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Modelling metal flows in the Australian economy

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ABSTRACT

The modelling of metal flows provides a comprehensive picture of metal use in the economy and allows for effective investigation into barriers and enablers to increase the recycling rates. In the export-oriented economy, such as Australia, the modelling requires clearly distinguishing the cycles within and outside of a country, and needs an adequate metrics to assess the country's targets in "closing the material loop". This article investigates Australian position in the global cycles of metals production and use, and assesses the potential for circularity of metals within the country based on data from 2002 onwards. The analysis shows that over the period from 2002 to 2011 the overall estimate of metals final consumption grew from 8.8 million tonnes to 12.3 million tonnes, or from 445 to 551 kg per person. Similarly, the amount of generated waste metal is estimated to have grown from approximately 5 million tonnes to 6 million tonnes, or 250–270 kg per person respectively. The amount of collected metal scrap grew from 3.3 Mt to 3.9 Mt, with the overall collection rates being relatively stable at about 70%. However, the domestic processing of collected scrap decreased significantly – from 67% in early 2000s to 41% in early 2010s, while the export of scrap increased accordingly. The current levels of waste metal generation, metal scrap collection, and domestic processing of metal scrap in Australia equal approximately 50%, 35%, and 15% of the country's metals final consumption respectively.

1. Introduction

The Australian economy is one of the fastest growing among developed countries (OECD, 2014), allowing for higher individual incomes, consumption rates, and overall standard of life. This also means a higher level of urban stocks and waste generation, representing good potential for recycling and transition to a circular type economy. The accumulated stocks of metals in modern economies are estimated at around 10–15 tonnes per citizen, being more than 98% represented by five metals – iron, aluminium, copper, zinc, and manganese (UNEP, 2013). The same five metals represent more than 99% of Australia's metal export flows (weight based), and together with gold, nickel and lead, these metals form more than 98% of the country's metal export revenue (BREE, 2014).

The closed loop economy model actively promoted internationally presupposes predominantly cyclical use of metals within the system (Ellen Macarthur Foundation, 2012; World Economic Forum, 2014). It is however economically impractical to limit the system to national or regional borders, but should be considered achievable on a global scale. This means that some countries may need to play the role of net providers of primary (mined) material resources, while others could play key role in supplying secondary resources and recycling.

The investigations of metal cycles in the economy are usually metal and region specific. In this article we focus on Australia, and overview combined major (by weight) metal flows, including iron and steel, aluminium, copper, zinc, manganese, chromium, lead, and nickel over the period from 2002 to 2013. The main aim of the paper is to identify the Australia's position in the global cycles of metals production and use, provide recommendations to enhance recycling of metals within the country and overview potential pathways to a circular economy model in an Australian context.

2. Metal flows modelling and previous studies on metal flows in Australia

In general terms, the flow of metal in the economy starts from mineral extraction, goes through several stages of transformation (such as processing, refining, fabrication, and manufacturing), includes product use in the economy (consumption), and ends up with product disposal, or recycling of metal for the next cycle. Export and import flows of minerals, refined metals, and

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manufactured products also play a significant role in estimating material flows, and often require a separate investigation. The material flow analysis techniques are usually employed to represent the circulation of specific material in the economy (Rogich and Matos, 2008; UNEP, 2010). A simplified model of metal circulation in the economy is presented in Fig. 1.

Metal production and direct shipments are usually well recorded through national and international statistics allowing for the estimation of apparent consumption of major metals in the economy, equal to metal production plus direct metal imports less direct metal exports as illustrated in Fig. 1. The true metal consumption in the country, however, may be significantly higher or lower than the apparent consumption, as it also takes into account all indirect import and export flows, where metals are associated with fabricated and manufactured goods, e.g. preassembled construction structures, engineering equipment, vehicles, and consumer products. The true metal consumption and in-use stocks are not easy to estimate; this requires additional investigations, often relying on multiple assumptions and expert opinion as the data associated with these flow are not typically recorded. The challenges with selecting reliable and consistent data sources, appropriate geographic boundaries, representative product categories to estimate the metal content, and assumptions on missing data result in considerable differences in these estimations if based on the outcomes from a range of different studies (Pauliuk et al., 2013).

