European Aluminium
ANYTHING BUT BASIC

RAMBOLL

THIRD-PARTY STUDY ON IMPACT OF CBAM ON ALUMINA & SCRAP MARKETS

Copenhagen, March 2025

Executive Summary

Aluminium is a key industrial metal to the European economy. Its chemical and physical attributes enable its transformation into a variety of shapes and sizes, fostering its widespread utilization in key sectors such as transportation, electrical equipment, electronics, packaging, and construction.

Recognizing its strategic importance, European Union policymakers have underscored aluminium's value within the EU economy. The designation of bauxite, alumina, and aluminium as critical raw materials in 2020, with reaffirmation in 2023, reflects concerns about supply vulnerabilities and the essential role that aluminium plays as a key material in driving the green transition, fostering economic stability and industrial resilience. Further emphasizing its strategic relevance, NATO has recently classified aluminium as a defence-critical raw material. Given the acknowledged necessity to secure aluminium value chains, attempts to increase their sustainability must be designed carefully, and cannot risk the destruction of EU production as an unintended consequence.

The Carbon Border Adjustment Mechanism (CBAM), as established under Regulation (EU) 2023/956, is a pivotal policy tool aimed at putting a fair price on the carbon emitted during the production of goods entering the EU. However, the current CBAM design and its potential development pose a risk for the overall competitiveness of the European aluminium industry. In particular, (i) the potential extension of the CBAM scope to include alumina, and (ii) the potential for foreign producers to circumvent CBAM fees using secondary material (i.e. scrap) raise concerns. These two issues are the main topics of focus in this study. Under each topic, also the inclusion of indirect emissions is addressed. The study shows how a correctly designed CBAM is required in order to reduce - albeit not fully eliminate - the competitive disadvantage for European producers resulting from the application of carbon pricing in Europe, but not elsewhere in the world.

Alumina

The alumina industry in the EU has come under pressure in recent years as producers' margins have been reduced by high energy prices, and alumina demand in Europe has fallen, due to aluminium smelter closures. Globally, however, alumina and aluminium demand and production are increasing. Under the development of the EU Emissions Trading Scheme (ETS), carbon costs for all Energy Intensive Industries (EIIs), including alumina refineries, are expected to raise significantly towards 2030.

Alumina is a globally traded commodity and subject to a significant carbon leakage risk. The remaining EU installations will face increasing ETS carbon costs, which are not faced by third-country installations. There are now just four remaining alumina refineries in the EU, following the closure of two. This makes the European aluminium value chain increasingly

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dependent on imports, even though EU alumina refineries are among the best performers globally, regarding emission intensity. A closure of EU refineries can thus be assumed to result in more carbon intensive production elsewhere.

The EU has introduced the CBAM as a carbon leakage prevention mechanism. Alumina, not yet in the scope of CBAM, will face large cost increases already from 2026, due to the fall-back benchmarks review which does not fit the alumina process.

This study investigates the impact of a CBAM on alumina and concludes the following:

1. If alumina is included in CBAM, the **European marginal price for alumina in the EU + EEA could raise by 12-16% in a 2030 scenario and by up to 24% in a 2034 scenario** under different CBAM/ETS assumptions.[1] The price increase would be beneficial to EU alumina refineries, by improving their cost competitiveness, relative to imports.
2. The **CBAM application in the aluminium industry raises concerns around downstream demand destruction**, where the **inclusion of alumina in the CBAM scope could significantly raise raw material prices for European primary aluminium smelters and all downstream producers**, thus adding an additional carbon cost to all aluminium products downstream, as alumina would become a precursor.
3. **Alumina should not be included in the CBAM scope** until all downstream industries, including final goods, are included under the CBAM scope and downstream demand impact from CBAM and ETS can be better understood. Furthermore, an export support mechanism would be necessary for alumina refineries to remain competitive on the global market.
4. In the absence of an effectively designed CBAM, the remaining European installations **require a dedicated ETS alumina product benchmark in the short- to medium-term** to mirror the high energy intensity of alumina production and the absence of technologically and economically viable decarbonisation options. The ETS fallback benchmark, which is the relevant benchmark for alumina refineries, covers a broad range of sectors and processes, and thus does not accurately reflect a level of emissions performance that can be achieved by any alumina refinery, resulting in disproportionately high carbon costs for alumina producers.

Aluminium Scrap

Aluminium and aluminium semi-fabricated products are subject to CBAM. European ETS installations will start losing free allocations by 2026. Simultaneously, the CBAM fee will be due upon import[2]. Under the current CBAM regulation, aluminium scrap is not assigned any embedded emissions. This study examines key aspects of aluminium production, trade, and pricing to analyse how the exclusion of scrap as an aluminium precursor will influence competition, product prices, and product flows within and outside the EU+EFTA. Ultimately, this study evaluates the effects of alternative CBAM designs and concludes the following on accounting for **aluminium scrap under CBAM**. As the main takeaway:

All aluminium metal (sold as unwrought aluminium or included in aluminium semi-finished products) should be accounted for under national default values at the level of primary aluminium in order to mitigate circumvention risks, ensure fair and simplified CBAM fee calculations, and incentivize global decarbonization efforts. This is based on the following underlying conclusions:

[1] Based on specific assumptions regarding CBAM/ETS outlined in this report and no significant changes to production and import volumes into Europe.

[2] Based on recent changes to the CBAM regulation (March 2025) importers will only need to buy certificates for 2026 in 2027

1. All metal available in the market was once produced though a primary process, which generated GHG emissions. If these emissions are **not accounted for in the CBAM regulation, European producers who pay a carbon price on their full value chain would be at a significant disadvantage**.
2. The **high complexity in global scrap flows for pre- and post-consumer scrap cannot be effectively managed through current CBAM reporting design**. Furthermore, recycled aluminium cannot be physically distinguished from primary aluminium, and it is also not possible to check upon import of a product whether it is made of primary metal, pre-consumer scrap or post-consumer scrap (or a mix of them). Self-declaration of these values would be the sole basis for the calculation of the CBAM fee. This high circumvention risk may result in CBAM failing to meet its objectives of mirroring the ETS system and incentivising decarbonisation in other geographies. **Default values would address these issues, making CBAM reporting more transparent and simplified.**
3. In the current design of the CBAM, where scrap is not assigned any embedded emissions, **importers can use scrap to undercut the European market, leading to carbon leakage.**
4. **The current design of CBAM allows for the reshuffling of resources on a wider scale**, whereby only lower-carbon installations or producers with access to larger scrap volumes would import to Europe, while foreign industries would have no effective incentive to decarbonize.
5. The **abundance of global scrap creates an opportunity for circumvention**. High EU aluminium prices will incentivize foreign producers to exploit scrap content, selling at elevated prices and benefiting from windfall profits.
6. Further, false claims, non-exclusive trade codes, and mixing of different scrap types are **other significant circumvention risks, if CBAM does not account for scrap emissions by a default value**.

