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ANTHROPOGENIC ALUMINIUM RESOURCES IN AUSTRIA AND SELF-SUPPLY POTENTIALS

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Introduction

Metals have ever played a vital role for technological and economic progress in society. In the past 60 years the global production of crude steel increased by factor 8, while the production of Al increased by factor 35. Especially due to light weight construction in vehicles, modern constructions in buildings as well as a flexible material in engineering and packaging, Al use increased considerably after 1960. Even though primary production is still the major supplier of Al on a global scale (45% China, 10% CIS, 9% Europe, 36% rest of the world) (EAA, 2012), secondary production has become more important, especially for countries with limited access to primary resources and high energy costs. After years of declining primary production in Europe, unwrought metal supply from intra Union primary production is now at a level of 14%, while secondary production and net-metal-imports have been increasing to 35% and 51% respectively. In Austria, a country without primary Al production, around 2/3 of unwrought metal demand is supplied by secondary production and around 1/3 from net-metal-imports (cf. Figure 1).

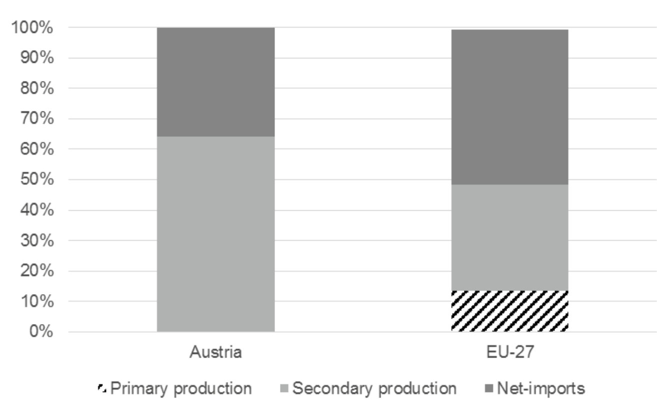

Figure 1 **Sources of unwrought Al supply. Comparison between Austria (2012 data) and the EU-27 (2013 data)**

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Since Al is predominantly used in products with long lifetimes, a considerable anthropogenic stock of Al has been built up as a consequence of the continuously increasing Al demand over the last decades. About 75% of all Al ever produced globally is expected being still in use (Bertram et al. , 2009). Therefore enhanced use of secondary raw materials is of common interest, from an industry perspective but also from an ecological and resource management perspective. In the present study, the quantitative opportunities of Al recycling in a national system are shown using a dynamic material flow model of Austrian Al flows from 1964-2050. Based on historical data current in-use stocks are calculated and forecasts of future in-use stock development and old scrap generation are produced based on assumptions about future final Al demand. Furthermore, the potential of Al self-supply (Al final demand can be satisfied solely based on domestic Al scrap supply) on the national level is evaluated. Finally, Al scrap flows are also discussed with respect to material quality, distinguishing between cast and wrought alloys. This allows for detecting future quality-related supply constraints and to evaluate the potential role of sorting technologies in this respect.

Methodology

An input driven dynamic material flow model is applied to calculate current in-use stocks based on historical production and trade data between 1964 and 2012. A special focus is put on the calibration and cross-checking of modelled stocks and flows with independent bottom-up estimates. Starting with data on the production of semi-finished products, all subsequent stages of the Al lifecycle are included in the model (cf. Figure 2). Considering national production, processing and manufacturing as well as the associated foreign trade flows, together with foreign trade of final products (e.g. cars etc.), the annual final Al demand with respect to the six most common sectors (Transport, Buildings and Infrastructure, Electrical Engineering, Mechanical Engineering, Electrical Engineering, Consumer products and Packaging) is calculated. Annual inputs into each sector are finally multiplied with sector-specific probability functions of discard in order to calculate old scrap generation in a given year from the inflows of the previous years. In-use stocks are finally derived from the annual delta between inflows and outflows of every sector. Cross-checks of the annual scrap generation with national secondary production in consideration of scrap trade and collection and processing losses are made to evaluate the plausibility of the model results in the light of independently derived estimates.

