Received: 07.02.25 | Revised: 28.02.25 | Accepted: 07.03.25

Rethink: Planetary Perspectives on Circularity

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Abstract: Circularity has advanced to a key strategy for transforming our society: closing the loop is expected to enable economic profits independent of resource consumption and its associated environmental impacts (Blomsma & Brennan, 2017; Bocken et al., 2021; Circle economy, 2023; Ellen MacArthur Foundation, 2019; European Commission, 2020). Thinking in circles and in systems is paramount for transforming our society to stay within planetary boundaries (Desing, Brunner, et al., 2020), yet specific circular strategies must target specific problems. Circularity is not a panacea (Blum et al., 2020; Geissdoerfer et al., 2017), thus it is important to distill when and where circularity can contribute to planetary wellbeing (Wiedenhofer et al., 2025). "Rethink" emerges as the most influential strategy: from the way we use energy, over which activities deserve priority, all the way to the role circularity itself can play.

Keywords: circular economy | planetary boundaries | basic needs | energy transition | climate change

Rethink: planetare Perspektiven auf die Kreislaufwirtschaft

Zusammenfassung: Kreislaufwirtschaft ist zu einer der wichtigsten Strategien für die Transformation unserer Gesellschaft aufgestiegen: Kreisläufe zu schliessen soll ökonomische Profite unabhängig vom Ressourcenverbrauch und dem damit einhergehenden Umweltauswirkungen ermöglichen. Das Denken in Kreisläufen und Systemen ist zweifelsohne essenziell, um eine Gesellschaft innerhalb planetarer Grenzen aufzubauen. Aber: Kreislaufstrategien müssen auf spezifische Probleme zugeschnitten sein. Kreislaufwirtschaft ist nicht ein Allheilmittel, daher ist es wichtig herauszukristallisieren, wann und wo Kreislaufwirtschaft zum planetaren Wohlergehen beitragen kann. Dabei stellt sich „Rethink" – umdenken – als wichtigste Strategie heraus: von der Art und Weise wie wir Energie verwenden, über die Priorität wirtschaftlicher Aktivitäten, zur Rolle die die Kreislaufwirtschaft selbst in der Transformation spielt.

Stichwörter: Kreislaufwirtschaft, planetare Grenzen, Grundbedürfnisse, Energiewende, Klimawandel

For a society to become absolutely sustainable, two conditions need to be fulfilled (Desing, Brunner, et al., 2020; Heide et al., 2023): (i) it has to provide basic needs for everyone (Millward-Hopkins et al., 2020; Rao & Min, 2018; Schlesier et al., 2024; United Nations, 2015), and (ii) all human activities combined have to happen within planetary boundaries (Richardson et al., 2023; Rockström et al., 2009, 2023). Only then will it be possible to ensure long-term planetary stability (Armstrong McKay et al., 2022; Wunderling et al., 2022) and a decent life for all (United Nations, 2015). Returning to within planetary boundaries needs to happen in the coming decades, because living in overshoot since nearly 40 years pushes the Earth system to the brink of tipping (Ditlevsen & Ditlevsen, 2023; Lenton et al., 2023; van Westen et al., 2024). To reach a doughnut economy, i.e., the operating space between fulfilling basic needs and planetary boundaries (Raworth, 2013), requires a fast and far-reaching transformation of society, as basic needs are still not fulfilled for everyone (Kikstra et al., 2021; O'Neill et al., 2018) and 6 out of 9 planetary boundaries are exceeded (Richardson et al., 2023). CO_2 emissions need to reduce by at least 98 %, the pressure on biodiversity by 90 %, phosphorus and nitrogen emissions by about 75 %, and land occupation by 50 % (Desing, Braun, et al., 2020). Primary material production—excluding biomass—is responsible for about 20 % of total CO_2 emissions and 14 % of biodiversity loss (Desing, Braun, et al., 2020; UNEP, 2024). Despite policy focus and international efforts, no absolute decoupling between resource use and economic activity could be observed (European Environmental Bureau, 2019; UNEP, 2024). Even if circularity could make primary production completely obsolete, this would reduce impacts by 20 % at best. Hence, the focus on material circularity is insufficient to achieve planetary stability alone. Similar to circularity, population control can have only a minor contribution towards achieving absolute sustainability (Schmalz, 2025; Springmann et al., 2018). In the absence of large-scale catastrophes—such as wars, pandemics, and famines—global population will likely reach a maximum of around 10 billion in 2085 before it will start to decline (UN, 2022). Even if global population could somehow humanly be reduced significantly in the next few decades—i.e., when actions are most important (United Nations Environment Programme, 2022)—, this would only reduce environmental impacts proportionally (Springmann et al., 2018).