Further relevant findings of the study for the overall aluminium value chain:

1. CBAM will **create a separate higher premium European market for aluminium**. CBAM fees will be directly passed on by importers and will affect downstream industries and consumers negatively, impacting the European economy.
2. In a high premium European market, **pre- and post-consumer scrap prices would rise, regardless of CBAM inclusion**.
3. The aluminium **downstream industry (manufacturing) must be simultaneously included in CBAM**. Otherwise, the European aluminium industry will face significant carbon leakage under the current ETS and CBAM design.
4. **Indirect emissions should not be included in the CBAM design for aluminium** and the product scope should first be expanded. In the meantime, indirect cost compensation remains vital to European smelter businesses, and the impact in terms of raw material costs increases, and the competitiveness of aluminium transformation and recycling companies must first be assessed. The inclusion of indirect emissions can only be considered in the long-term, once European grids have been mostly decarbonised and third-country importers supplying European demand have had reasonable opportunities to switch to low-carbon electricity.
5. The European aluminium industry exports significant volumes. Under increasing ETS and raw material costs, **an export compensation mechanism is needed to remain competitive on the global market** while providing lower-carbon aluminium compared to global competition.

6. Under increasing ETS costs, a **correctly designed CBAM is required in order to reduce - albeit not fully eliminate - the competitive disadvantage for European producers** resulting from the application of carbon pricing in Europe, but not elsewhere in the world.

Third party study on impact of CBAM on alumina & scrap markets

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- Metlen
- Novelis
- Speira
- Trimet

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ABBREVIATIONS

˚C	Degrees Celsius
CBAM	Carbon Border Adjustment Mechanism
CO2	Carbon Dioxide
CO2e	Carbon Dioxide Equivalent
CSCF	Cross-sectoral correction factor
EA	European Aluminium
EEA	European Economic Area
EFTA	European Free Trade Association
EII	Energy Intensive Industries
ETS	Emissions Trading System
EU	European Union
EVs	Electric Vehicles
GHG	Greenhouse Gas
IAI	International Aluminium Institute
LCA	Life Cycle Assessment
PFCs	Perfluorocarbons
PPA	Power Purchase Agreement
UBCs	Used Beverage Cans

TABLE OF DEFINITIONS

Carbon Border Adjustment Mechanism (CBAM). EU regulation that imposes carbon pricing on imports of certain goods, including aluminium products, to prevent carbon leakage and ensure a level playing field for European industries.

Carbon budget. The amount of GHG emissions that can be released into the atmosphere while limiting global warming to a specific target, helping to manage and mitigate climate change.

Carbon dioxide equivalent (CO_2e). Unit of measurement that represents the amount of GHG emissions released into the atmosphere in terms of their equivalent warming potential to carbon dioxide (CO_2) over a specified time period, usually 100 years. It is used to compare and aggregate the impact of different GHGs, each with its own global warming potential (GWP), on climate change.

Carbon leakage. Carbon leakage refers to the situation that may occur if, for reasons of costs related to climate policies, businesses were to transfer production to other countries with laxer emission constraints. This could lead to an increase in their total emissions.

Direct emissions. Direct emissions under CBAM refer to greenhouse gas (GHG) emissions released directly from the production process of a good. These emissions result from: Combustion of fuels (e.g., burning coal or gas in industrial furnaces) or Chemical reactions inherent to production (e.g., CO_2 emissions from limestone calcination in cement production).

Indirect emissions. Indirect emissions under CBAM/ETS refer to greenhouse gas (GHG) emissions associated with the electricity consumed during the production of a good. These emissions occur upstream, primarily from power generation, rather than directly at the facility producing the CBAM goods.

European Union Emissions Trading System (EU ETS). Cap-and-trade program established by the EU to limit GHG emissions from various industries, including aluminium, by allocating and trading emission allowances.

ETS Product Benchmark. Benchmarks, expressed as GHG emitted per tonne of product produced, that determine the free allocation that installations should receive.

Free allocation. An ETS mechanism to mitigate the risk of carbon leakage, whereby industrial installation receives a significant part of their emissions allowances for free.

Paris Agreement. Global treaty within the United Nations Framework Convention on Climate Change (UNFCCC) that aims to combat climate change by setting international targets for limiting global warming and promoting efforts to reduce GHG emissions.

Power Purchase Agreement (PPA). A PPA is an electricity purchase agreement between two actors to secure long-term supply of renewable energy. In this study, only physical PPA are consider when referring to PPA. This includes the actual delivery of electricity, from a specific energy generating facility, to the buyer's location.

Primary aluminium. New aluminium metal produced from raw materials through the electrolytic process, also referred to as the aluminium smelting process.

Scope 1, 2 and 3 emissions: Common classification of GHG emissions established by the GHG Protocol. Scope 1 includes direct emissions from a company's own activities, mainly on-site fuel combustion and other process related emissions. Scope 2 covers indirect emissions from purchased electricity or heat. Scope 3 encompasses all other indirect emissions, including for example emissions from material extraction and production in supply chain, employee commuting, and product use.

Secondary aluminium. Recycled aluminium derived from pre- or post-consumer scrap, which is reprocessed to create new aluminium products. In this report, Secondary and recycled aluminium are used interchangeably.

Semi-fabricated aluminium. Aluminium products that have undergone initial shaping or processing steps, such as rolling, extrusion, or forging, before being further fabricated into finished products.

Precursor good (in the CBAM). A precursor in CBAM is an input material used in the production of a CBAM good, where the emissions from the precursor's production are added to the total embedded emissions of the final product.

Only CBAM goods can be considered as precursors (i.e., they must already fall under CBAM's scope).

Simple goods. Simple goods under CBAM are goods where the embedded emissions are based entirely on the emissions occurring during their own production, without the need to account for precursors.

Complex goods. Complex goods under CBAM are goods that require consideration of embedded emissions from precursor materials used in their production. These precursors are themselves CBAM goods.

1. Introduction: Objective and overview of the study

1.1 Objective of this study

The aim of this study is to understand the implications of the European Union's Carbon Border Adjustment Mechanism (CBAM) on the alumina and scrap markets. The report presents an overview of the aluminium value chain and analyses the potential impacts of various CBAM on various stages within this value chain.

1.2 Overview of the report

Chapter 2 introduces the EU CBAM, explaining its purpose, geographic scope, and specific relevance to aluminium products. It addresses initial concerns about the CBAM implications for the aluminium industry and details the calculation methods and dependencies used in the study to assess these impacts.

Chapter 3 provides an extensive analysis of the aluminium value chain, both globally and within the EU. This chapter highlights the importance of aluminium in the EU economy and provides a detailed examination of EU+EFTA production, imports and exports at each stage in the value chain, including bauxite mining, alumina refining, primary aluminium production, semi-fabrication, manufacturing, and recycling.

Chapter 4 focuses on the energy and emission profiles associated with each stage of the aluminium value chain. It discusses the energy intensity and costs of alumina production, as well as the emission intensity and energy costs related to primary and secondary aluminium production. The geographical average energy intensities, emissions intensities and costs serve as inputs in the analysis of CBAM impacts in Chapter 5.

