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Providing an economy-wide monitoring framework for the circular economy in Austria: Status quo and challenges

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ABSTRACT

The circular economy (CE) concept is gaining momentum among industry, politics and academia, putting forward a number of claims about environmental and climate-related benefits. Recently, the European Union has enacted a policy package calling for a transition from linear- towards circular production cycles across its Member States by 2050. The majority of research so far has focused on the micro- and meso-level, investigating CE implications on the product- and firm-level. On the national level however, a CE monitoring framework has yet to be developed.

To take up this challenging task, we develop and apply an economy-wide monitoring framework to the case of Austria, by substantially extending previous work linking official data from economy-wide material flow accounting (ew-MFA), with waste and emission statistics. Herein, we present results of our circularity assessment for the year 2014. We find, that Austria exhibits a 8.5% share of secondary raw materials in processed materials (Input socioeconomic cycling rate - ISCr), while the share of recycled materials in interim outputs (IntOut)) is at 16.8% (Output socioeconomic cycling rate - OSCr). Challenges to the robustness of those estimates may be grounded in gaps in data availability and reporting both at the input and output side, which need to be harmonized for achieving an effective, combined CE monitoring. Furthermore, we find that there is a strong nexus between the CE and energy use and that the CE subsequently could contribute to climate change mitigation.

1. Introduction

The Circular Economy (CE) – viewed as concept by some, as framework by others – is being promoted as an alternative to the traditional take-make-dispose linear economy, aiming to keep products, components and materials at their highest utility and value at all times (Bocken et al., 2017, p. 476). The CE has received increased attention in recent years by policy makers, industry and science. In the last decade or so, countries such as China, Japan, Germany and more recently, the European Union, have explored options to transition from linear- to circular economies, with varying degrees of success (Gregson et al., 2015; Mathews and Tan, 2016, 2011; McDowall et al., 2017; Ohnishi et al., 2016). Some proponents of the CE have stressed the economic benefits from increased reuse and recycling and were instrumental in establishing basic concepts with regard to circularity strategies (Bocken et al., 2017; Ellen MacArthur Foundation, 2014; Preston, 2012). A study from the Club of Rome, covering seven European countries, concluded that, under economy-wide implementation, material savings through CE policies and measures could help reduce each country's GHG emissions by up to 70%, while also increasing its workforce by 4% (Wijkman and Skanberg, 2015).

With the European Commission rolling out its roadmap for a low-carbon economy (European Commission, 2011), and more specifically its integrated strategy to transition from a linear- to a circular economy, calls for an economy-wide CE monitoring framework have become more prominent (European Commission, 2017). In early 2018, the European Commission adopted a new circular economy package, including a new set of measures, which include strategies to increase reuse and recycling of (critical) materials, minimize waste impacts, and implement a EU-wide monitoring framework (European Commission, 2018). Thus, it is increasingly recognized that in the endeavor to craft a meaningful monitoring framework to inform CE policies and provide links to resource and climate policies, resource inflow- and outflow data, as well as waste and emissions data, need to be integrated and conceptualized together (Elia et al., 2017; Haupt et al., 2017; Pauliuk, 2018). Numerous proposals on how to measure circularity on the micro (product) - and meso-level (e.g. industrial symbiosis) have been provided (cf. Boons et al., 2017; Bressanelli et al., 2017; den Hollander

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et al., 2017; Li et al., 2016; Mathews and Tan, 2016, 2011; Mouzakitis et al., 2017; Mulrow et al., 2017; Stahel, 2016). However, only recently, efforts have gone into addressing circularity nationally, economy-wide, or even globally (cf. Allwood, 2014; Geisendorf and Pietrulla, 2017; Haas et al., 2015; Haupt et al., 2017; Kalt, 2015; Krausmann et al., 2017, 2016; Moriguchi, 2007; Schandl et al., 2016; Van Eygen et al., 2018).

Given the evident gap of biophysical capacity in the predominantly economic discussion around CE (Ellen MacArthur Foundation, 2014; Ellen MacArthur Foundation et al., 2016; European Commission, 2016; Zink and Geyer, 2017), we propose a socio-metabolic approach, aiming at a better understanding of the overall material flows, wastes and emissions in the economy and related environmental pressures (Fischer-Kowalski, 2012; Haas et al., 2015; Haberl et al., 2016). Recognition of the fundamental thermodynamic principle of 'inputs equal outputs' enshrined into Material Flow Analysis (MFA) (Brunner and Rechberger, 2016), demands a shift in the way practitioners and policy makers view resources, wastes and emissions. Currently, these are considered in a fragmented fashion, as in themselves controllable entities, which can be regulated separately (Pauliuk, 2018). Instead, inputs of resources and outputs of waste and emissions are intrinsically linked, on a conceptual and empirical level. Only then, meaningful and impactful systemic policies can be formulated. We therefore argue, that the CE provides an important case, for which the mass-balanced integration of information from economy-wide Material Flow Analysis (ew-MFA), with waste accounts and emissions data can provide substantial new insights. Providing a robust monitoring approach at the economy-wide level, by linking inputs of material resources with outputs of wastes and emissions, therefore also highlights systemic dynamics and trade-offs for a more circular and climate-friendly economy.

