Resources, Conservation and Recycling 122 (2017) 135–142

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Potential recycling constraints due to future supply and demand of wrought and cast Al scrap—A closed system perspective on Austria

Hanno Buchner[a,*], David Laner[a], Helmut Rechberger[b], Johann Fellner[a]

[a] Christian Doppler Laboratory for Anthropogenic Resources, Vienna University of Technology, Karlsplatz 13, A-1040 Vienna, Austria
[b] Institute for Water Quality, Resource and Waste Management, Vienna University of Technology, Karlsplatz 13, A-1040 Vienna, Austria

ARTICLE INFO

Article history:
Received 25 September 2016
Received in revised form 15 January 2017
Accepted 24 January 2017
Available online 21 February 2017

Keywords:
Aluminum
Recycling
Wrought cast alloy
Closed loop
Austria
Sorting

ABSTRACT

Closing regional material cycles by efficient use of secondary raw materials is a prioritized goal of European politics and industry. The extent to which material cycles may be closed at a regional level has, however, hardly been investigated so far, and mostly without consideration of material quality. Thus, in the present study quality aspects of aluminium (Al) recycling in Austria with respect to alloy composition are investigated in order to identify potential limitations for future Al recycling. Therefore, a dynamic material flow analysis of wrought and cast alloys is carried out for Austria covering the time span from 1964 to 2050. A closed system perspective is introduced with respect to future Al scrap supply and to which degree it can satisfy Al demand associated with final consumption. Results indicate that if current recycling practice is retained, a surplus of mixed Al scrap over final cast Al demand is expected around 2045. Assuming a more intensive use of Al in the transport sector (light-weight construction material), this surplus is likely to occur already in 2030. Model results further indicate that intensive sorting of mixed scraps from end-of-life vehicle treatment represents an effective measure to prevent a surplus of mixed Al scrap. In practice, i.e. in an open economy, the high level of Al scrap imports and exports impairs the evaluation of quality-induced Al recycling constraints, as observed in the model. Nevertheless, lower specific prices of scrap exports from Austria compared to imports may indicate a net import of higher quality scrap to satisfy quality requirements associated with the high share of wrought alloys in secondary production. Therefore, apart from enhanced scrap sorting, international scrap trade is a key element to bring together scrap supply with the scrap demand for the needs of secondary production.

1. Introduction

Material flows analysis (MFA) aims at quantifying the flows and stocks of materials in arbitrarily complex systems (Brunner and Rechberger, 2004) and has been applied at the national, regional and global levels (Chen and Graedel, 2012a,b). With respect to dynamic material flow modelling, mainly metals have been analysed up to now (Müller et al., 2014) due to their good recyclability, their importance for industry as well as the impacts of metals and the mining industry on the environment. However, most of the existing studies focus on the quantification of material flows such as trends in old scrap generation, development of in-use stocks as well as issues of secondary raw material supply (Hatayama 2009; Chen and Graedel, 2012a,b; Liu and Müller, 2013; Buchner et al., 2015). In some cases environmental issues such as associated greenhouse gas emissions (Liu et al., 2013) as well as technological issues (Pauliuk et al., 2013) have also been analysed based on dynamic material flow models (dMFMs). Up to now aspects of material quality (e.g. alloy composition), which play an important role in terms of secondary raw material use, have rarely been addressed in aluminium (Al) dynamic material flow studies (Hatayama 2007; Cullen and Allwood 2013). Thermodynamic aspects with respect to removal of alloying elements in Al scrap recycling have been analysed (Nakajima et al., 2010) as well as the area of conflict between technical limits in recycling and recycling quotas (Reuter et al., 2006). For the example of steel recent studies illustrate flows of alloying elements in vehicle recycling in Japan (Ohno et al., 2014) as well as the distribution and flow of steel over several recycling cycles (Pauliuk et al., 2017)

Studies regarding the use of wrought (w) and cast (c) Al alloys have mostly been conducted for specific sectors, such as the global vehicle system (Hatayama et al., 2012; Modaresi and Müller, 2012; Løvik et al., 2014), where the current use and possible future limitations of Al recycling in the transport sector are analysed in great

* Corresponding author.
E-mail address: hanno.buchner@gmail.com (H. Buchner).

http://dx.doi.org/10.1016/j.resconrec.2017.01.014
0921-3449/

detail (e.g. alloys used in single car components). Even though these studies provide deep insights into the use and long-term sustainability of Al in the global vehicle system, the most substantial sector in terms of cast Al consumption and in-use stock, a potential influence of other in-use sectors derived from a differentiation between wrought and cast (w/c) alloys for the Al supply of all in-use sectors is not available. Furthermore potential limits of regional Al recycling, according to the circular economy objectives of politics and industry, are not captured by global models.

In this study the Austrian system of Al flows (all in-use sectors) is analysed with respect to the future final Al demand and the availability of w/c alloys. An existing dMFM (Buchner et al., 2015) of Austrian Al flows between 1964 and 2050, which has so far been limited to quantification of national Al flows, is therefore expanded to the level of material qualities, focusing on a differentiation between w/c alloys. The future availability and recyclability of w/c alloys are analysed from an integrated system perspective, which includes a consideration of demand and scrap generation all sectors of Al use (Transport, Building and Infrastructure, Mechanical Engineering, Electrical Engineering, Consumer and Packaging).