Chapter 5 delves into the potential specific impacts of the CBAM on alumina It includes scenario assessments for the inclusion or exclusion of alumina in the CBAM and explores the resulting implications for alumina refineries and for producers downstream.

Chapter 6 analyses the current exclusion of aluminium scrap under CBAM and highlights the existing circumvention risk. It further describes how CBAM fees will be holistically applied to global imports and investigates resulting price implications. Further its recommendations on how the CBAM regulation should be adapted to minimize circumvention risk and carbon leakage.

Chapter 7 explores potential future developments in the European Emission Trading Scheme (ETS) and their influence on the CBAM. This chapter includes speculative policy designs and long-term development scenarios, drawing sub-conclusions regarding the treatment of alumina and aluminium scrap under evolving regulatory frameworks.

2. The EU Carbon Border Adjustment Mechanism

The aim of this chapter is to describe the objective, scope and features of the CBAM regulation and how it applies to aluminium.

This chapter also introduces the main points of concern from the European aluminium industry about the CBAM and explains which of these will be of focus in the study.

2.1 Introduction to the EU CBAM

The EU CBAM is closely linked to the European Emissions Trading Scheme. The Emissions Trading Scheme (ETS) is a cap-and-trade carbon price system that, in its current phase, aims to bring EU emissions down by 62% by 2030 compared to 2005 levels. The tighter cap on emissions raises the price of carbon in the EU, putting EU producers at a cost-disadvantage compared to foreign producers, who have lower or no carbon price. Thus, the ETS is coupled with mechanisms that aim to protect EU producers. Until now, industries with a high risk of **carbon leakage**, have had **free allocation** of carbon allowances under the ETS.

The system of free allocation is based on **product benchmarks**, which are expressed as tonnes of GHG emitted per tonne of product produced. The benchmarks represent the performance of the 10% best installations covered by the EU ETS producing that product. In principle, this means that the most efficient installations do not need to buy allowances, and the less efficient installations purchase allowances to cover their emissions. There are 52 product-specific benchmarks and two benchmarks for heat and fuel consumption, which function as fall-back benchmarks for products not covered by the product-specific benchmarks[3].

In phase four of the ETS, free allocation is being phased out for certain sectors. The reasoning behind this, according to the CBAM regulation, is "free allocation weakens the price signal that the system provides and thus affects the incentives for investment into further reducing greenhouse gas emissions." [4]

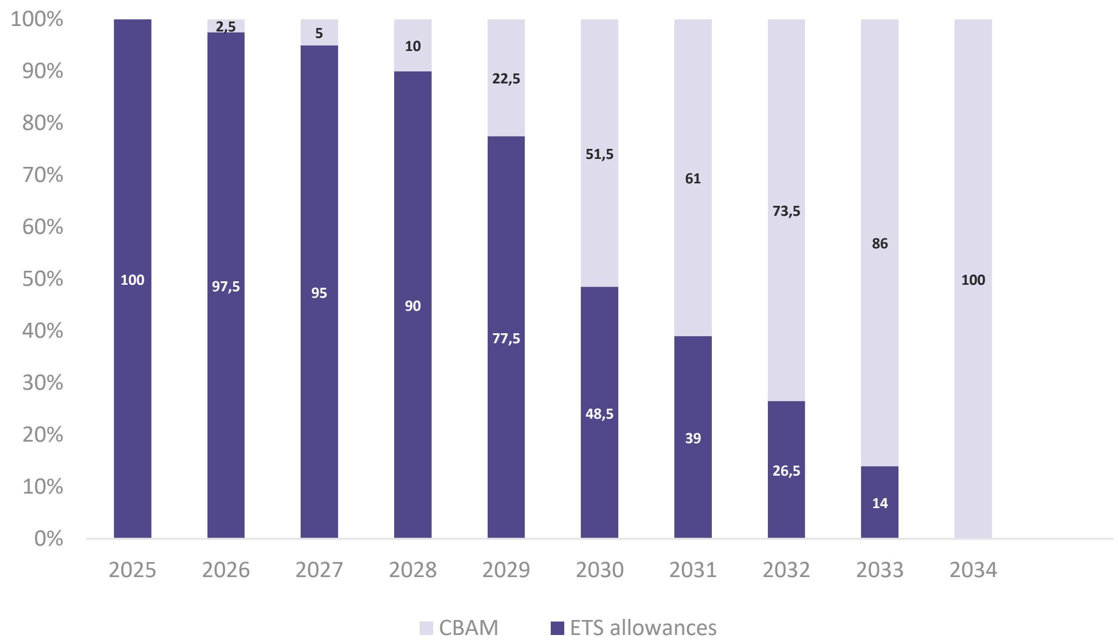
The CBAM is thus being phased in as the new mechanism to address the risk of carbon leakage. The CBAM will put a price on carbon emitted during the production of carbon intensive goods entering the EU. As such, the CBAM regulation has three stated aims.

1. Improving the market-based incentives for EU industry to decarbonise, in line with the ambitions of the EU Green Deal.
2. Prevent the risk of carbon leakage from industries within scope.
3. Encourage producers from third countries to use technologies that are more efficient in reducing emissions.

[3] European Commission (2021). Update of benchmark values for the years 2021 - 2025 of phase 4 of the EU ETS. Available at: https://climate.ec.europa.eu/system/files/2021-10/policy_ets_allowances_bm_curve_factsheets_en.pdf

[4] Regulation 2023/956

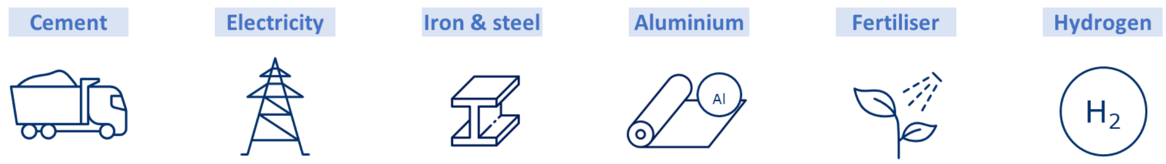
Figure 1: ETS Free Allocation phase-out and CBAM phase-in - %



Source: Regulation (EU) 2023/956

The CBAM includes a transitional phase from 2023 to 2025, where specific products within the categories in Figure 2 are within scope. Importers of these products are obligated to report the embedded direct and indirect emissions during the transitional phase. From 2026 onwards, importers will be required to acquire CBAM certificates, thus actually paying for the emissions from imported products. The price of these certificates will be calculated based on the weekly average auctioning price of the EU ETS allowances.

Figure 2: CBAM product categories



Direct emissions are the emissions generated during the production process, including from the production of heating and cooling. **Indirect emissions** are emissions from the electricity consumed during the production of the good. For complex goods under the CBAM regulation, the embedded direct and/or indirect emissions of relevant **precursor goods** are also included. A relevant precursor good is a raw material used in the production of a CBAM good, when that raw material is also a product under the CBAM scope. For simple goods, precursors do not apply.

