Present Potentials and Limitations of a Circular Economy with Respect to Primary Raw Material Demand

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The limited availability of many natural resources has become a growing concern within the last few decades. Continuous growth in global resource consumption during the last century, which has resulted in an enormous increase of material turnover as well as increases in commodity prices during the last decades, is the main driver of this concern. In addition to existing efforts to intensify exploration for new deposits, proposals for higher efficiency in resource use, substitution of critical raw materials, and the recycling of materials have been put forward to overcome the potential danger of more pronounced material shortages.

Based on the "Raw Materials Initiative" of the European Union (EU), which can be considered as a strategic pillar for "boosting resource efficiency and recycling," an EU action plan for a circular economy (COM/2015/0614 Circular Economy Package) was released in December 2015 (EC 2015). It foresees a "transition to a more circular economy, where the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized, which is seen as an essential contribution to the EU's efforts to develop a sustainable, low carbon, resource efficient and competitive economy." Within the action plan for a circular economy, waste management plays a central role. The released proposal (COM/2015/0614) on waste contains quantitative targets for the reduction and recycling of wastes. By the year 2030, for instance, 65% of the municipal waste and moreover 75% of packaging waste generated should be recycled or prepared for reuse, whereas landfilling of all wastes should be reduced to 10% in each member state. Separately collected wastes are completely banned from landfilling. All these measures are believed to significantly contribute to the development of a sustainable and resource-efficient economy. The expected benefits of a circular economy include reduced demand for primary raw materials and thus lower expenses for material resources, reduced environmental impacts, including lower energy demand and greenhouse gas (GHG) emissions, lower waste volumes and, in particular, less landfill space required, a significant reduction of raw material imports, creation of green jobs, and a boost for economic growth. Based on these expectations put forward by the European Commission (EC), the proposed transition from the current "linear type" to a circular economy might be considered as a solution for various problem areas. However, to what extent the raised expectations can be met is questionable.

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In the following, the overall significance of a theoretical fully circular economy (100% recycling of wastes generated) is discussed with regard to resource consumption (primary raw material demand) using different indicators (consumption of primary raw materials, cumulative energy demand in raw material supplies, expenses for primary raw materials required, and GHG emissions associated with the supply of raw materials). In particular, potential savings of emissions, energy, and money

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Table 1 Annual final consumption, waste generation, recycling, and export of different commodities for the EU-28 (figures given in kg/capita/yr)

	Commodities consumed	*Waste/old scrap*		
		Generated	*Recycled within EU*	*Exported for recycling*
	kg/capita/yr			
Aggregates (gravel & sand) incl. recycled aggregates	5,000	800 to 1,000	400 to 600	—
Iron & steel	290	140 to 160	100 to 110	15 to 20
Aluminum	21	11 to 13	7 to 8	2
Plastics	95	50 to 55	8 to 9	6 to 7
Paper & board	150	142 to 147	94	16

Note: Figures are based on reports of the respective European associations (e.g., Plastics Europe, CEPI, European Aluminum, and Eurofer) and Eurostat. EU = European Union; kg/capita/yr = kilograms per capita per year; incl. = including.

by 100% waste recycling are compared to the current waste management practice in the EU. The analyses are illustrated for five commodities, namely iron & steel, aluminum, plastics, aggregates (gravel & sand), and paper & cardboard, which account for a major part of the material resources consumed not only in terms of mass, but also with respect to energy demand or economic value. Based on production figures and market prices, the annual turnover of European producers of these five commodities is estimated to be more than 250 billion euros (€).

When comparing material flow data given in table 1, different aspects relevant for the potential of a circular economy become evident.

First of all, for most commodities (except for paper & board), waste generation is, by far, smaller than consumption, indicating that, even in highly developed economies like the EU, material stocks are still growing at a significant rate and the system itself is not in a steady state. Even for base metals like iron or aluminum, net stock additions account for more than 40% of the annual consumption. In case of aggregates (used as construction material), the net stock addition amounts to around 80%, meaning that even in case a theoretically 100% recycling society could be achieved, only around 20% of the demand for aggregates in the construction sector could be substituted. Given that current recycling rates of demolition waste are in the range of around 50%, the remaining potential reduction in demand for virgin aggregates would be in the range of 400 to 500 kilograms per capita per annum kg/cap/a and thus less than 10% of present primary production. This estimate neglects that, over time, different construction materials have been utilized and hence the materials arising as waste may not necessarily meet the present demand.

