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Current status, future expectations and mitigation potential scenarios for China's primary aluminium industry

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Abstract

Over the past three decades, China has undergone a strong economic growth, largely industry-driven. The rise of consumption resulted in increasing material requirements like steel, cement, plastic and aluminium. Regarding aluminium, the in-use stock increased to 58.9 kg/capita in 2009, from around 8.5 kg/capita in 1989 and 19.4 kg/capita in 1999. China's role in the aluminium industry is crucial. On its own, it produces around half of the world's primary aluminium output, destined for both domestic consumption and international export markets. However China's domestic bauxite reserves are limited and at current static exploitation would last for only 18 more years. Considering the low quality of its bauxite and the young and relatively low in-use stock level, China has to rely mainly on primary production, by heavily depleting its bauxite resources and by importing foreign bauxite and alumina. Primary aluminium production takes however a high environmental toll. This paper evaluates the effect of changes in: energy efficiency due to the technological level of both electricity and aluminium production, quality of resources and share of secondary and primary production; on the environmental impact due to the Chinese primary aluminium sector, by means of forecasting scenarios and mitigation potentials.

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Keywords: Primary aluminium; electricity; China; LCA.

1. Introduction

In this paper the environmental damage caused by primary aluminium production in China is estimated for 2020 and three scenarios are developed to identify potential mitigation efforts. The situation in China is of peculiar interest because of the country's unique strong growth over the last decades. According to the World Bank [1] its Gross Domestic Product (GDP) grew from US$356 billion in 1990 to US$1.199 billion in 2000 and US$5.930 billion in 2010. Meanwhile, its population grew but at a slower pace and amounted to 1.360 million in 2010 [2]. The people steadily got richer, improving living standards and consumption levels. Modern Chinese consume manufactured goods like cars, foils and cans, building space, electronics and aircraft in strongly increasing volumes. As a result, the in-use stock of aluminium grew to 58kg/capita in 2009 [3], up from about 10kg in 1990 and 20kg in 2000 [4]. The growth of in-use stock was mainly supplied by primary aluminium production. Secondary production is still relatively low in China as the in-use stocks are young compared to the average life time of aluminium products (which is 16 years according to Yue et al. (2014) [5]) and because the logitics required for efficient recycling in China are not yet fully developed. Most of the additional in-use stock in China consists of construction materials, engineering machinery and transportation means [3,5]; all of which have long to very long life times. Our impact analysis shown that in 2012 the average CO_2 density of primary aluminium production in China was 19.24kgCO_2/kg. In comparison, the global average CO_2 density of secondary aluminium production is 1.45kgCO_2/kg, or 92.5% less than for primary production in China. As China has limited access

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to secondary aluminium production, it is compelled to rely on the heavily polluting primary source.

The primary aluminium production processes studied in this paper are the extraction of bauxite ore, the refining of bauxite ore into alumina and the electrolysis of alumina into molten aluminium. Refining is a mainly fuel-based process, to supply the large quantities of heat, while the electrolysis is a mainly electricity consuming process. The Ecoinvent dataset v3 were used as an main Life Cycle Inventory (LCI) source [6]. According to the USGS [7], China produced about 22Mtonnes of primary aluminium in 2013, or about 46% of the global output. In comparison its factories only churned out 8.6Mtonnes of secondary aluminium that same year [7-8]. This paper focus on the global warming potential expressed in CO_2eq. emissions of all integrated processes in order to facilitate the comparison of the results with those from literature.

Primary production of aluminium affects the environment in both direct and indirect ways. The implemented production technology and bauxite quality are examples of endogenous factors while the electricity production technology and electricity mix are examples of exogenous factors. These affect the energy efficiency and carbon density of the studied processes. This paper evaluates the effect of changes in the aluminium production technology, the electricity production technology and mix, bauxite quality and share of secondary production on the future environmental impact of the Chinese aluminium industry. Starting from the situation in 2012, three scenarios are defined for 2020. At first the Best Available Technology (BAU) scenario is analysed (A), followed by two mitigation scenarios (B and C). Future trends in the above characteristics are extracted from various studies of the Chinese aluminium and electricity industry [9-11]. Future production volumes in China are estimated through a regressive forecast taking into account the country's expected population [2] and GDP growth [12].