The detailed information on metal cycles in the economy is relatively limited worldwide (UNEP, 2010). World historic flows of selected technological metals were investigated in the Yale University stocks and flows (STAF) project, which included analysis of country level details for iron and steel (Wang et al., 2007), copper (Graedel et al., 2004), zinc (Graedel et al., 2005), lead (Mao et al., 2008), nickel (Reck et al., 2008; Reck and Rotter, 2012), chromium (Johnson et al., 2006), and silver (Johnson et al., 2005) as shown in Table 1. The Australian focused study was performed only for copper and zinc (van Beers et al., 2007). Data on iron and steel, and aluminium flows are available from international reports, e.g. of World Steel Association (Worldsteel, 2013) and International Aluminium Institute (www.world-aluminium.org), and relevant parts of this data were considered representative of the Australian situation for this study. These reports are usually regularly updated and provide the most recent information, while academic investigations are static and quite quickly become outdated. A summary and overview of recent studies and models used for metal stocks and flows modelling can be also found elsewhere (Chen and Graedel, 2012a; Müller et al., 2014).

Most studies listed in Table 1 cover all major stages of metal circulation – from mining to recycling. However, only a few of them include a deeper investigation into the sectoral structure of metal end use, in-use stocks, and waste metal generation. There have been no publically available studies on the analysis of combined metal flows for Australia that provide a comprehensive picture of metal circulation in the Australian economy.

3. Metal flows in the Australian economy

The major metals by weight used within modern economies include six metals – iron, aluminium, copper, zinc, manganese, and lead (UNEP, 2010). The statistics on iron and steel often accounts for major alloying elements (e.g. manganese, chromium, zinc, and nickel), as do the statistics on aluminium (e.g. manganese, zinc, and magnesium). Considering only metals in metallic rather than a minerals form, eight metals – iron, aluminium, copper, zinc, manganese, chromium, lead, and nickel – represent more than 99% of overall metal flows and in-use stocks in the economy. Therefore, in this investigation, we mainly focus on these metal streams.

The national statistics in Australia is primarily reported on a financial year basis (which runs from July to June), while international statistics is on a calendar year basis. This represents an additional challenge in compiling the datasets from the quarterly or monthly reports. For estimations in this paper we predominantly use the quarterly reports from the Australian Bureau of Statistics (ABS) and Bureau of Resources and Energy Economics (BREE) to get the data based on calendar year.

3.1. Metal mining and processing, and metal export and import

The abundance of natural resources and the relatively low population has predetermined the role of Australian economy on the global market as a resources supplier as illustrated in Fig. 2. Metals and metal concentrates currently deliver the country's main export revenue (A$b 113 in 2013), followed by energy resources such as coal, natural gas and uranium (A$b 68) (BREE, 2014). More than 90% of minerals mined in Australia are directly exported; for metals and metal concentrates this figure is close to 98% (BREE, 2014). In 2013, Australia exported 700 million tonnes of metallic minerals (contained about 400 million tonnes of recoverable metals) (Fig. 2). Some metals are primarily exported as concentrates (e.g. iron ore, bauxite and alumina, copper, zinc, lead, manganese), while others in the form of refined metals (e.g. nickel, gold, silver) or chemicals (e.g. titanium dioxide pigment).

The mining of metallic minerals in Australia is driven by iron ore, bauxite, and manganese ore (Fig. 2); the country covers about 20% of world needs in these metals (BREE, 2014). Australia is also one of the leading producers of zinc, copper, lead, gold and nickel.

In 2013 the mining output in Australia was more than 50 times that of refined metals – refer to Figs. 2 and 3 – and was mainly for export (Fig. 4). For smelting operations, the steel industry is equally oriented on domestic and international market, while the refined aluminium, zinc, copper, lead and nickel are also mainly exported – refer to Figs. 3 and 5. As shown in Fig. 5, Australia roughly exports

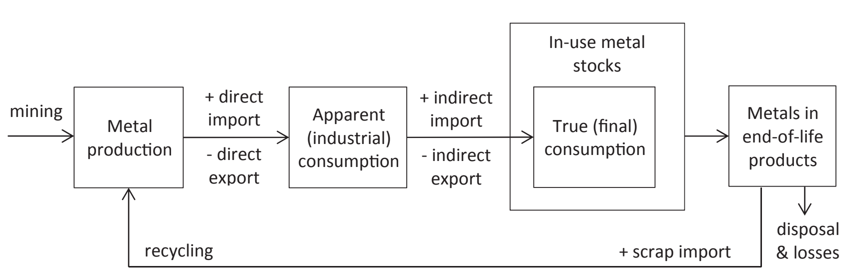

Fig. 1. Estimation of metal use in the economy.
Source: Corder et al., 2015.

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