Similar situations, although not as drastic, can be observed for iron & steel as well as for aluminum. The potential for reducing primary raw material demand for both commodities is limited (<20%), attributed to the fact that there are already rather high recycling rates in place (meaning that the transition from a linear to a circular economy has already been initiated a long time ago) and old (i.e., postconsumer) scrap amounts are significantly lower than current consumption figures. Further, it becomes obvious that a significant amount of scrap or recyclable waste (in case of plastics) is exported and thus not utilized by European industry, although significant benefits with regard to energy demand or GHG emissions would be expected. Hence, it might be questioned whether higher quantities of recyclable materials would inevitably also translate into increased secondary raw material utilization by European manufacturers. Based on overall scrap/recyclables import and export figures of the EU, it might be speculated that high-quality (new) scrap/recyclables are preferably imported and low-quality (postconsumer) materials are exported (Buchner et al. 2017), indicating that the EU might already face a quality problem for recyclables. This quality problem is definitely not to be solved by higher (quantitative) recycling targets given that it further bears the risk of unwanted recycling of hazardous substances, such as chemicals contaminating the paper product cycle (Pivnenko et al. 2016).

Neglecting these qualitative obstacles as well as the second law of thermodynamics and assuming that theoretically 100% of wastes could be turned into secondary resources, the following benefits, in terms of reducing GHG emissions, energy demand, and costs for acquiring primary resources, could, at maximum, be achieved for the five commodities investigated. Potential saving of GHGs (global warming potential over 100 years) are in the range of 140 kg of carbon dioxide equivalents per capita per year (CO_2-eq/cap/yr). For the cumulative energy demand of the raw material supply, the annual reduction potential approximates 2.5 megajoules (MJ)/cap. Both estimates are based on conventional figures (see Turner et al. 2015) about savings induced by substituting primary raw materials through secondary resources (e.g., 95% reduction of energy demand for aluminum production). Comparing these figures to the overall GHG emissions and the total energy demand of the EU

demonstrates the limited potential of a "circular economy." Current GHG emissions of 9,000 kg CO_2-eq/cap/yr could be reduced by less than 1.6% and energy savings would at maximum contribute to a similar reduction (1.8%) of the present consumption (140 MJ/cap/yr).

With respect to the economic value of commodities consumed, the implementation of a 100% recycling society could lower costs for primary raw materials by less than 90 €/cap/yr at the maximum in comparison to the status quo (neglecting expenditures for processing wastes and generating secondary raw materials out of them). If avoided disposal costs (for landfilling or incineration) are included in the calculation, financial savings that could pay for enhanced recycling, and thereby shift the added value from primary to secondary raw material production, would increase to 110 €/cap/yr, which equals approximately 0.4% of the EU-28´s overall gross domestic product (GDP). Whereas higher costs for establishing a circular economy would inevitably to be covered by final consumers (i.e., through waste fees or extended producer responsibility contributions), it is hitherto not clear to what extent these additional costs translate into added value in the EU's industry, for instance, through the creation of "green jobs" or if it would only manifest as a subsidy for scrap/recyclable exports.

Altogether the results demonstrate that a theoretical implementation of a circular economy (all waste is turned into secondary raw materials) may reduce the demand for primary raw materials and therewith associated environmental impacts (e.g., GHG emissions). However, because a significant share of commodities is still used to build up our infrastructure and thus accumulates in societies´ material stock, the overall potential for reducing primary raw material consumption and accompanying impacts (including costs for primary raw materials) is limited at present, even for a highly developed economy like the EU. However, to conclude from our results that the circular economy, as a strategy to achieve more sustainability, has only marginal relevance would be wrong. What we need is an economy where consumption of resources and generation of wastes are more balanced and stocks are rebuilt and maintained, but stay rather constant; only then the circular economy can evolve to its full potential.

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