In order to estimate future development of in-use stocks and old scrap generation, current in-use stocks (derived from the historical model described above) are combined with forecasts on future final Al demand. For the sectors Transport, Buildings and Infrastructure and Electrical Engineering a stock-driven approach (i.e., the future stock development is pre-defined and thereby drives Al consumption) is used, for the remaining sectors Mechanical Engineering, Consumer and Packaging an input-driven approach (i.e. Al consumption of the different sectors is pre-defined in a scenario) is used in order to estimate future in-use stock and old scrap generation for each sector (Buchner et al. , 2015c).

Future self-supply is calculated considering two different perspectives. On the one hand, modelled old scrap generation is compared with expected future quantities of secondary Al production in order to analyse self-supply at the industry level. On the other hand, modelled old scrap generation is compared with expected future final Al demand in order to analyse (theoretical) self-supply at the product consumption level.

In order to analyse self-supply with respect to wrought and cast alloy recycling (an excess of alloying elements could potentially limit direct recycling of cast alloys) a historical split of wrought and cast alloys in European product shipments (IAI, 2011) is applied to the modelled inflows. Future splits on wrought and cast alloys are kept at the level of 2012 values. Taking the current recycling practice of end-of-life vehicle management, where mostly no separation between cast and wrought alloys is conducted, a comparison between future final Al demand and old scrap generation regarding wrought and cast alloys is conducted. The comparison is based on theoretical inflows and outflows neglecting collection, processing and melting losses as well as product exports.

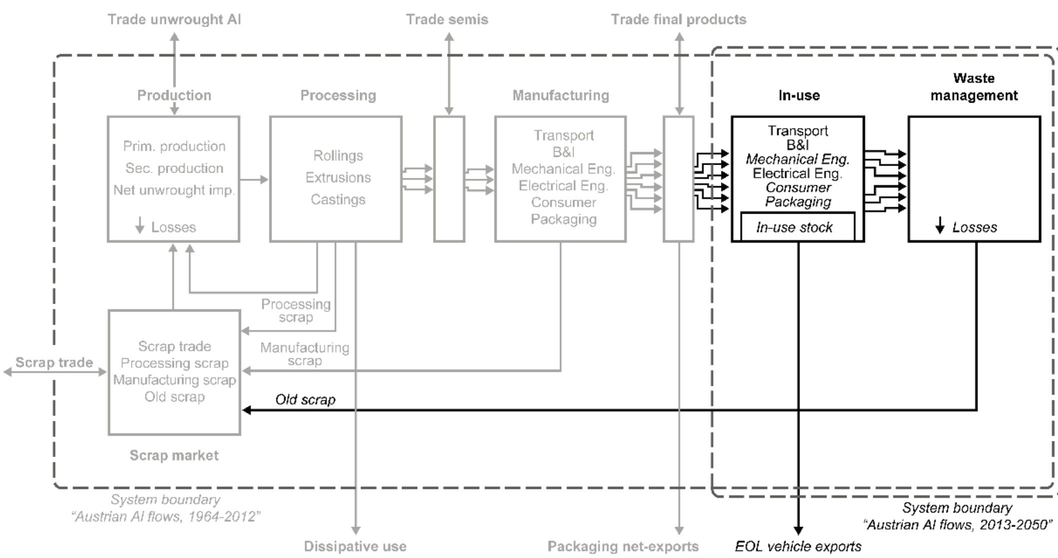


Figure 2 **National dynamic material flow model. System definition after Buchner et al. (2015a)**

Results

About two-thirds of all anthropogenic Al is currently (2012) stored in buildings and Infrastructure (159 kg/cap) and transport applications (109 kg/cap). Lower Al amounts are retained in engineering applications (66 kg/cap), consumer products (14 kg/cap) as well as reusable packaging material (5 kg/cap.), which yields a total stock of nearly 360 kg/cap. Regarding final Al demand, flows have been slightly increasing over time (except for the period of the financial crisis) to a level of 25 kg/cap in 2012. Per capita final Al demand over time as well as in-use stock development and old scrap generation are shown for selected years in Table .

