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Uncovering driving forces on greenhouse gas emissions in China' aluminum industry from the perspective of life cycle analysis

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HIGHLIGHTS

- Energy-related GHG emission trajectories, features and driving forces of CAI are analyzed from the perspective of LCA.
- CAI experienced a rapid growth of energy-related GHG emissions from 2004 to 2013.
- Energy-scale effect is the main driving force for energy-related GHG emissions increase in CAI.
- Construction and transportation-related activities account for more than 40% of the total embodied emissions.
- Policy implications such as developing secondary aluminum industry, improving energy mix etc, are raised.

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ABSTRACT

With the rapid growth of aluminum production, reducing greenhouse gas (GHG) emissions in China's aluminum industry (CAI) is posing a significant challenge. In this study, the energy-related GHG emission trajectories, features and driving forces of CAI are analyzed from the perspective of life cycle analysis (LCA) from 2004 to 2013. Results indicate that CAI experienced a rapid growth of energy-related GHG emissions with an average annual growth of 28.5 million tons CO_2e from 2004 to 2013. Energy-scale effect is the main driving force for energy-related GHG emissions increase in CAI, while emission-factor effect of secondary aluminum production plays a marginal effect. Construction and transportation-related activities account for the bulk of the embodied emissions, accounting for more than 40% of the total embodied emissions from CAI. Policy implications for GHG mitigation within the CAI, such as developing secondary aluminum industry, improving energy mix and optimizing resource efficiency of production, are raised.

1. Introduction

In recent years, tracking GHG emissions has become an increasingly important aspect of a global climate change research as such data inform both national and international political, economic and environmental negotiations [1]. Broad consensus amongst the scientific community that anthropogenic GHG emissions have contributed significantly to global climate change [2] has concentrated the global response; GHG emissions reduction is seen

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as the primary mitigative action to combat climate change. In addition, many nations are taking a sector-based approach to the implementation of such action, targeting specific high-emitting industries with emissions caps, reduction targets or other measures designed to incentify or regulate emission outputs.

The aluminum industry has faced increased scrutiny, as a high-emitting industry but also as one where significant GHG reductions per unit output are considered possible. Aluminum was not commercially produced until the Hall–Héroult process was discovered in 1886, but since then aluminum usage has grown rapidly; in that time there has been a notable shift in aluminum stocks – from geogenic to anthropogenic reservoirs. Like other metals, aluminum can exist indefinitely within products and infrastructures; a recent worldwide estimate showed that approximately 75% of all the aluminum product is still in use [3].

Aluminum products have a number of advantages over other metal used in industries. Its high strength-to-weight ratio, ease of recycling, and excellent corrosion resistance make it an attractive light-weight alternative to traditional steel in various applications (e.g. automotive industry, aerospace, construction) [4]. Recent decades have witnessed a significant increase of aluminum use in transportation, building, packaging, and electrical engineering due to its versatile properties [5,6]; it is now second only to steel as the most used metal within modern society. However, the energy consumed producing one ton of aluminum (primary production) is about 4.5 times higher than producing one ton steel [7]. In addition, the corresponding CO_2 emissions are 7–9 times higher than steel [8]. Currently, primary aluminum production is responsible for ~1% of global GHG emission [9] and is extremely challenged by the rapid increase of primary aluminum production.

In China, the aluminum industry has developed rapidly in the past few decades. Between 2005 and 2014, annual primary aluminum production increased from 7.8 million tons to 27.5 million tons. During the same period, the total global production (excluding China) rose from 24.1 million tons to 25.6 million tons [10] (Fig. 1). This rapid increase of nearly 19.7 million tons over ten years means that China now accounts for 51.8% of world's total primary aluminum production in 2014; this increase also represents ~80% of the global increase in production overall since 2005 [11]. While the raw materials used in aluminum production in China are comparable to those in other countries, China has one of the highest GHG emission intensities due to the widespread use of coal and coal gas for its electricity production [12]. In response, the Ministry of Industry and Information Technology (PRC) introduced legislation focused on improving the energy efficiency and reducing the GHG emission in a number of "key industries". The aluminum industry was included.

Primary aluminum production is one of the most energy intensive bulk material industries. Generally, the aluminum industry includes both primary and secondary production, however primary production is approximately 10 times more energy-intensive than secondary production (new aluminum from recycled scrap). In 2010, the power consumed to produce aluminum ingot was 14,013 kW h/t; the total power consumption for primary aluminum production was 4192.3 billion kW h, accounting for 5.27% of China's total energy use [13].

However, compared with other metal production, aluminum does have an advantage linked to its recyclability. For example, Ding et al. [14] found that under the right conditions secondary production could be used to produce of 1 ton of aluminum using 95.14% less energy and producing 95.83% fewer GHG emission. In the past few years, China's secondary aluminum industry has made significant progress; the use of recycled metal has increased steadily over much of the last decade (Fig. 2). However, there is still much to be done.

There are a few studies investigating the GHG emissions linked to the CAI; the focus and/or findings can be summarized in one of two ways. Firstly, many studies focused primarily on the material flow analysis [15–17]. Secondly, studies focused on the assessment methodology used to calculate GHG emissions for CAI [14,18,19]. As well, most studies focused on only one type of aluminum production, namely, either primary or secondary. Moreover, some studies were concerned with only the GHG emissions of specific part of the industrial process, such as those focusing on developing metrics for perfluorinated carbon compounds (PFC) [20]. There is also paucity of literature related to CAI development specifically and the various driving forces behind it, nor are there many studies from the perspective of life cycle analysis [5,12,21,22]. Therefore, this study addresses a gap by assessing CAI GHG emissions of CAI as a whole, including both primary and secondary production outputs. Furthermore, the GHG emissions associated with downstream activities are also investigated. The main objective of this paper is to study the energy-related GHG emission trajectories, features and driving forces of CAI. Based on this, policy implications for GHG mitigation within the CAI, such as developing secondary aluminum industry, improving energy mix and optimizing resource efficiency of production, are raised.

The paper is structured such that this section is followed by a description of the study's methodology, including the research scope, data collection, and details for calculating energy-related GHG emissions in CAI. Results and discussion are then presented in the Section 3. A scenario analysis offering CAI GHG-emission projections for 2015–2030 is offered in Section 4 in an effort to inform an optimized strategy for future development of CAI. Subsequently, policies recommendations are offered through the context of Chinese realities, and followed by our conclusions.

2. Methodology

The system boundary of the LCA in this instance includes GHG emissions from both primary and secondary aluminum production. During primary aluminum production, energy-related GHG emissions are linked to mining (bauxite) operations, alumina refining, smelting and ingot casting. However, each subset with the overall

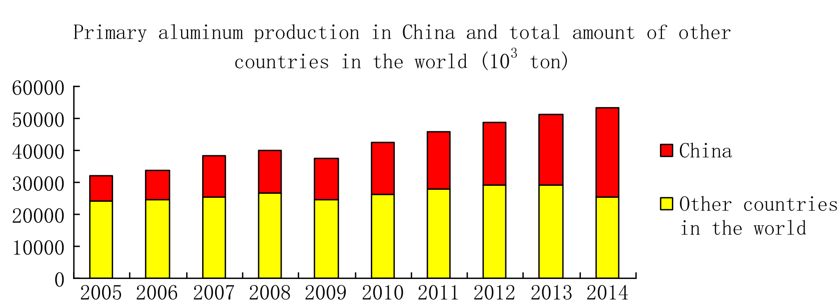

Fig. 1. Comparison of primary aluminum production between China and other countries in the world from 2005 to 2014.

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