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Environmental consequences of recycling aluminum old scrap in a global market

Eva Sevigné-Itoiz[a,b,*], Carles M. Gasol[a,c], Joan Rieradevall[a,b], Xavier Gabarrell[a,b]

[a] Sostenipra, Department of Chemical Engineering, Universitat Autònoma de Barcelona (UAB), Building Q UAB – 08193 Cerdanyola del Vallès, Barcelona, Spain
[b] Institute of Environmental Science and Technology (ICTA), Universitat Autònoma de Barcelona, (UAB), Building C Campus UAB – 08193 Cerdanyola del Vallés, Barcelona, Spain
[c] Inèdit Innovació s.l., Research Park of the UAB, Carretera de Cabrils, km. 2, IRTA, 08348 Cabrils, Spain

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ABSTRACT

Nowadays, aluminum scrap is traded globally. This has increased the need to analyze the flows of aluminum scrap, as well as to determine the environmental consequences from aluminum recycling. The objective of this work is to determine the greenhouse gases (GHG) emissions of the old scrap collected and sorted for recycling, considering the market interactions. The study focused on Spain as a representative country for Europe. We integrate material flow analysis (MFA) with consequential life cycle assessment (CLCA) in order to determine the most likely destination for the old scrap and the most likely corresponding process affected. Based on this analysis, it is possible to project some scenarios and to quantify the GHG emissions (generated and avoided) associated with old scrap recycling within a global market. From the MFA results, we projected that the Spanish demand for aluminum products will be met mainly with an increase in primary aluminum imports, and the excess of old scrap not used in Spain will be exported in future years, mainly to Asia. Depending on the scenario and on the marginal source of primary aluminum considered, the GHG emission estimates varied between −18,140 kg of CO_2 eq. t^{-1} and −8427 of CO_2 eq. t^{-1} of old scrap collected. More GHG emissions are avoided with an increase in export flows, but the export of old scrap should be considered as the loss of a key resource, and in the long term, it will also affect the semifinished products industry. Mapping the flows of raw materials and waste, as well as quantifying the GHG impacts derived from recycling, has become an essential prerequisite to consistent development from a linear toward a circular economy (CE).

1. Introduction

For decades, aluminum recycling was a regional concern, traditionally concentrated in regions with high aluminum demand and a well-organized aluminum recycling industry (i.e., Europe or North America). Today, however, aluminum scrap is a global raw material commodity (EAA, 2006a). In fact, national or regional markets for raw materials, intermediate products, and final products have become increasingly interconnected in a globalizing world, creating more complexity in the supply chain (Liu and Müller, 2013). Several documents have been presented recently (EC, 2012a,b; NPSCS, 2008) to promote Circular Economies (CE) by encouraging recycling as a material independence strategy for green economic development and the reinforcement of local markets. Nevertheless, the first step in determining the potential environmental gains resulting from achieving those objectives is to map properly the material flows along the whole production chain in order to assess the flows and stocks and to establish past trends to project alternative trade patterns. In the case of aluminum, studies were recently published assessing aluminum flows for the United States (Chen and Graedel, 2012), China (Chen and Shi, 2012), and Italy (Ciacci et al., 2013) and also at the global scale (Cullen and Allwood, 2013; Liu and Müller, 2013). All these studies assessed flows and stocks using material flow analysis (MFA), and all of them also noted the need for further environmental studies in order to evaluate the impacts of the aluminum industry.

There is a clear need for studies considering how recycling fits into the bigger economic picture (Gardner, 2013), but studies calculating the environmental impacts derived from the international trade are also essential because increasing trade means increasing

* Corresponding author at: Sostenipra, Department of Chemical Engineering, Universitat Autònoma de Barcelona (UAB), Building Q UAB – 08193 Cerdanyola del Vallès, Barcelona, Spain. Tel.: +34 935813760; fax: +34 935813331.
E-mail addresses: eva.sevigne@uab.cat, esevigne@gmail.com (E. Sevigné-Itoiz).

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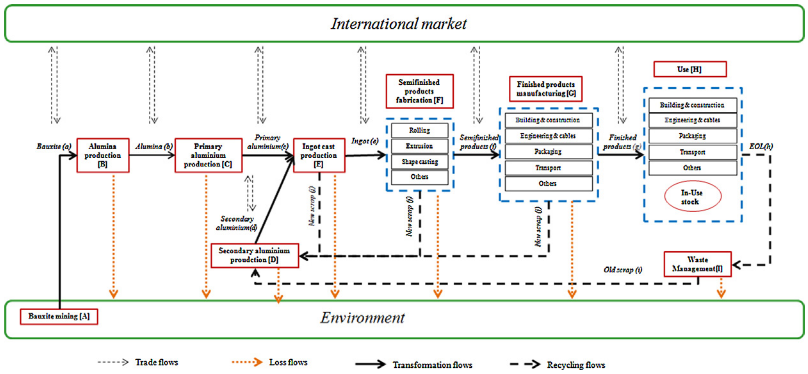