Geographic scope of the CBAM

The CBAM regulation applies to imports into the EU from non-EU countries, but not imports from the countries in the European Free Trade Association (EFTA), namely Norway, Iceland, Switzerland and Liechtenstein.

Norway, Iceland and Liechtenstein are also a part of the European Economic Area (EEA), which has yet to formally decide to incorporate the CBAM.[5] Switzerland has decided to abstain from introducing a CBAM for now. For the purposes of this study, it will be assumed that Norway, Iceland and Liechtenstein will adopt the CBAM, so imports into these countries will fall within scope of the regulation.

2.2 The CBAM on aluminium products

The current CBAM scope addresses electricity, steel, aluminium, cement, fertilisers and hydrogen, where each product category has its own specifications. There are three key features that distinguish how the regulation applies. These are:

1. The specific **products** that are in scope.
2. The **types of emissions** that require CBAM certificates.
3. Which **emissions sources** are within scope.

Product scope

The CBAM on aluminium currently includes unwrought aluminium and aluminium semi-finished products as well as a few finished goods. These are designated by their trade codes.

Table 1: CBAM on aluminium products list

CN Code	Greenhouse Gas
7601– Unwrought aluminium	Carbon dioxide and perfluorocarbons
7603– Aluminium powders and flakes	Carbon dioxide and perfluorocarbons
7604– Aluminium bars, rods and profiles	Carbon dioxide and perfluorocarbons
7605– Aluminium wire	Carbon dioxide and perfluorocarbons
7606– Aluminium plates, sheets and strip, of a thickness exceeding 0,2 mm	Carbon dioxide and perfluorocarbons
7607– Aluminium foil (whether or not printed or backed with paper, paper- board, plastics or similar backing materials) of a thickness (excluding any backing) not exceeding 0,2 mm	Carbon dioxide and perfluorocarbons
7608– Aluminium tubes and pipes	Carbon dioxide and perfluorocarbons
7609 00 00– Aluminium tube or pipe fittings (for example, couplings, elbows, sleeves)	Carbon dioxide and perfluorocarbons
7610– Aluminium structures (excluding prefabricated buildings of heading 9406) and parts of structures (for example, bridges and bridge-sections, towers, lattice masts, roofs, roofing frameworks, doors and windows and their frames and thresholds for doors, balustrades, pillars and columns); aluminium plates, rods, profiles, tubes and the like, prepared for use in structures	Carbon dioxide and perfluorocarbons
7611 00 00– Aluminium reservoirs, tanks, vats and similar containers, for any material (other than compressed or liquefied gas), of a capacity exceeding 300 litres, whether or not lined or heat-insulated, but not fitted with mechanical or thermal equipment	Carbon dioxide and perfluorocarbons
7612– Aluminium casks, drums, cans, boxes and similar containers (including rigid or collapsible tubular containers), for any material (other than compressed or liquefied gas), of a capacity not exceeding 300 litres, whether or not lined or heat-insulated, but not fitted with mechanical or thermal equipment	Carbon dioxide and perfluorocarbons

[5] Norway announced a CBAM introduction, official statements from Iceland and Liechtenstein are pending

7613 00 00– Aluminium containers for compressed or liquefied gas	Carbon dioxide and perfluorocarbons
7614– Stranded wire, cables, plaited bands and the like, of aluminium, not electrically insulated	Carbon dioxide and perfluorocarbons
7616– Other articles of aluminium	Carbon dioxide and perfluorocarbons

Source: Regulation (EU) 2023/956 Annex I

Emissions scope

Emissions of carbon dioxide and perfluorocarbons are within scope for aluminium products.

Emissions sources

Importers of aluminium will only have to declare and acquire CBAM certificates for direct emissions when it comes into effect in 2026. In other words, indirect emissions related to electricity consumed in the production process is not included for aluminium, distinguishing it from some of the other product categories.

2.3 Initially identified concerns about CBAM for the aluminium industry

The current design of the CBAM on aluminium raises several concerns from the industry, which are summarized below. Foundational to these concerns is that the carbon costs on aluminium, through the ETS for domestic production and the CBAM for imports, will raise the marginal aluminium price in the EU+EFTA.

Destruction of downstream competitiveness

With a higher primary aluminium price, costs are passed down the value chain and will likely lead to a destruction of downstream industry competitiveness, relative to imports. European installations will be required to absorb ETS costs on their full production volume, while 3rd country importers can decide what percentage of their production volume is to be exported to the CBAM jurisdiction.

De-industrialisation

At the current design no final goods are included within the CBAM scope, so there is a risk that downstream manufacturing will move outside the EU. To illustrate, an automotive manufacturer could potentially save costs by manufacturing cars in a location outside the EU, where the aluminium content would not bear a carbon cost upon import or local production, thereby lowering the overall cost of production. The scope of CBAM might eventually change to include final products[6], although this will also likely increase the complexity of the emissions calculations, as emissions will have to be traced back along the value chain.

Substitution with alternative materials

Use of aluminium can be substituted, in some sectors, by plastics or copper. For example, plastics and alumina compete in the packaging market and copper competes within electrical. Neither plastics nor copper products are included within the initial CBAM scope and could potentially see increased use because of higher aluminium costs.

[6] In October 2024, the European Commission Directorate-General for Taxation and Customs Union (TAXUD) conducted a survey gathering stakeholder evidence for a study on a potential CBAM scope extension to downstream products.

Potential for circumvention

Another concern is that foreign aluminium producers will adopt production and export strategies to circumvent the CBAM. One circumvention strategy would be to increase the proportion of scrap in aluminium products that are exported to the EU. Because scrap is not a precursor within the current CBAM scope, scrap content carries zero embedded emissions. Circumvention through scrap is further investigated as one of the main objectives of this study. If indirect emissions are included in the CBAM scope for aluminium, another viable circumvention strategy would be to reshuffle, so production using low-carbon electricity sources is exported to the EU and high-carbon production is reserved for other markets.

Reduced competitiveness of European companies on export markets

The CBAM addresses the competitiveness of importers compared to domestic EU production but does not compensate for EU producers that export to other countries. Aluminium producers or manufacturing companies that rely on aluminium will not be cost competitive with foreign producers from countries with lower carbon costs.

Potential inclusion of indirect emissions and indirect ETS cost for European producers

The current CBAM scope excludes indirect emissions for aluminium under CBAM. Including indirect emission could significantly increase CBAM fees, due to the high electricity demand and emissions intensity of aluminium smelting. For reference EU average direct emissions from primary aluminium are 1.87 t CO2e/t aluminium, while the inclusion of indirect emissions would result in an additional average 3.86 t CO2e/t aluminium. The inclusion of indirect emissions creates additional imbalances between 3rd country producers and EU+EFTA producers, due to the electricity price setting mechanisms in Europe.

Potential inclusion of alumina as a product and precursor to primary aluminium

Alumina might be added to the CBAM as a product and as a precursor to aluminium, as the CBAM scope increases. This would be beneficial for EU alumina refineries, because importers of alumina would have to pay carbon costs similar to those paid by EU refineries, but it could also raise costs and increase circumvention risk from foreign producers for the producers further downstream. This concern is investigated in further detail as part of this study.

