Aluminium Sector Historical Greenhouse Gas Emissions Trends Over the Last Two Decades

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Abstract

Primary aluminium production is an energy-intensive process with the aluminium sector being responsible for approximately 2 % of all global greenhouse gas (GHG) emissions. This paper explores nearly two decades worth of IAI aluminium greenhouse gas data, from 2005 to 2018, utilising data collected directly from the industry. The data covers all production worldwide by implementing informed estimates from reporting plants and conservative assumptions from non-reporters. Here we present annual primary aluminium and global aluminium sector emissions, in tonnes CO_2 equivalent, accounting for all emissions sources and processes. The data is presented at unit process and emissions type level, enabling granular analysis of GHG trends. While fossil fuel generated electricity has increased over the years (51 % in 2005 to 71 % in 2018), the GHG emissions intensity of electrolysis has remained relatively stable. This has been possible mainly due to energy efficiency gains over this period, with total electricity required per tonne of primary aluminium decreasing from 15 080 kWh in 2005 to 14 221 kWh in 2018. Moreover, the evolution of the power mix utilised in the electrolysis process across 8 different regions is considered, along with implications of how different electricity generation sources influence the overall aluminium industry's greenhouse gas emissions. Non-CO_2 greenhouse gases in the primary aluminium production process have been declining consistently, from 1.6 to 1.1 tonnes CO_2e per tonne primary aluminium in 2018, highlighting the industry's efforts to reduce perfluorocarbon emissions. Emissions from thermal energy, ancillary materials and transport emissions have also shown a consistent decline.

Keywords: Aluminium greenhouse gas emissions, GHG, aluminium sector emissions, primary aluminium emissions, electrolysis energy mix.

1. Introduction and Background

Aluminium production begins with the mining of bauxite ore, which contains 30-54 % aluminium oxide (Al_2O_3, hereafter alumina), the rest being a mixture of iron oxides, silica and titanium oxide [1]. Alumina is extracted and purified in the Bayer Process, requiring energy in the form of heat and steam, as well as ancillary materials such as sodium hydroxide. After being calcined, the alumina is shipped in dry bulk to an aluminium smelter. Significant amounts of electricity are then required to break the strong oxygen bonds of alumina in the smelting process. The smelting of aluminium currently takes the form of a reduction-oxidation reaction between the raw material, alumina, and carbon anodes, in which three electrons are provided to each aluminium ion to reduce it to its metal form, while the carbon atoms of the anodes are oxidised to form carbon dioxide, as characterised in the following reaction:

$$2Al_2O_3 + 3C \rightarrow 4Al + 3CO_2 \tag{1}$$

In addition to alumina, the electrolysis process requires a variety of inputs including electricity, carbon anodes and other ancillary products. All of these come with a carbon footprint. Electricity-related emissions dominate the 75 % of sectoral emissions that smelting represents [2]. Electricity-related emissions can vary significantly across the industry, depending on the power mix used by smelters. Historically, the aluminium smelting power mix was dominated by electricity generated using hydropower. However, over the past 20 years, the overall power mix of the sector has shifted with greater amounts of coal and natural gas and is now dominated by coal-powered electricity [2] driven by the growth of production in India and China.

Aluminium is infinitely recyclable. Recycling aluminium requires up to 95 % less energy than production from ore [2], as it only requires melting the aluminium scrap, eliminating CO_2 that is associated with the smelting process. As such, increasing the global recycling efficiency rates for end-of-life products will be essential to further decrease the overall carbon footprint of aluminium.

The International Aluminium Institute (IAI) has recently explored the ways forward for decarbonising the aluminium industry, setting out three broad pathways to 2050. These include electricity decarbonisation, direct emissions reduction, and recycling & resource efficiency [2]. In contrast, this paper analyses the aluminium industry's historical trends, looking back at previous historical moments and changes that have influenced the industry's greenhouse gas emissions, and presents the most recent analysis of the industry's baseline emissions. Nearly two decades worth of aluminium GHG data, from 2005 to 2018, is presented at unit process and emissions type level making this is one of the most comprehensive GHG datasets of any material. This paper also considers the historical changes to the regional energy mix and how that has impacted the emissions intensity in those regions.

2. Methodology

The dataset covers life cycle (cradle-to-gate) GHG emissions (as CO_2e) for the 2005–2018 period and is publicly accessible via International Aluminium Institute's website [3]. Aluminium GHG cradle-to-gate emissions comprise electricity, thermal energy, direct process, ancillary materials, transport, and non-CO_2 GHG emissions. This includes all sector generated emissions in its own facilities (primary and recycling), in addition to those embedded in the raw materials, ancillary materials and energy that the sector consumes. The data covers all production worldwide by using informed estimates for plants that report their data to IAI, and conservative assumptions for the sites that do not currently report their data to the IAI. Emissions types are summarised below:

- Direct process: direct, non-fuel combustion inputs and outputs (emissions) associated with primary aluminium production processes (bauxite mining, alumina production, anode/paste production, electrolysis, and casting).
- Thermal energy: material inputs and emissions associated with primary aluminium production thermal energy generation processes, including fuel extraction and preparation (e.g., coal from mine to boiler).
- Ancillary materials: all material and energy inputs and emission outputs associated with non-fuel input materials used in the production of primary aluminium (e.g., caustic soda, lime, aluminium fluoride, pitch & coke production).
- Electricity: all inputs and outputs associated with processes to generate and distribute the electricity directly used in primary aluminium production processes, including fuel extraction and preparation.
- Transport: inputs and outputs associated with the seaborne, road and rail transport of input materials.
- Non-CO_2: perfluorocarbon (PFC) emissions generated during operational disruption in the electrolytic cell due to anode effects.

carbon anode consumption during the electrolysis process, and PFCs generated in the electrolytic cell due to anode effects.

Primary aluminium production over the last two decades has grown consistently to meet growing demand. From 2005 to 2018, global aluminium production increased by 101 % and global aluminium sector emissions by 87 % as a result. Over this same time period, the emissions intensity per tonne of ingot and per tonne of semis has remained fairly stable at between 16.5 t and 18.5 t CO_2e (primary) and 11 t and 13 t CO_2e (semis) respectively.

The emissions intensity of primary aluminium production has a significant influence on the overall emissions intensity for the aluminium sector. Primary aluminum emissions intensities can vary significantly depending on the source of energy for electricity generation. The proportion of recycled aluminium production as a proportion of the overall production also plays a notable role in the emissions intensity for the sector.

5. References

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