approach with the Circular Footprint Formula, standards like ISO 14040/44 and ISO 14067 have fortunately steered clear of such rigid regulation. This acknowledgment of the inherent ambiguities and the flexibility in applying LCA methods make them more honest and adaptable tools for addressing the intricate challenges of circular economy assessments.

Concluding remarks

By taking the role of a 'devil's advocate', my intention is not to oppose the circular economy. Quite the contrary, I am a proponent of it. However, it is crucial to approach it with a critical eye. The enthusiasm of some advocates, coupled with the economic interests inherently linked to the circular economy, can sometimes overshadow objective analysis. It is essential to clearly articulate our true objectives and rigorously evaluate the potential contributions and limitations of various measures or strategies towards these goals. Unfortunately, this level of critical discourse is often lacking, even though there is a wealth of methodological expertise available, particularly within the Life Cycle Assessment community. It is my hope that going forward, the circular economy community will increasingly leverage this existing knowledge, employing it more extensively and effectively in their planning and implementation processes. This integration of critical, methodologically sound perspectives is vital for the meaningful and sustainable advancement of the circular economy.

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