2.4 CBAM calculations and dependencies for this study

At the writing of this report (February 2025) the remaining legislative CBAM process leaves some uncertainties about the calculation of CBAM fees, as Implementing Acts of the CBAM, have still to be published. Most uncertainties lie in the assumptions made about the reduction of the benchmark values for the European ETS beyond 2025. Additionally, the CBAM product benchmarks have not been published at this point. This study derived benchmarks based on existing ETS benchmarks and process energy intensities.

The calculation of the CBAM fee consists of several variables. The general formula for calculating the CBAM fee can be calculated as follows:

$$CBAM\ fee = \left[EF_{non-EU\ import} - CBAM\ Factor_{import\ year} * \ FAB_{product}\right] \\ * EUA\ price_{\ weekly\ average} - \ EF_{non\ EU\ import} * 3^{rd}\ country\ carbon\ price$$

The full description of the variables can be found below in Table 2.

Table 2: Variables for CBAM fee calculation

Variable relevant	Full description and effect on CBAM impact	Unit
CBAM fee	Full import fee due at border for importing products in CBAM scope.	*EUR/ton*
EF $_{\text{non-EU import}}$	Emission Factor of non-EU import, based on the declared emission intensity of the product imported.	*t CO2/ ton product*
CBAM Factor $_{\text{import year}}$	Free allocation factor applied based on phase-in of CBAM from 2026 to 2034 (e.g. 97,5% in 2026, 0% in 2034).	*%*
FAB $_{\text{product}}$	Specific free allocation benchmark applied to imported product, mirroring set ETS benchmarks.	*t CO2/ ton product*
EUA price $_{\text{weekly average}}$	Specific price of the EU Allowances under the ETS setting the price per ton of CO2. Based on the variable dynamics EUA price.	*EUR/ton*
3rd country carbon price	Carbon price paid in 3rd country, deducted from CBAM fee.[7]	*EUR/ton*

Source: Ramboll definitions, based on EU Regulation and CBAM questionnaire

Following the introduction curve of CBAM, calculated CBAM fees and ETS costs for domestic production are driven by 2 main factors:

1. The remaining free allocation benchmarks, that become increasingly irrelevant
2. The future development of the EUA price

Whereas companies will be required to buy more ETS allowances/CBAM certificates at a higher price from 2026 to 2034. After 2034 price increases will only be driven by the increasing allowances price, except products that might be introduced under CBAM at a later stage.

[7] There are a few pending global carbon taxation schemes (e.g. China) those have not been investigated in further detail as part of this study.

3. The Aluminium Value Chain Globally and in the EU+EFTA

The aim of this chapter is to firstly describe the uses and value of aluminium in the context of the EU economy and provide an overview of the aluminium value chain.

Secondly, this chapter includes a deep dive into each of the main stages in the value chain. These deep dives describe the main processes, provide an overview of global production, and evaluate current EU production and trade.

3.1 The importance of aluminium in the EU economy

Aluminium is a metal with a wide range of uses, due to its favourable chemical and physical properties. It is versatile, meaning it can be processed and manufactured into a variety of shapes and sizes. Additionally, it is lightweight, resistant to corrosion, a good electrical and heat conductor, highly reflective, odourless, water resistant and highly recyclable. As a result, aluminium is an extensively used material in a variety of industries, including transportation, electrical equipment, electronics, packaging and construction[8].

The importance of aluminium to the EU economy has been highlighted by policymakers. The European Commission has established a priority, within the area of raw material policy, to pursue access to non-energy raw materials, diversify supply sources and reduce import dependencies. Critical raw materials are those that are of high economic importance and at risk of supply disruption. The Commission added bauxite, alumina and aluminium to the EU list of critical raw materials for the first time in 2020 and included it on the updated list in 2023[9]. Furthermore, NATO has identified aluminium as a defence critical raw material[10].

In sum, aluminium is an important material across the EU economy and EU policymakers have already identified a need to secure aluminium value chains and reduce supply dependencies. To help achieve these aims, it is crucial that the CBAM on aluminium is designed to protect European industry.

3.2 Overview of the aluminium value chain

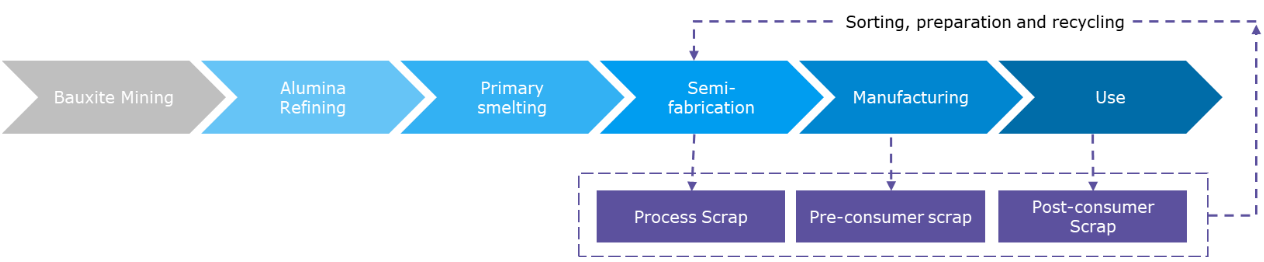
The aluminium value chain begins with mining of the raw material, followed by refining, smelting fabrication, manufacturing, use and recycling. This is illustrated in Figure 3. The value chain has an added complexity because aluminium scrap is generated and recycled at several stages. The following sections of this chapter will elaborate on each stage of the value chain globally and in the EU.

[8] European Aluminium (2023). Net-zero by 2050: Science-based decarbonisation pathways for the European aluminium industry. Available at: https://european-aluminium.eu/blog/netzeroby2050/

[9] DG GROW (2023). Study on the Critical Raw Materials for the EU 2023 – Final Report. Available at: https://single-market-economy.ec.europa.eu/publications/study-critical-raw-materials-eu-2023-final-report_en

[10] NATO (2024). NATO releases list of 12 defence-critical raw materials. Available at: https://www.nato.int/cps/en/natohq/news_231765.htm