Fulfilling basic needs for 10 billion people with today's predominantly fossil-based and linear provisioning system would allow to cut environmental impacts by roughly half. However, this would still transgress planetary boundaries (Schlesier et al., 2024). Prioritizing the fulfillment of basic needs allows to increase living standards for more than half of the current population (Kikstra et al., 2021, 2025; Millward-Hopkins, 2022), while the remaining would have to *reduce* consumption. Sufficiency is important (Creutzig et al., 2024; European Environmental Bureau, 2021; Pauliuk, 2024), yet by itself insufficient to achieve a planet-compatible society. What is needed is a transformation of the provisioning systems catering basic needs. And here, fossil energy is the largest driver of impacts (Desing & Widmer, 2021; IPCC, 2022; Schlesier et al., 2024). Completely defossilizing energy supply—i.e., replacing coal, oil, and gas with solar and other renewables (Desing et al., 2019)—allows a giant leap towards absolute sustainability, reducing CO_2 emissions by more than 95 % and half biodiversity impacts again (Schlesier et al., 2024). The remaining impacts beyond planetary boundaries are dominated by the industrial production of animal-based products and land use change in agricultural systems (Gerten et al., 2020; Schlesier et al., 2024; Shepon et al., 2018; Willett et al., 2019). Fortunately, meat and dairy are not essential for our bodies, allowing to design healthy and predominantly vegan diets (Chen et al., 2019; Willett et al., 2019). Some animal products from extensive forms of agriculture may still be possible, however large scale, industrial meat and dairy production is environmentally untenable (Springmann et al., 2018, 2023). Also, improved agricultural practices, which do not deplete soils, can be sustained on the same land for millennia, eliminating the need for additional land transformation. When supplying basic needs with renewable energy, without industrial meat and dairy, and without additional natural land conversion, living within planetary boundaries becomes possible (Schlesier et al., 2024).

Material circularity was not yet necessary to construct scenarios where society could sustain itself within planetary boundaries. This is because impacts from primary material production for providing basic needs are of minor importance compared to the changes described before. Even when reaching the doughnut, primary material production still accounts only for about 20 % of CO_2 emissions, global warming potential, and biodiversity loss (Schlesier et al., 2024). Circularity can thus increase the safe and just operating space beyond basic needs.

More important, however, is the role of circularity in the transformation process. The biggest contribution to reach planetary boundaries is defossilizing the energy system (Desing et al., 2022; Desing & Widmer, 2021). Building renewable energy infrastructure needs a lot of materials (Carrara et al., 2023; IEA, 2023), the primary production of which causes environmental impacts (Tost et al., 2020), impedes vulnerable communities (Lebre et al., 2020), and opening new mining and processing facilities takes time (Desing et al., 2024). Given the urgency of the climate crisis, we need to accelerate the transition (Desing & Widmer, 2021) and one way to facilitate this is by applying circular strategies. Scraping and *recycling* fossil infrastructure—such as cars, heat boilers, power plants, pipelines—immediately when they become obsolete, can significantly increase the availability of secondary raw materials for the transition, which reduces the need for primary materials and—consequently—environmental impacts (Schlesier et al., in review). Using secondary materials in the transition requires a *redesign* of renewable energy components to make use of materials contained in fossil infrastructure. For example, aluminum in mounting systems in solar PV is flagged as a potential bottleneck (Lennon et al., 2022) but can be replaced by steel recycled form fossil infrastructure (Schlesier et al., in review). This focus on recycling can be counter-intuitive in the light of the often promoted "waste hierarchy", suggesting reuse and repair as higher value strategies than recycling (European Commission, 2020; Potting et al., 2017). When optimizing for minimal impacts (Baum, 2018; Haupt et al., 2018; Hummen & Desing, 2021), the waste hierarchy proves to be unfit as a general rule, requiring to select appropriate circular strategies on a case-by-case basis instead. For example, gas boilers in domestic heating systems should be replaced with heat pumps immediately, irrespective of their working condition (Hummen & Desing, 2021). This is because extending the use of fossil devices is counterproductive for achieving the transition. In contrast, *repurposing* functional parts of fossil infrastructure—e.g., e-retrofitting diesel buses and trucks (Desing, 2024) or pipelines for district heating pipes (Creutzig et al., submitted; Wiedmann & Desing, 2024)—can help to accelerate and thus reduce cumulative impacts.