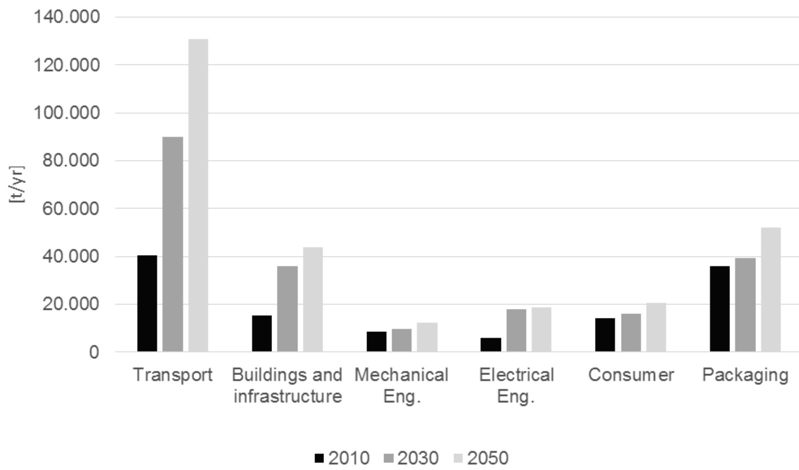


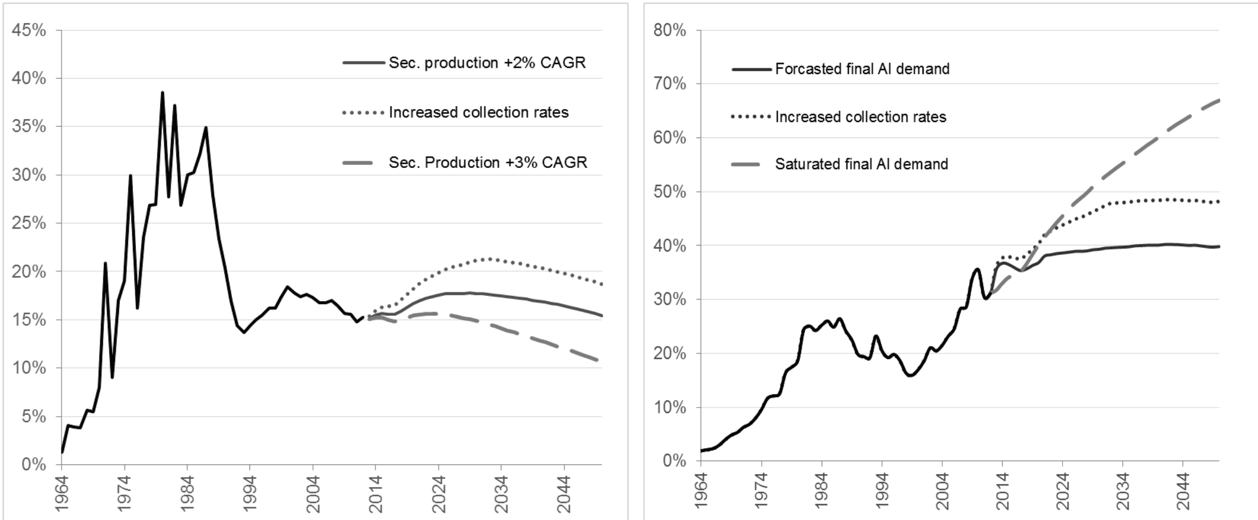
Figure 3 Current and future old scrap generation subdivided by in-use sectors (based on (Buchner et al. , 2015b)

Table 1 Historical and forecasted development of most important model outputs (Total in-use stock, final Al demand and old scrap)

	1982	1992	2002	2012	2030	2050
Total in-use stock [kg/cap.]	94	150	280	360	440	530
Final Al demand [kg/cap.]	6.9	17	25	25	28	35
Old scrap [kg/cap.]	3.5	6.1	8.8	12	24	31

Future self-supply regarding industrial Al demand (secondary production) is estimated assuming a +2% and a +3% compound annual growth rate (CAGR) for secondary production. The self-supply level is currently around 15% and is not expected to increase (substantially) in the future even in case of the lower growth (2%) scenario. Thus, in case of a CAGR of 3%, self-supply is expected to decrease. . These results highlight the crucial importance of CAGR with respect to the evaluation of future industrial Al self-supply. Enhanced recycling, which is modelled by recycling rates of at least 90% in all in-use sectors, could contribute about 3-4% to industrial self-supply (Figure 4a).