Figure 3: Aluminium value chain

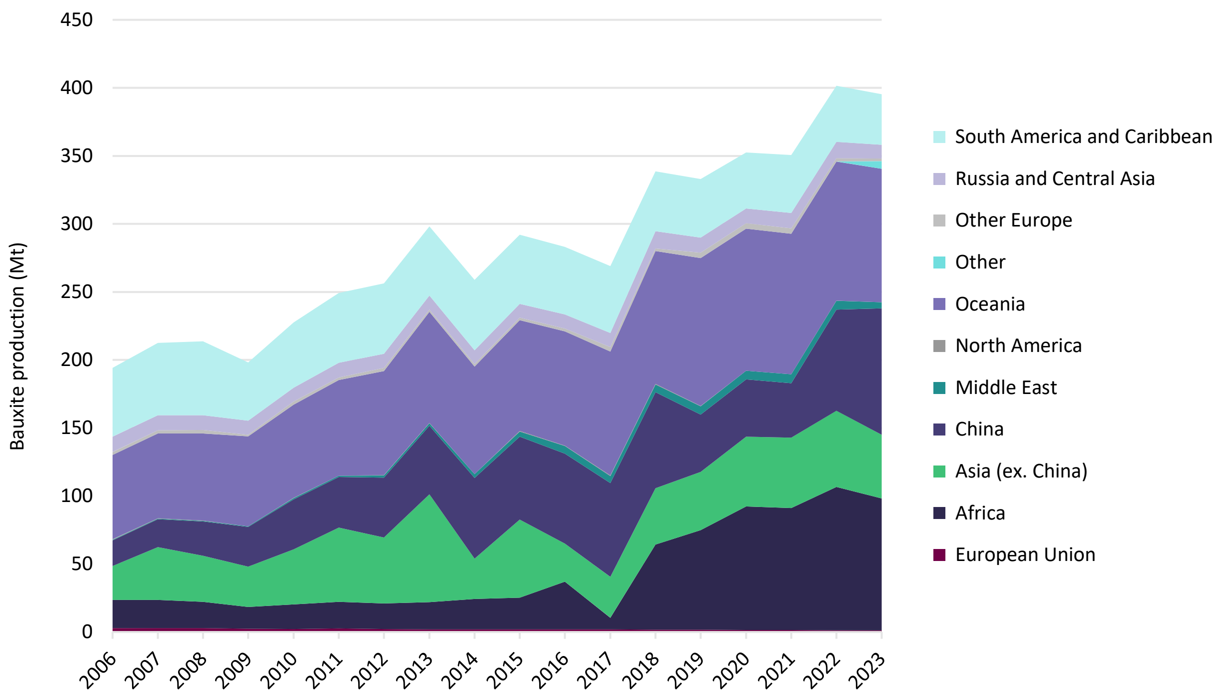


Source: Ramboll analysis

3.3 Bauxite

Bauxite is the most commonly mined ore to produce aluminium. Bauxite mining globally is increasing, and total global production doubled between 2006 and 2023, from about 200 million tonnes to about 400 million tonnes. Oceania and Sub-Saharan Africa are the largest bauxite mining regions and the regions with the largest known bauxite reserves.

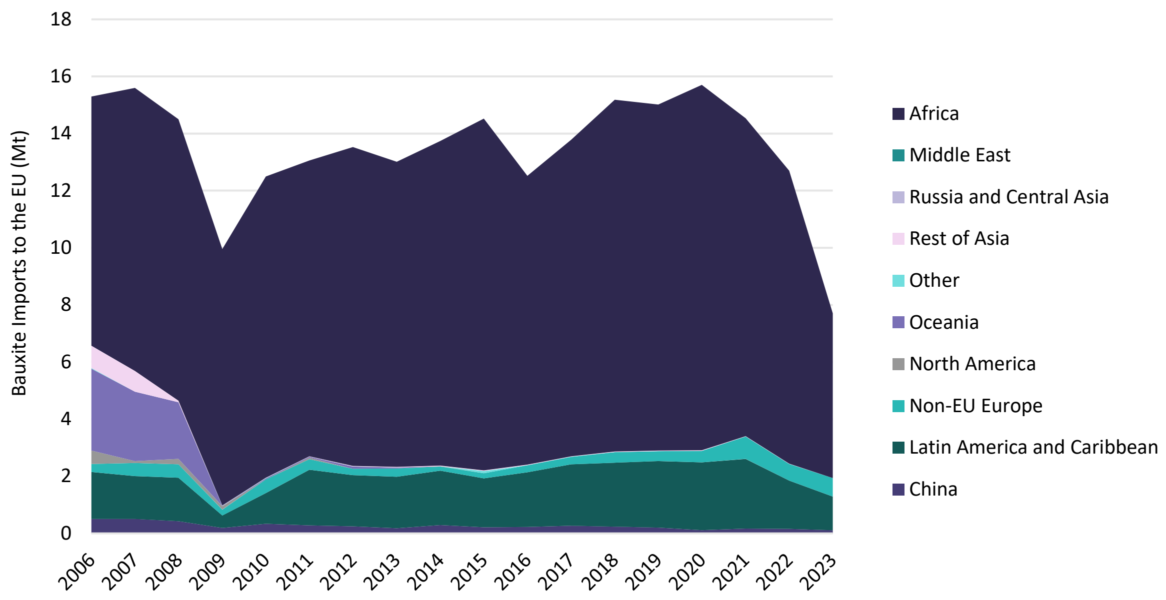
Figure 4: Global Bauxite Production



Source: British Geological Survey & US Geological Survey

There is some bauxite mining in Europe, although it has been decreasing over the last 20 years. Annual output in the EU more than halved between 2006 and 2023, from 2.9 million metric tonnes per year to 1.2 million metric tonnes.

Figure 5: EU Bauxite Imports



Source: UN Comtrade - HS 260600 (aluminium ores and concentrates)

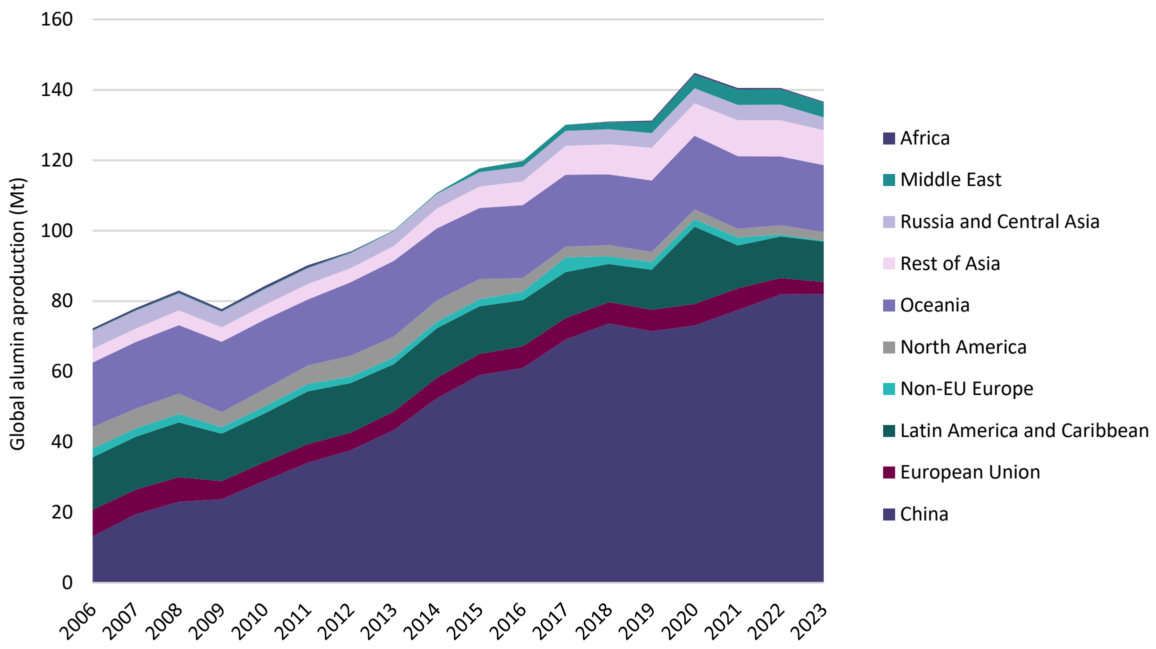
The EU primarily imports bauxite from Guinea in West Africa. These imports have been fairly stable over the last twenty years, although there was a significant drop in 2023, due to falling demand. The second most important region for imports to the EU are Latin America and the Caribbean, where Brazil and Jamaica are the most important sources.