Another way to accelerate the energy transition is to recycle idle or hibernating material stocks of materials essential to the energy transition. One such example is silver, required as current collector in state-of-the-art crystalline silicon PV modules (Hallam et al., 2022; Victoria et al., 2021). Silver replacements are intensively researched (Grübel et al., 2021; Heath et al., 2020; Zhang et al., 2021), yet their scaling on the market is still uncertain and will take some time. Until then, we could resort to the silver we have already mined, about 70 % of which is hibernating as silverware and financial holdings (Sverdrup et al., 2014; The Silver Institute and Metal Focus, 2023). Recycling these stocks alone would be more than enough to power basic needs for everyone with current solar PV technology

(Desing et al., 2024, 2025) on the surface of the already built environment (Desing et al., 2019).

Many materials deemed critical in the context of the energy transition are needed for energy storage, such as lithium, cobalt, or platinum group metals (Carrara et al., 2023). Insignificant stocks of those materials are present in society today (Wang et al., 2018), making recycling to build desired energy storage unfeasible. *Rethinking* the way we use energy in society today, however, can reduce the demand for energy storage significantly (Creutzig et al., 2018, 2024; Desing & Widmer, 2022). Aligning societal energy demand with the intermittent availability of renewable energy avoids material supply bottlenecks, reduces costs, accelerates the transition, and lowers its cumulative impacts (Barnhart & Benson, 2013; Desing & Widmer, 2022). Following the course of the sun in a sunflower society (Desing & Widmer, 2022) will require to rethink societal operations: making work schedules more flexible, prioritizing essential energy uses, developing grid connected modes of transport, or seasonal stockpiling products to store embodied energy.

Returning to a safe climate mandates the removal and safe storage of at least 1500Gt of CO_2 as soon as possible (Armstrong McKay et al., 2022; Desing, 2022; Wunderling et al., 2022). As the biosphere's potential and capacity to bind CO_2 is slow and limited (Fuss et al., 2018; Griscom et al., 2017), speeding up carbon removals will need a new type of industry: *cleaning up* the atmosphere. Simply putting CO_2 underground is an end-of-pipe solution and represents a cost to society. Converting CO_2 into carbon-dense, valuable, solid materials and storing them underground after material use allows to generate value for society (Desing, 2022). Mining the atmosphere (Lura et al., 2025), however, needs large amounts of green energy, requiring the scaling of renewable energy capacities far beyond of what is needed to power basic needs (Desing et al., 2022). And it needs to aim at maximizing the linear flow of CO_2 out of the atmosphere to safe final sinks until 350ppm atmospheric CO_2 concentration is reached. All supporting materials—be it hydrogen, water, steel, silicon—must circulate to best facilitate the linear flow of carbon (Desing & Blum, 2023). Furthermore, the idea of cleaning up needs to extend to toxic and persistent chemicals (Persson et al., 2022), as well as restoration of ecosystems (IPBES, 2019).

All of this can only happen, if we fundamentally rethink the way we organize our society: From business operations (Bocken et al., 2016) to economic paradigms (Bärnthaler et al., 2021; Desing et al., 2025), from the way we live (Vita, Hertwich, et al., 2019; Vita, Lundström, et al., 2019; Waldinger & Schulz, 2023) to how we participate in political decision making (Gerwin, 2022), and from interacting with each other (Graeber & Wengrow, 2021) to our relationship with the natural world (Ivanova et al., 2024). When used for purpose, circularity offers us tools to build the future we want.

Declaration of Interest

The author declares no known competing interests which could have appeared to influence the work reported in this paper.

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