Fig. 1. Spanish aluminum life cycle system boundaries.

transport, logistics and emissions (Liu and Müller, 2013). However, massive international trade requires life-cycle thinking and a global perspective to take into account burden shifting across borders (EEA, 2012). In this sense, consequential life cycle assessment (CLCA) seems to be an effective methodological framework to address the environmental impacts of international industries because it provides a modeling approach that seeks to describe the consequences of decisions when processes are linked via market mechanisms (Weidema et al., 2009) and allows the limits of the system to be expanded beyond national boundaries. Nevertheless, the CLCA approach applied to quantifying the impact of recycling presents two challenges. First, the process affected by recycling (i.e., raw primary aluminum production or other process) must be identified, and second, the most sensitive technology in the market to a change in demand must be determined (Weidema et al., 2009). Both identifications depend on the market trend and delimitation. Thus, to quantify recycling through the CLCA methodology, it is necessary to conduct in-depth analysis of changes in the dynamic of supply and demand of material flows. Therefore, because MFA studies require complementary studies of CLCA to assess the environmental impacts, while at the same time, the CLCA needs the material information provided by the MFA studies; the integration of both methodologies is a good strategy to assess the material flows and environmental impacts of recycling within trade interactions.

In this paper, we evaluate the environmental performance associated with an increase of old aluminum scrap collection in Spain for recycling by integrating a dynamic MFA model with a CLCA in order to evaluate the interactions of recycling markets. MFA traces material flows both along technological life cycles and across national boundaries, allowing the most-probable destinies of the old scrap collected in Spain for recycling are determined. CLCA calculates the greenhouse gases (GHG) emissions of recycling related to marginal (product systems) displacements according to local markets and global market considerations. Aluminum scrap is categorized as new and old, representing pre- or post-consumption scrap, respectively; new scrap is nearly 100% recycled either inside a plant or directly by a remelter. We focus on old scrap, therefore, because it is the key issue in recycling and scrap supply (JRC, 2007). Spain was selected because it is one of the main exporters of aluminum scrap in the European Union (EU) to non EU-countries (Liu and Müller, 2013; EAA, 2012b), and in a previous study, it was detected that there is no study quantifying the GHG emissions due to aluminum old scrap recycling for Spain (Sevigné et al., 2013). Finally, the present study focuses on GHG emissions because the world's aluminum industry contributes approximately 1% of the total anthropogenic GHG emissions (JRC, 2007; Menzie et al., 2010), but it has been reported that recycling of aluminum products requires as little as 5% of the energy and emits only 5% of the greenhouse gas (GHG) of primary production (IAI, 2009).

2. Methodology

The methodology proposed in this study consists of two steps. First, a dynamic MFA is conducted in order to monitor trends and changes in the dynamics of raw materials, products and waste, and second, MFA results are integrated into the consequential life cycle inventory (LCI) modeling to project the cause and effect relationships to quantify the GHG emissions associated with recycling. In the following sections, the methodologies used for the quantifications of flows (2.1) and for the quantification of GHG emissions (2.2) are explained.

2.1. Dynamic material flow analysis (MFA)

2.1.1. Scope and system boundaries

We have applied a dynamic MFA in Spain for 15 years to obtain not only a picture at a specific time but also an overview of the evolution in the recent past of the whole cycle of aluminum to determine changes and trends in raw materials and waste markets and to observe the influence of the accumulated in-use stock; altogether, this information can be useful to anticipate scenarios in the near future. Along its life cycle, we considered the following life cycle stages: bauxite mining [A], alumina production [B], primary aluminum production [C], secondary aluminum production [D], ingot cast production [E], semifinished products fabrication [F], finished products manufacturing [G], use [H] and waste management [I]. Every life cycle stage produces aluminum-containing products (ACP) classified as: bauxite (a); alumina (b); primary aluminum (c); secondary aluminum (d); ingot (e); semifinished products (f); finished products (g); end of life (EOL) products (h); old scrap (i) and new scrap (j). Based on the classification by the European Aluminum Association (EAA) and the International Aluminum Institute (IAI), semifinished products can be classified as rolling products, extruded products, shape casting products and other products, while the end-use markets for the finished products are usually classified as building & construction, transport, engineering & cables, packaging and others (EAA, 2006a; IAI, 2009; EAA, 2012b). Fig. 1 presents the system boundaries of the Spanish aluminum life cycle and shows every flow that has to be determined, including importations and exportations and losses. In addition, in the Appendix A, Table A.1 summarizes the definitions associated with the ACPs considered in this study.

2.1.2. Accounting methods of flows

The system under study concerns only material flows and their calculation are based on the principle of mass conservation. For