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Perspective

Greater circularity leads to lower criticality, and other links between criticality and the circular economy

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Society requires a stable and secure supply of raw materials. Raw materials supply stability and security are, amongst others, addressed by the concept of raw materials criticality, which focuses on the vulnerability of an economic unit (most commonly a country or region, but also the world, specific sectors, companies or products) to supply restrictions of certain mineral raw materials (cf. Schrijvers et al., 2020). The idea of keeping materials in the economic cycle for longer is specified in the Circular Economy (CE) concept, which encompasses efforts that reduce waste and improve material efficiency (Ellen McArthur Foundation, 2013; European Commission, 2018). So far, CE beyond recycling has not played a prominent role in the criticality debate. At the same time, critical raw materials (CRM) have only been a minor topic in the discussion on CE (recent exceptions include European Commission, 2018, and Gaustad et al., 2018). If properly aligned, criticality assessments might help in defining priority materials for the CE, and circularity strategies could substantially mitigate supply risks. In this paper, we explore the potential benefits, as well as caveats, of adopting a CE approach to CRM, based on our own experiences and our discussions organized by the IRTC (International Round Table on Materials Criticality) project.

For orientation, we use a simplified representation (Fig. 1) of CE and match this to key issues addressed in the criticality discussion: the diversity and stability of supply chains, including the contribution of recycling to supply, and the ability to use different materials or technologies to achieve a given function (substitution).

Diversity and stability of primary supply are fundamental to criticality assessment methodologies and reflected in all of them (cf. Schrijvers et al., 2020). Although CE models can have supply security as an objective, the aspect of securing primary supply is absent. Instead, they focus on gaining more value from raw material extraction and maintaining this value (cf. European Commission, 2018).

CE and criticality share common ground regarding recycling: both encourage it. Recycling of end-of-life (EoL) products, constituting the longest loop of CE models, is an important component of both (Fig. 1).

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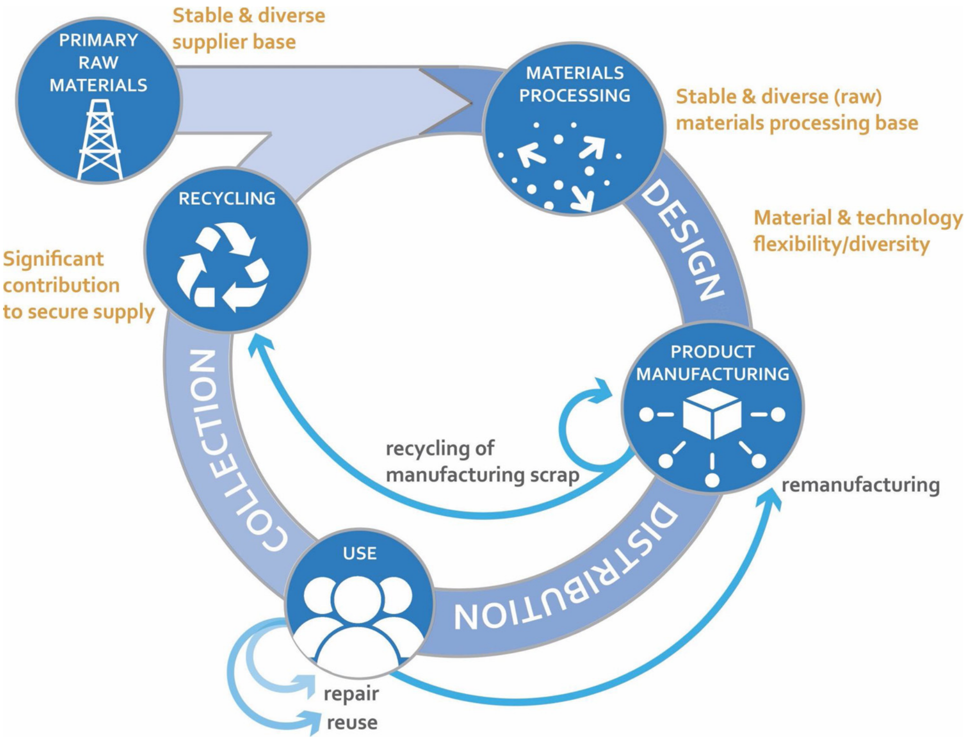

Fig. 1. Simplified representation of a more circular economy (all loops) coupled to key points of the criticality concept, formulated as objectives for the stages "raw materials", "design" and "recycling". The material losses occurring at all stages of the life cycle are not shown.