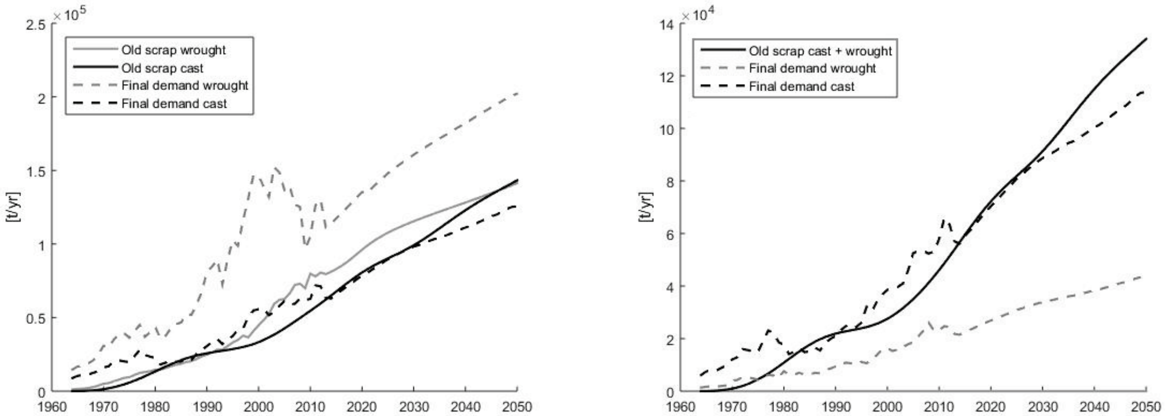
From a final demand perspective self-supply remains quite stable in the range of 40%, if no changes in system regarding scrap collection and final Al demand occur. Through enhanced national recycling an increase of self-supply by nearly 10% could be achieved. If final Al demand for the future is fixed to current levels (constant final Al demand) an increase of self-supply up to 70% is observed (Figure 4b).



a) b)

Figure 4 Calculated self-supply of Austrian Al industry (Figure 4a) and theoretical self-supply with respect to final Al demand (Figure 4b)

A comparison of future final Al demand and old scrap generation with respect to wrought and cast alloys is shown in Figure 5. Total old scrap generation and total final Al demand (all in-use sectors) is shown in Figure 5a, final demand and old scrap generation of the Transport sector is shown in Figure b. If no separation of wrought and cast alloys from vehicles is conducted, an excess of cast scrap (mixture of cast and wrought alloys) in the whole system is soon to be expected. Considering an increasing share of (wrought) Al components in cars, this situation might be further exacerbated, if no separation techniques are applied in vehicle recycling. However, it should be emphasized that currently scrap markets are not locally confined but open, which might decrease the pressure to separate cast and wrought alloys (either at the source or using processing technologies) and even lead to a higher level of scrap trade. Nevertheless, the use of low-quality scrap is ultimately dependent on primary Al production to dilute unwanted constituents. Hence, if secondary Al production shall continue to gain importance, scrap quality aspects will become a crucial issue, sooner or later.



a) b)

Figure 5 **Old scrap generation with respect to cast and wrought alloys. Total final Al demand and old old scrap generation (Figure a) and final Al demand and old scrap generation of the Transport sector (Figure b)**

Conclusions

Base on the analyses performed in this study, it could be shown that there are opportunities and limits for utilizing anthropogenic Al resources. Strategies for the sustainable management of Al resources need to consider quantitative as well as quantitative characteristics of the Al resource system, in particular with respect to the implementation of new recycling schemes and their potential effect on secondary raw material supply. The potential for Al self-supply of the Austrian industry is low given no extreme developments. Also form a final demand perspective, self-supply might hardly reach levels above 50%. Thus, high levels of self-supply can only go along with constant or decreasing Al consumption. This is also highlighted by the respective demand assumptions being the dominant factors for the estimated levels of self-supply. However, further analysis of the national material flow system, especially with respect to material quality aspects, is required in order to provide robust recommendations on how to optimize future recycling systems. In any case, an excess of certain old scrap qualities (cast alloys mixed with wrought alloys) might be unfavorable, in terms of raw material availability as well as in terms of resource efficiency.

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