3.4 Alumina

In the second step of the aluminium value chain, bauxite is refined into aluminium oxide using the Bayer process, most commonly known as alumina. There are other processes to obtain alumina from metal ores, but the Bayer process is the most economically viable and other methods make up a small percentage of global production[11].

[11] Brough, D. & Jouhara, H. (2020). The aluminium industry: A review on state-of-the-art technologies, environmental impacts and possibilities for waste heat recovery. *International Journal of Thermofluids.* Available at: https://doi.org/10.1016/j.ijft.2019.100007

Figure 6: Global alumina production



Source: British Geological Survey & US Geological Survey

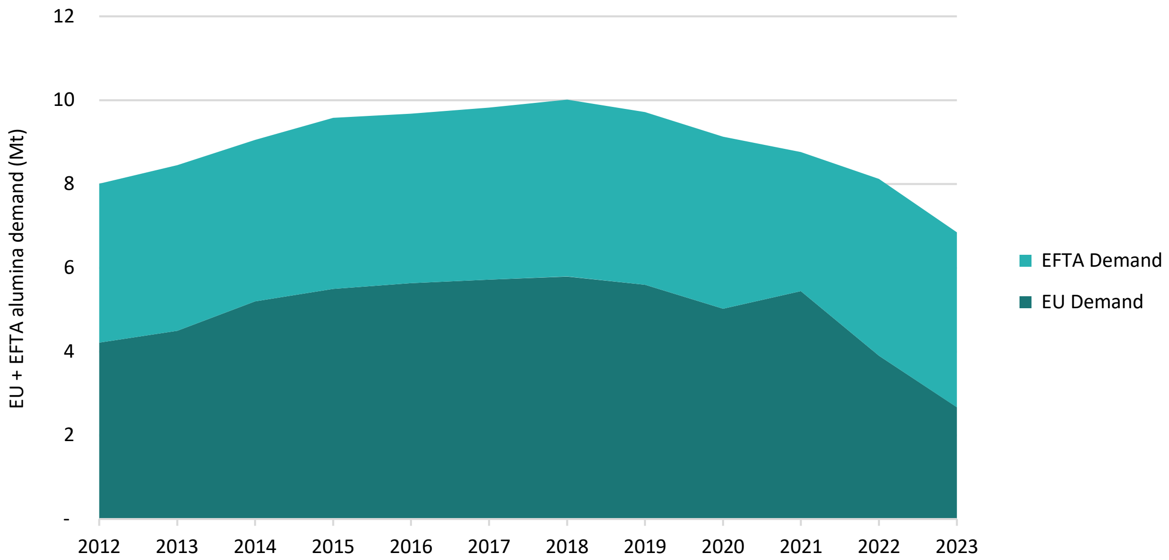
In 2023, about 138 million tonnes of alumina was refined globally, of which 60% was refined in China. Other countries with significant production are Australia, Brazil and increasingly, India. Total global production has increased with a 3.9% compound annual growth rate between 2006 and 2023.

In the EU, there were six alumina refineries with a total output capacity of 6.8 million tonnes of alumina per year, at the start of 2021. However, rising energy prices have led to two recent closures and the curtailment of another, which is now only operating at 50% capacity[12]. As a result, 2023 production was only 3.4 million tonnes, at a steep decline from the 6.2 million tonnes of production in 2021.

The EU has been a net exporter of alumina since 2011 and has seen a sharp drop in demand since 2021. The EU imports very limited amounts of alumina from the rest of the world, and increasingly exports to aluminium smelters in Norway, Iceland and Russia. This is because Norway and Iceland have significant primary aluminium production capacity, but no alumina refineries of their own.

[12] Joint Research Centre (2024). Decarbonisation Options for the Aluminium Industry. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC136525

Figure 7: EU and EFTA alumina demand



Source: British Geological Survey & UN Comtrade - HS 281820 (aluminium oxide, other than artificial corundum)

Alumina is a highly traded commodity with a set market set price. Many refineries are vertically integrated with Bauxite mines and/or aluminium smelters, to ensure their raw-material demand and offtake. Other alumina refineries operate independently on the market.

Table 3: European alumina refineries

Refinery	Country	Approximate 2023 Production (tonnes)
Distomon	Greece	869,000
Stade	Germany	332,963
Aughinish	Ireland	1,385,000
San Ciprian	Spain	640,000
Tulcea	Romania	(closed)
Gardanne	France	(not producing metallurgical alumina anymore)

Source: Joint Research Centre, 2024; Interviews with alumina producers[13]

In sum, the alumina industry in Europe is challenged by energy prices and has seen a drop in production as a result.

3.5 Primary Aluminium

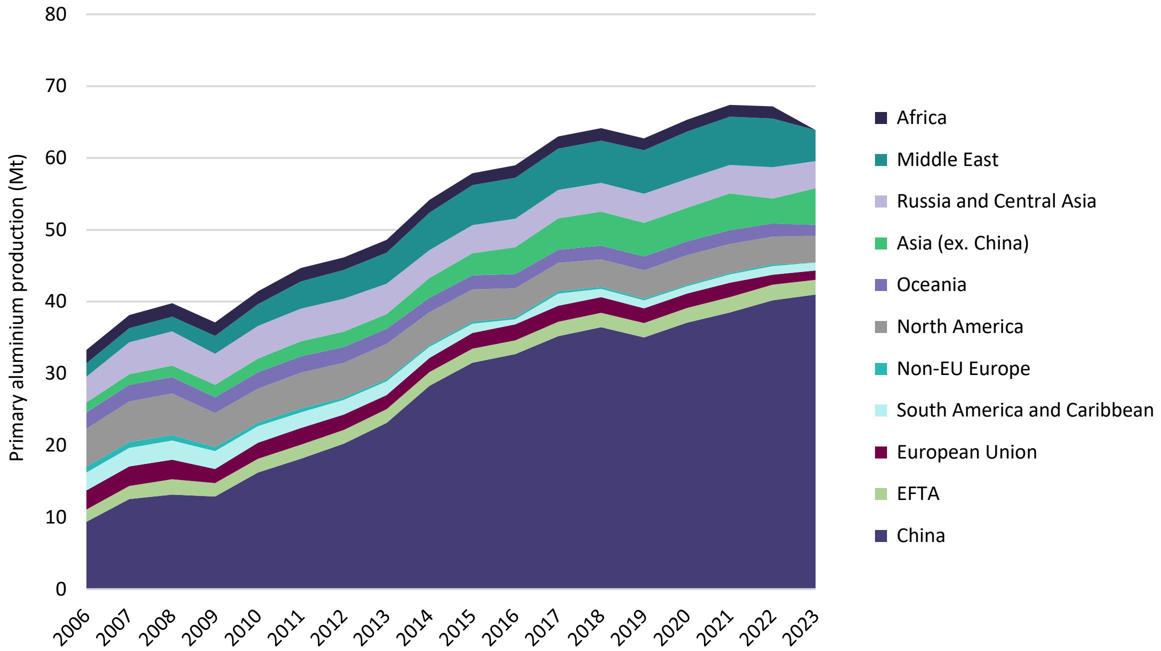
Primary aluminium producers use alumina as their primary raw material, and smelter it into liquid aluminium by the Hall-Héroult electrolysis process, which uses electricity to break the chemical bonds between aluminium and oxygen. The output at this stage is called 'primary' aluminium to distinguish it from secondary, or recycled, aluminium.

