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GHG emissions from primary aluminum production in China: Regional disparity and policy implications

Han Hao [a], Yong Geng [b,*], Wen Hang [c]

[a] State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing 100084, China
[b] School of Environmental Science and Engineering, Shanghai Jiaotong University, Shanghai 200240, China
[c] Transportation College, Southeast University, Si Pai Lou 2, Nanjing, Jiangsu 210096, China

HIGHLIGHTS

- GHG emissions from primary aluminum production in China were accounted.
- The impact of regional disparity of power generation was considered for this study.
- GHG emissions factor of China's primary aluminum production was 16.5 t CO_2e/t Al ingot in 2013.
- Total GHG emissions from China's primary aluminum production were 421 mt CO_2e in 2013.

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ABSTRACT

China is the world-leading primary aluminum production country, which contributed to over half of global production in 2014. Primary aluminum production is power-intensive, for which power generation has substantial impact on overall Greenhouse Gas (GHG) emissions. In this study, we explore the impact of regional disparity of China's power generation system on GHG emissions for the sector of primary aluminum production. Our analysis reveals that the national GHG emissions factor (GEF) of China's primary aluminum production was 16.5 t CO_2e/t Al ingot in 2013, with province-level GEFs ranging from 8.2 to 21.7 t CO_2e/t Al ingot. There is a high coincidence of provinces with high aluminum productions and high GEFs. Total GHG emissions from China's primary aluminum production were 421 mt CO_2e in 2013, approximately accounting for 4% of China's total GHG emissions. Under the 2020 scenario, GEF shows a 13.2% reduction compared to the 2013 level, but total GHG emissions will increase to 551 mt CO_2e. Based on our analysis, we recommend that the government should further promote energy efficiency improvement, facilitate aluminum industry redistribution with low-carbon consideration, promote secondary aluminum production, and improve aluminum industry data reporting and disclosure.

1. Introduction

Aluminum is one of the most important metal materials in our economy and is widely used in construction, manufacturing, and many other industrial sectors. One major application of aluminum is the structural material for various equipment. Compared with steel, aluminum offers the benefit of lowering weight on the basis of maintaining structural strength. For example, as estimated by Du et al. [1], for a conventional Chinese passenger car with a curb weight of 1445 kg, a 17.7% weight reduction can be achieved with the uses of aluminum-intensive body-in-white, closures, etc. Globally, light-weighting has become one major trend in equipment manufacturing [2]. Particularly, for sectors such as transportation, light-weighted equipment contributes to reducing

Abbreviations: AC, alternating current; ASM, American Society for Metals; CNMIA, China Nonferrous Metals Industry Association; CO_2e, CO_2 equivalent; EAA, European Aluminum Association; EPA, Environmental Protection Agency; GEF, GHG emissions factor; GHG, Greenhouse Gas; GWP, global warming potential; IAI, International Aluminum Institute; IPCC, Intergovernmental Panel on Climate Change; IEA, International Energy Agency; JAA, Japan Aluminum Association; MIIT, Ministry of Industry and Information Technology; mt, megaton; NBS, National Bureau of Statistics; NDRC, National Development and Reform Commission; PFC, perfluorocarbon; PFPB, Point Feed Pre Bake.

* Corresponding author at: School of Environmental Science and Technology, Shanghai Jiaotong University, No. 800 Dongchuan Road, Shanghai 200240, China. Tel.: +86 2154741065; fax: +86 2154740825.
E-mail address: ygeng@sjtu.edu.cn (Y. Geng).

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energy consumption and GHG emissions associated with equipment operating [3,4]. Under such a circumstance, as a key structural material, aluminum is playing a more critical role in global manufacturing industry.

Global aluminum industry experienced a rapid growth over recent years. As reported by International Aluminum Institute (IAI), global primary aluminum production increased from 24.7 mt (megaton) in 2000 to 53.0 mt in 2014, with an annual growth rate of 5.6% [5], and was projected to reach 97 mt by 2020 [6]. Among all regions and countries, China experienced the fastest growth on its aluminum industry and now is the largest aluminum production country in the world. China's primary aluminum production increased from 2.8 mt in 2000 to 27.5 mt in 2014, with an annual growth rate of 17.7% [5,7]. The share of China' primary aluminum production out of global total increased from 11% in 2000 to over half in 2014. However, China's primary aluminum import and export were 0.27 mt and 0.10 mt in 2014, which were both lower than 1% of domestic production. This indicates that China's primary aluminum production is mostly aimed at domestic market. The low export can be mostly attributed to China's tariff policy for constraining primary aluminum export.

Aluminum industry is both energy-intensive and emission-intensive. As reported by IAI [8], global power consumption of primary aluminum smelting increased from 301.7 TW h in 2000 to 611.9 TW h in 2013, with an annual growth rate of 5.6%. Aluminum sector accounted for around 3.5% of global electricity consumption [9,10]. In China, energy consumption of primary aluminum production was estimated to be 58% of total energy consumption of the nonferrous metals industry in 2010 [11]. GHG emissions from China's aluminum industry were responsible for 49.5% of global total emissions from aluminum sector in 2008 [11].