In order to analyse the potential of Al cycling (final demand versus scrap generation) on a national scale a hypothetically closed system is assumed. Therefore, final Al demand is directly compared to supply of secondary Al solely based on domestic old scrap generation. But, the recycling in the closed system is not limited to closed-loop recycling, which would mean that Al scrap is recycled within same products, it's rather an overall balance between old scrap generation and final Al demand. Having in mind that the system in Austria is nowadays heavily influenced by foreign trade flows (e.g. unwrought Al, Al contained in products as well as scrap trade), the closed system assumptions represents a potential future scenario, where regional Al demand saturates and material cycles are to be closed to the maximum extent. Such a scenario analysis is particularly interesting in view of current policy initiatives and strategies on the European level, where closed material cycles are promoted to increase resource efficiency and sustainable economy in Europe. However, so far the material quality dimension and potential recycling constraints due to open loops (incl. downgrading due to unfavorable alloy mixtures) is not reflected in the discussion on how to design such systems. The present analysis of a closed Al cycle in Austria therefore adds to this discussion by emphasizing the importance of the material quality for the transition towards circular resource systems. The results for the Austrian case are expected to be more generally valid also for Western Europe since demand and in-use stocks are at similar levels (Liu et al., 2013) with comparable Al utilization patterns.

The following questions are addressed in this study: 1) Given the current recycling practice, is the generation of mixed scrap going to surpass the domestic demand for cast Al in a hypothetically closed system? 2) Could enhanced sorting mitigate or avoid a potential surplus of mixed scrap? 3) What information can be derived from foreign trade data regarding regional supply and demand of Al scrap?

2. Materials and methods

2.1. Model description

In Buchner et al. (2015) a dMFM is developed consisting of a historical part (based on reported data) and a forecasting part (based on future trends of Al use) which illustrates future development of in-use stocks and old scrap generation (cf. Fig. S1).

For the historical part, an input driven modelling approach is used with semi-finished products as model driver. Foreign trade as well as material losses (e.g. material efficiencies in production)

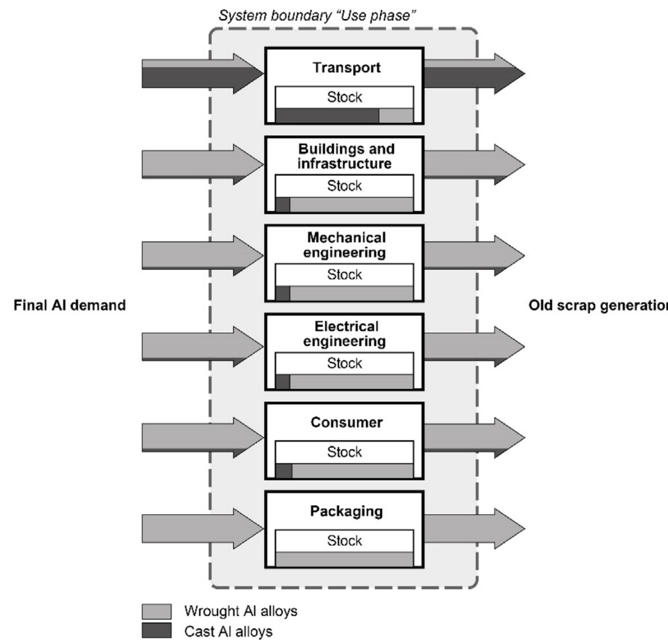

Fig. 1. System definition of this study and modelled final Al demand from Buchner et al., 2015.

are considered at each stage of the value chain in order to derive annual final Al demand for the six major sectors of Al use (Transport, Building and Construction, Mechanical Engineering, Electrical Engineering, Consumer and Packaging). In-use stocks and old scrap generation is calculated through applying sector-specific lifetime functions (cf. Table S1). The amount of scrap available for domestic recycling is derived in consideration of foreign scrap trade and losses due to treatment (e.g. scrap processing) as well as due to end-of-life (EOL) product exports (cf. Table S2).

The historical model serves to determine the current in-use stocks and current old scrap generation. In order to forecast future development of final Al demand, in-use stocks and old scrap generation, a stock driven approach is used for the Transport, the Building and Infrastructure, and the Electrical Engineering sector. Using additional parameters such as the level of motorization, Al content per vehicle, size of dwelling units, Al content per m^2 floor space and the magnitude of electrical grid expansion, the future in-use stock development as well as the associated final Al demand and old scrap generation are predicted. For the remaining sectors (Mechanical Engineering, Consumer and Packaging) the future final Al demand is modelled based on current final demand quantities in consideration of expected future growth rates. Total historical and future final Al demand is illustrate in Fig. S4.

2.2. Integration of material quality aspects into dMFM

In order to extend this quantitative model to a model differentiating between w/c Al alloys, a historical split of w/c alloys based on reported European data, derived from the regional European part of the GARC model (IAI, 2013) is incorporated into the model of Buchner et al. (2015) (cf. grey part of Fig. S1). Since the main interest of this study is the current and future availability of Al scrap differentiated by w/c alloys, the (historical) splits of w/c alloys for different sectors (Fig. 2) from the GARC model are applied to the final Al demand (=inflows into in-use, cf. Fig. 1) of the Austrian model. The application of European average Al consumption patterns to Austria appears feasible because consumption patterns with respect to final Al demand are expected to be similar within Europe and national data for Austria is not reported.