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Defining regional recycling indicators for metals

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ABSTRACT

Recycling indicators are useful for characterizing anthropogenic metal cycles. While there are suitable and generally accepted recycling indicators at the global level, they are not necessarily useful for regional cycles (where the region of interest can be a part of country, an entire country or a group of countries), which are open and interact with other regions such that cross-border flows need to be considered. Herein, we theoretically examine the applicability of available (global) recycling indicators to the regional level and, in the case of the recycling input rate (*RIR*) and the recycled content (*RC*), propose modified versions that are both conceptually compatible with the corresponding global indicators and readily accessible through data collected and estimates generated in regional material flow analysis work. The practicability and usefulness of the proposed set of indicators is explored by using published aluminum cycles for the USA (*RIR* = 44%, *RC* = 40%), China (*RIR* = 18%, *RC* = 18%) and Austria (*RIR* = 100%, *RC* = 73%) and compared to the global (*RIR* = 31%, *RC* = 31%) aluminum cycle.

1. Introduction

Simple indicators are very useful for capturing and highlighting certain aspects of complex systems. In the case anthropogenic metal cycles, recycling indicators are a widespread means of global assessment and are used as guidelines or targets in sustainability-related plans and regulations, albeit at the level of product or waste types (e.g., packaging waste, waste electrical and electronic equipment (WEEE), end-of-life vehicles). At the level of individual metals, recycling rates are useful for assessing environmental impacts, e.g. in life cycle assessment (LCA), in assessing resource efficiency, as well as in determining criticality of raw materials (e.g. European Commission, 2014, 2011).

Recycling indicators are usually produced from estimation of the pertinent material flows (material flow analysis, MFA) either for one year or for a sequence of years (e.g., Glöser et al., 2013; IAI, 2015) at the global level. Estimates of these flows are now increasingly available from dynamic models, many of them not global but regional in scope (e.g., Graedel et al., 2004; Chen et al., 2010; Buchner et al., 2015; Chen and Graedel, 2012a; Hao et al., 2017; Yen et al., 2016; Ciacci et al., 2017). While there are accepted definitions of recycling rates at the global level, these are not necessarily transferable to the regional level because there is a certain amount of material crossing the regional system boundaries at different stages of the cycle (e.g. imports/exports of metal, finished products, or metal scrap). This complication is absent in the definition of global recycling rates as the system boundaries there encompass the entire planet.

As a consequence of these missing definitions, current work performed on regional stocks and flows is being neither used for comparing the performance of recycling systems in different regions nor for examining differences between recycling patterns of different metals in a selected region. Instead, magnitudes of estimated stocks and flows are still usually reported without a reasonable means of benchmarking (e.g. Yen et al., 2016; Hao et al., 2017). Thus, we postulate that the availability of adequate definitions for regional recycling indicators would lead to more useful insights being derived from regional MFA work.

Addressing this need, the objective of this study is to provide an appropriate and easy-to-use set of recycling indicators at the regional scale. This is achieved by: (i) reviewing existing global recycling indicators; (ii) based on those, defining recycling indicators at the regional level; (iii) illustrating the use of the indicators using three case studies based on published MFA work to show practicability; and (iv) comparing and contrasting the recycling systems for aluminum in Austria, China and the USA as a test case of additional insights gained by computing the proposed indicators.

It is worth noting that the indicators proposed here are different from recycling potential estimations used in scenario work for particular technologies at the global and regional level. In that type of work, the focus is on how much material could be recovered by recycling certain types of (expected) waste streams (e.g. Rademaker et al., 2013; Gu et al., 2016; Wang et al., 2015). The work presented herein pertains to anthropogenic cycles of metals, covering all uses and recycling of all