Academically, studies have been intensively conducted in order to understand both energy and environmental impacts of aluminum industry. The IAI and GHG Protocol jointly developed the aluminum tool [12], a spreadsheet-based model with the ability of calculating plant-level CO_2 and perfluorocarbon (PFC) emissions from primary aluminum production. The aluminum tool and other similar works typically employed a life-cycle framework with process-based accounting methods. IAI investigated the life cycle inventory of global primary aluminum industry using the 2000, 2005 and 2010 data respectively [13,14]. These studies revealed a continued reduction of PFC emissions from aluminum production. In addition, the European Aluminum Association (EAA) and American Society for Metals (ASM) released the EU-specific and US-specific life cycle inventories of primary aluminum production, respectively [15,16].

GHG emissions from China's industrial sector have been highly concerned by researchers [17,18], in which aluminum industry is an important focus. Gao et al. [19] revealed that the GHG emissions factor (GEF) of primary aluminum production in China was 21.6 t CO_2e/t Al ingot in 2003, 70% higher than the global average level. Wu et al. [20] estimated the overall GHG emissions from China's primary aluminum production in 2005 and found that primary aluminum production was responsible for 2.9% of national energy consumption. Moreover, according to Zhang et al. [21], GEF of primary aluminum production in China was 14.7 t CO_2e/t Al ingot in 2011, implying a very significant improvement over recent years.

Power generation has substantial impact on GHG emissions from primary aluminum production. Existing literatures suggested that the indirect GHG emissions from electricity consumption within the aluminum smelting process accounted for over 70% of life cycle GHG emissions. GHG emissions from electricity consumption are determined by two factors: (1) electricity consumption and (2) GEF of power generation. Regarding electricity consumption, the difference between the most advanced aluminum smelting facilities (assuming 13,000 kW h/t Al ingot) and outdated ones (assuming 15,000 kW h/t Al ingot) is within 15%. However, GEF of power generation has a great uncertainty, from near zero to as high as over 1000 g CO_2e/kW h, depending on grid mix and power generation technologies.

Significant regional disparity of GEF exists in China's power generation sector. National Development and Reform Commission (NDRC) annually releases the baseline GEFs of China's regional power grids. Under their accounting framework, China is divided into six major regional power grids, i.e., North China, Northeast China, East China, Central China, Northwest China, and South China, each covering several provinces [22]. According to their most recent update in 2014, the marginal GEFs of power generation ranged from 810 g CO_2/kW h (East China) to 1128 g CO_2/kW h (Northeast China).

The diversity of power generation across China's different regions poses significant impacts on the GHG emissions from power-intensive sectors. For example, Huo et al. [23] estimated GHG emissions from electric vehicle use in China from the life cycle perspective. Rather than employing the nationwide average GEF of power generation, they employed the regional power generation GEFs and calculated GHG emissions from electric vehicles in different regional contexts. Their study suggested that the GHG emissions from electric vehicles were quite different among regions, ranging from about 160 g CO_2/km (South China) to 240 g CO_2/km (North China). The comparison of GHG emissions between conventional vehicles and electric vehicles can be completely reversed in different regional contexts. Their study highlighted the importance of analyzing GHG emissions from power-intensive sectors by considering regional power generation disparities.

As a power-intensive sector, primary aluminum production is also critically affected by regional disparities of power generation. In order to avoid any potential evaluation errors, it is necessary to consider such regional disparities. Besides, region-specific policies regarding primary aluminum production cannot be well developed based on country-level studies. With the aim of filling such gaps, we target to establish an accounting framework at provincial level, with specific power generation and aluminum production profiles for each province. Based upon this accounting framework, we estimate GHG emissions from primary aluminum production for the year of 2013 both at the provincial and national levels and also project the future emissions for the year of 2020. The focus of this study is to quantify the impact of regional disparity of power generation on China's primary aluminum production, and to develop policy recommendations with region-specific implications. The whole paper is organized as follows. After this introduction section, we describe our research methodology and data collection and treatment. Then we present research results and provide detailed discussions. Finally, we draw our conclusions and raise our policy recommendations.

2. Methodology and data

2.1. Methodology

Fig. 1 presents the system boundary of primary aluminum production. Five major processes, including bauxite mining, alumina production, anode production, aluminum smelting and ingot casting, are considered in our analysis. The detailed descriptions of each process can be found in the IAI [14] study. Four major GHG emissions sources are considered, including fossil fuel combustion (CO_2 and CH_4), anode consumption within the aluminum smelting process (CO_2), anode effect within the aluminum smelting process (CF_4 and C_2F_6), and indirect GHG emissions from power generation.