In this article, we substantially expand the economy-wide CE monitoring proposed by Haas et al. (2015), by integrating official ew-MFA data with waste and emissions statistics in a mass-balanced and systematic manner. We present and discuss the empirical results of such a circularity assessment for the case of Austria in 2014. We argue that material circularity is strongly linked with energy use and thus climate policy, and lastly, we highlight conceptual weaknesses, gaps in data availability and required next steps.

2. Material and methods

Herein, we further extend the economy-wide CE assessment based on ew-MFA principles (Fischer-Kowalski et al., 2011; Krausmann et al., 2015), building upon prior research by some of the authors (Haas et al., 2015) and in line with Mayer et al. (under review). Innovatively, we go beyond the empirical application by Haas et al. (2015) by explicitly utilizing not only data on extraction and material consumption from ew-MFA (Eurostat, 2017a), but also systematically linking national statistics on waste production (BMLFUW, 2015, 2011) and emissions (UBA, 2016) into the assessment. Thereby we extend the standard ew-MFA approach to investigate materials extraction, trade and consumption, towards further tracing their uses in the socioeconomic system and establishing a mass-balanced linkage with waste and emissions statistics, utilizing official national data sources.

In the following paragraphs, we define and conceptualize the indicators used in our model, providing information on calculation steps, data sources and associated challenges. A summary of all model variables and indicators including their definition and mathematical expression is provided in Table 1, whereby the order of appearance is from left to right, based on the diagram in Fig. 1. An overview of data sources used for the calculations is provided in the supplementary information (Table S2 of the supplementary information). All variables are denoted in metric tons/per year unless otherwise noted.

All model variables on physical inputs into the socioeconomic system depicted in blue in Fig. 1 (DE, imports and export) are derived directly from ew-MFA data (Eurostat, 2017a). The amount of materials processed (PM) is calculated from ew-MFA data and recorded EoL recycling flows (see Table 1). The split into material and energetic use is performed according to literature (see Table S2 of the Supplementary information). The amount and composition of EoL waste (red-colored box) is directly retrieved from the associated 2015 waste statistics report of the Austrian BMLFUW (BMLFUW, 2015). Emission data (depicted in brown) is obtained through the 2016 emission inventory (UBA, 2016), who reports emissions in line with the UNFCCC's Common Reporting Framework (CRF). The CRF enforces common emissions reporting in five aggregated sectors: Energy, Industrial Production and Product Use (IPPU), Agriculture, Waste and Land-Use Change (LUC) (IPCC, 1996; UBA, 2016). The positive sink effect in the LUC sector (through increased afforestation in Austria), is omitted in calculating the results and leads to an overestimation of 1.5 Mt of carbon net-emissions (UBA, 2016). Carbon emissions from fossil fuel combustion are calculated using coefficients sourced from literature (see Table S2 in the Supplementary information), which agree well with the emissions from energy use reported in the Austrian GHG emission inventory (UBA, 2016). The remaining outputs from energetic use, which are vapor and solid and liquid outputs (SLOs), are calculated from the water content of biomass, fossil energy carriers and to some extent for minerals (e.g. clay for brick-making); while for SLOs digestion factors for humans and livestock are used (see Table S1 in the Supplementary information). Additionally, some of the solid residues from fuel combustion (e.g. ashes and slags) also end-up in the SLOs. Subsequently, we compare the results of the calculated SLOs from combustion and digestion processes to the reported waste statistics' categories 'ashes and slag' and 'municipal sewage sludge' respectively (BMLFUW, 2015), which agree well. Extractive waste from mining is computed using ore grade factors (Krausmann et al., 2015).

Flows to in-use stocks are calculated based on the following assumptions. (1) Additions to stock rate for a specific material (percentage of material use added to stocks) is used according to literature (see Table S2 in the Supplementary information), if *addition rate*material use (addition to stock) < EoL waste of that specific material*. If this is not the case, the literature-based addition rate is adapted to fulfill this condition.

2.1. Mass-balanced linking of waste statistics to ew-MFA

For the CE assessment conducted herein, a mass-balanced linkage of material consumption to waste and emissions statistics is necessary. However, this kind of information is collected along different scopes and definitions, without any official concordances. Ew-MFA data is available at 45 material categories on the most detailed level (3-digit), which can be summarized into 16 and ultimately into four main material groups, i.e. biomass, metals, non-metallic minerals and fossil energy carriers (Eurostat, 2017a; Krausmann et al., 2015). Ew-MFA categories are classified based on material characteristics, and in some cases on their use (Haas et al., 2015). Wastes in Austria, on the other hand, are reported based on the NACE classification (Eurostat, 2013) and ÖNORM (BMLFUW, 2015), which refer to economic activity, collection systems and/or hazard potential. These different reporting frameworks prohibit a simple one-on-one pairing.

In order to solve the allocation problem of waste flows to ew-MFA 3-digit categories, a literature-based, three-step approach is used. First, waste amounts generated are classified according to their waste treatment, including material recovery (recycling) as one treatment option. Recycling is further defined as waste substances that are entirely or partially reused, recycled or remanufactured, regardless whether or not the final use of the recovered material is inferior to the original (BMLFUW, 2011, 2015). This means, the amount of waste that undergoes material recovery (recycling) represents a collection rate of potentially recyclable (or 'down-cyclable') materials, rather than the amount of materials actually being recycled. However, due to the system boundary of our model, we distinguish only between wastes