Recycling is also regarded as a mitigation strategy in the criticality discussion because it can increase supply independence and complement current primary extraction. In particular, a number of critical materials are by-products or co-products of other metals and minerals mined and their markets are dependent on those of the host metals. Introducing supply through recycling could potentially reduce risks by partially decoupling supply from the primary material source. Three caveats should be considered. First, primary and secondary production of a given raw material affect economic viability of recycling through price; however, this is not explicitly accounted for, either in criticality methodologies or in the CE model. Second, although recycling is usually considered riskless in criticality methodologies and has priority over disposal in the CE model, neither of these is necessarily the case. The quality and quantity of EoL scrap cannot be taken as a given in many cases. There are challenges in collecting and channeling EoL products to the appropriate facilities, and it can be impractical during recycling to recover certain metals that are used together in products but which are thermodynamically incompatible with conventional thermal or chemical separation processes used in recycling (International Resource Panel, 2013). In the latter case, the EoL product is recycled but some materials (including CRM) are nevertheless lost to other cycles or to slags because their recovery would imply prohibitive economic and/or environmental burdens. Third, bulk materials such as cement, paper, plastics, iron and copper dominate current discussions on CE. CRM tend to be used in smaller volumes than these base materials and are not in high profile from a CE perspective alone (although some CE models look at individual material flows, e.g. the EU Material System Analysis). Since recycling targets are usually mass-based, there is a need for adequate indicators and targets for the circularity of CRM. Ideally, both indicators and targets could be standardized in a way that is directly useful at the level of individual companies and for policy making.

The shorter loops of the CE model are neglected in many discussions on criticality (cf. Schrijvers et al., 2020), as is the discussion on resource efficiency in CE (i.e., improving the ratio between a certain benefit or result and the resource use and environmental burdens associated with it). Nevertheless, a move towards a more circular economy could reduce material resource demand by increasing the longevity of products and parts even though the enabling technologies for the "shorter loop" activities (reuse, repair, refurbish/remanufacture) can be CRM dependent themselves. Overall, the "shorter loops" could limit demand growth, which is included as an indicator in some criticality methodologies. This is particularly important for CRM related to the energy transition. If demand stagnates or even decreases, it is possible that the share of recycling in total supply would increase – also seen as positive in criticality discussions within the caveats sketched above.

A key pillar for establishing all loops in the CE model is appropriate design for circularity, for example material selection that includes the use of metal mixtures which are compatible with recycling technologies (International Resource Panel, 2013). Design for the shorter loops of the circularity model could use a modular approach which makes it easier for components to be separated, recovered, or replaced during repair, reuse, or remanufacturing. Increased recyclability and longevity of products – as a consequence of design for circularity – support supply security, which is a central aspect in criticality assessments.

Another aspect of design pertains to material flexibility: the ability to provide the same function using different raw materials and/or technologies, also discussed as "substitution". Substitution plays a key role in criticality discussions (Schrijvers et al., 2020) and is also relevant in the CE model. Whereas criticality assessments evaluate the potential of replacing CRMs by non- (or less) critical materials or technologies, CE approaches are interested in the impact of the substitute material or technology on reducing the overall inflow of non-recoverable and non-biodegradable materials (Ellen McArthur Foundation, 2013). In both approaches, unwanted side effects can occur: from a criticality point of view, material substitution increases demand for the substitute materials, potentially leading to shortages, and from a CE point of view, additional/different waste might be generated in the alternative process. There appears to be no intrinsic contradiction between CE and criticality regarding the goal of material flexibility/substitution.

The arguments sketched above show there is a potential to mitigate criticality through a move towards a more circular economy. This is most obvious in the case of recycling, where both CE and criticality discussions align. Less obvious considerations have to do with design choices and the shorter loops of the CE model, where long-term planning, including logistics of materials and products – and possibly decisions on trade-offs – will be crucial. A continued transformative process will be required to provide both the societal basis and the technical infrastructure for a sustainable future and to ensure a reliable long-term supply of the raw materials needed by society.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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