2. Current situation

2.1. Material flows

To supply its primary aluminium industry, China produces about 50% of the required bauxite domestically, and imports the other half. In 2013 the remaining bauxite reserves in China equaled 830Mtonnes [13], enough to last around 18 more years at current extraction rates. Chinese bauxite is mostly of the diasporic type, which contains relatively more silica then the rest of the lateric type. Unfortunately, diasporic bauxite requires much more energy intensive refining processes than lateric bauxite. In order to cope with the lower bauxite quality, China heavily relies on imported lateric bauxite and developed specialised processes for refining silica-rich ores. In 2013 China refined 44Mtonnes of alumina [14], or about 43% of the global output. In that same year it produced 22Mtonnes of primary and 8.6Mtonnes of secondary aluminium [7-8]. On average the primary production grew slightly stronger between 2012-13 than dictated by the 12th Five-Year-Plan [14]. It set the limit at 8.6% while output grew by 8.8%. The growth of bauxite, alumina, primary and secondary production volumes in China between 2000-13 is shown in figure 1.

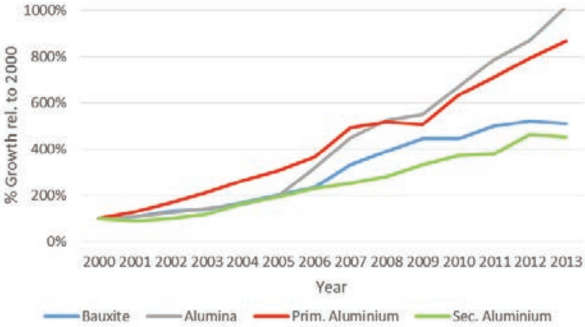
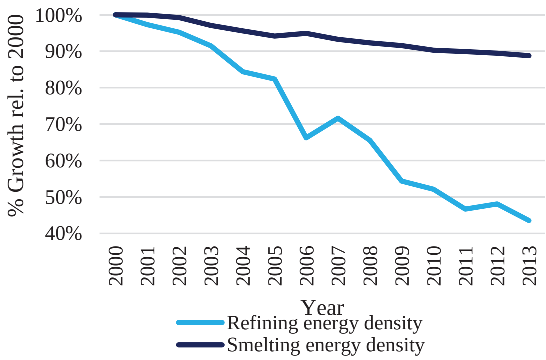


Figure 1: Relative growth of bauxite, alumina, primary aluminium and secondary aluminium production in China since 2000 (in %, 2000=base year). Source: USGS, IAI [7-8, 14].

2.2. Aluminium production technology

Bauxite extraction requires almost no energy compared to refining and smelting, it is hence excluded from the explicit analysis. Refining is a heat-intensive process and its main heat source are fossil fuels. China's average refining energy density has been rapidly decreasing over the last decade from 10kWh/kg to about 4.3kWh/kg in 2013 [15] (Figure 2). The average energy density however remains above the global average, mainly because of the share of low-grade bauxite in its raw material mix. As briefly stated above, China has been busy developing special refining processes to increase its energy competitiveness compared to diasporic bauxite refiners. According to Zhang et al. (2014) [11], refining diasporic bauxite with the classical Bayer process results in 2-4 times higher energy densities. The Lime Bayer Process (LBP) and Ore Dressing Bayer Process (ODBP) are typical examples of alternative processes, but they however result in about 40% higher bauxite consumption.

Figure 2: Evolution in energy density of refining and primary smelting



processes in China (in %, 2000=base year). Source: IAI [15].

The electrolysis energy density has steadily been decreasing too, from 15.5kWh/kg in 2000 to 13.7kWh/kg in 2013 [16] (Figure 2). It quickly became smaller than the global average due to its late-mover advantage: Chinese production plants