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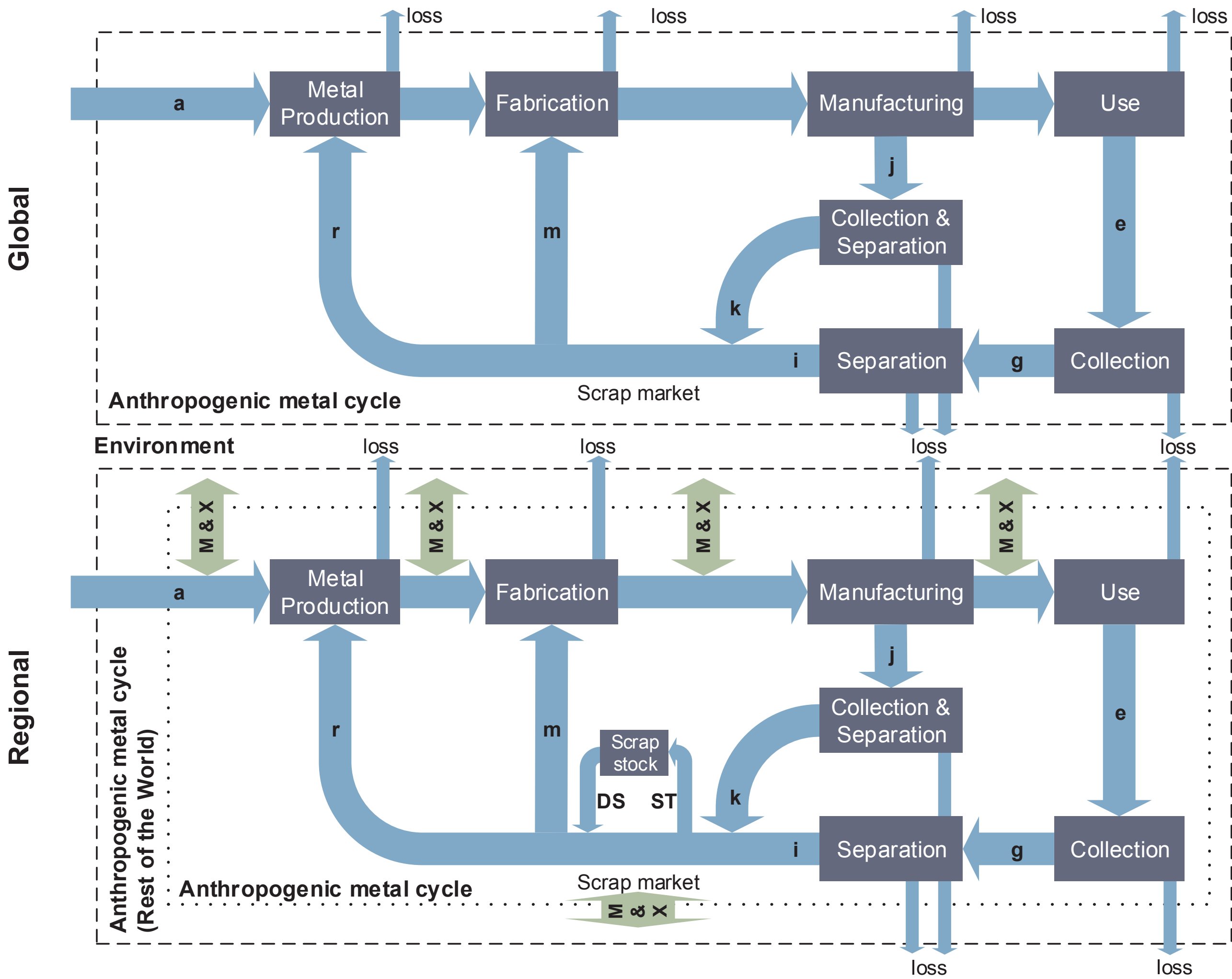

Fig. 1. Global (top) and regional (bottom) flows used in the definition of recycling rates. The lettering follows largely that proposed by Eurometaux and Eurofer (2012) based on Reck et al. (2008), and is compatible with (but not identical to) those used by UNEP (2011) and Graedel et al. (2011). Only letters needed for estimating recycling rates have been depicted.

pertinent waste streams.

It is our hope that the set of indicators discussed here will contribute to gaining more insights from the laborious MFA work being already carried out by different research groups.

2. Methodology

In order to provide relevant recycling indicators at the regional level, we started by examining an accepted set of recycling indicators at the global level and then testing the applicability of each global definition at the regional level. Two questions stand at the center of this examination: (1) What is the intention of the indicator, i.e. what information does it intend to convey? (2) Does the application of the global definition (equation) yield the desired information also at the regional level? If the answer to the latter question is positive, the global definition for the recycling indicator can be also used at the regional level. If the answer is negative, appropriate adjustments are proposed.

A common nomenclature for the relevant flows was derived from published work and is shown in Fig. 1. While the scheme of a general metal cycle will differ in the details from metal to metal, Fig. 1 captures all relevant features necessary for estimating recycling rates (UNEP, 2011; Graedel et al., 2011) and published metal cycles can be mapped directly to the flows shown. In essence, global and regional metal cycles are alike. The key difference is the existence of trans-boundary flows (as ore/concentrate, as intermediate (metallurgical) products or chemicals, as metal, as semi-finished products, embedded in final products, as scrap) in regional metal cycles. These trans-boundary flows are absent from global cycles as the system boundaries encompass the entire planet. Examination of global recycling indicators shows that the existence of these trans-boundary flows affects the applicability of the global definitions to the regional level for some—but not all—indicators (cf. Sections 3 and 4). We aimed to propose regional equations as more general forms of the global equations. That is, eliminating the terms emerging from trade flows (and stocking/destocking, see below) yields the global definition for each modified indicator. This examination is presented and discussed in Section 3.

A further difference between the global and regional metal cycles as depicted in Fig. 1 is the explicit consideration of scrap stocks. Scrap stocks are generated when scrap is collected and held back instead of recycled. A common reason for doing this is the expectation of higher prices in the future. Interviews with scrap collectors and processors in Europe, China and the USA revealed that this is common practice and remains unreported—making an estimation of their magnitude very difficult and a worthwhile subject for further research. These stocks reside largely in scrap yards, where little cost is incurred by holding back material (collection costs are essentially independent of metal prices). In contrast, scrap traders and processors tend not to hold back material since they have to purchase and finance it. Obviously, if a scrap stock exists in any one region, it also exists at the global level. However, the existence of these scrap stocks is not customarily depicted in global cycles. As a consequence, global definitions of recycling indicators ignore this stocking and destocking process (cf. UNEP, 2011;