Globally, primary aluminium production has increased at a rate similar to that of alumina and bauxite, mainly driven by increases in Chinese production. Total global production of primary aluminium in 2023 was 71 million tonnes, compared to 33 million tonnes in 2006, resulting in a 4.5% compound

[13] Production numbers are approximate values, exact values reported by specific producers may differ.

annual growth rate for the period. More than half of global primary aluminium production, 58%, was in China in 2023.

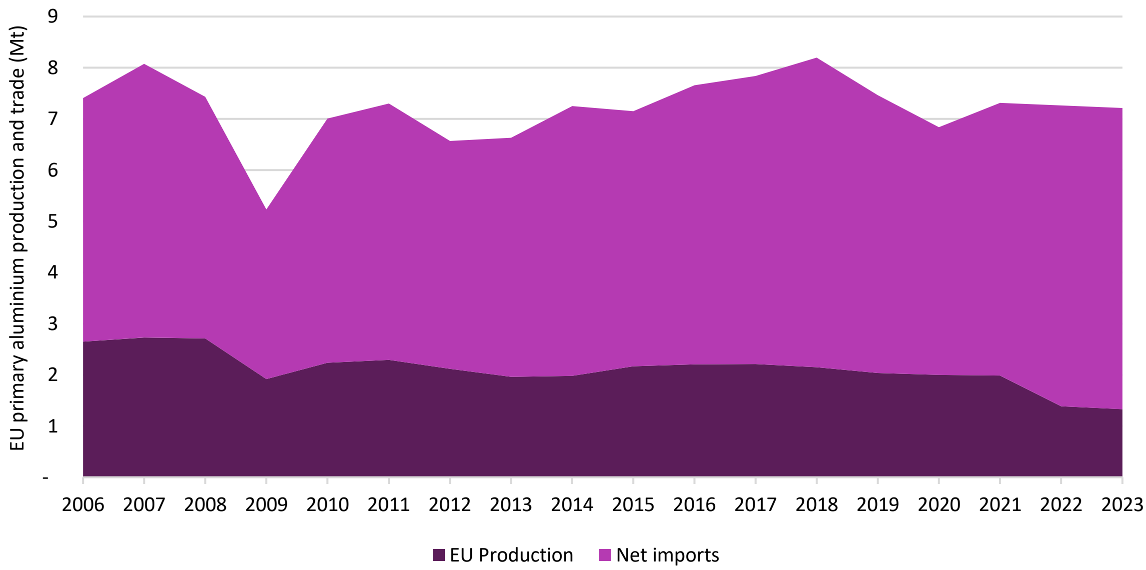
Figure 8: Global primary aluminium production



Source: British Geological Survey & US Geological Survey

In the EU, there were 13 primary aluminium smelters at the beginning of 2022, but five of these closed or halted operations in 2022 and 2023, resulting in eight currently operational primary smelters. In 2021, the EU produced 2 million tonnes of primary aluminium, compared to only 1.3 million tonnes in 2023, or a 35% decrease.

Figure 9: EU primary aluminium production and net imports



Source: British & US Geological Surveys and UN Comtrade

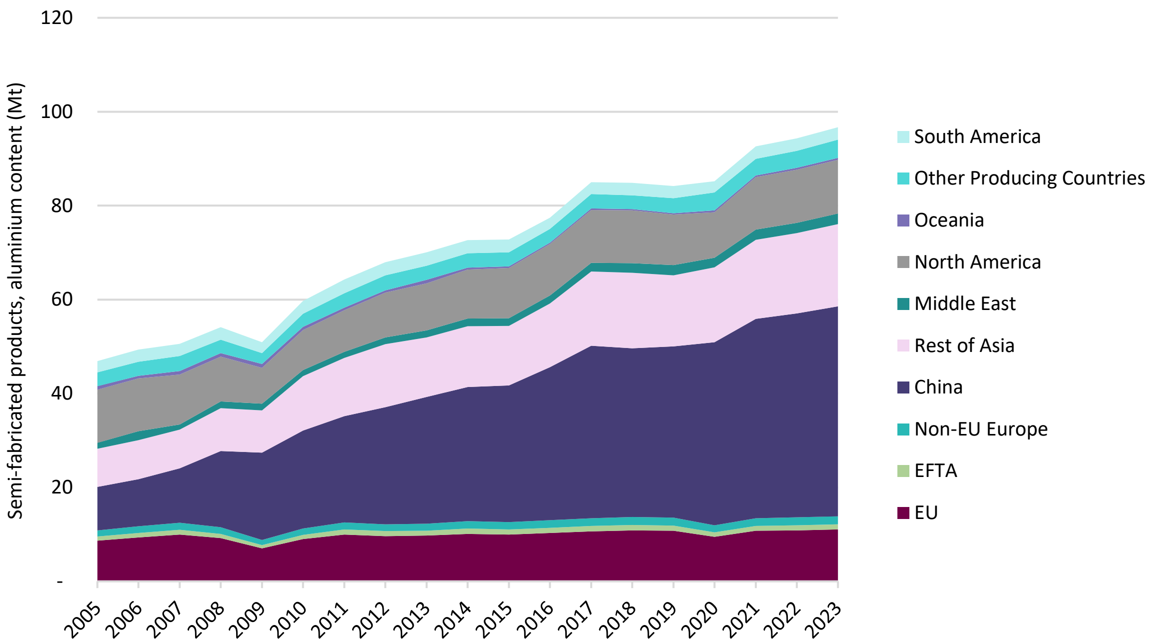
Primary production is decreasing, but demand remains stable and is increasingly met by imports. In 2023, net imports of primary aluminium were 5.8 million tonnes. Thus, overall demand for primary aluminium was about 7.2 million tonnes. The most important regions for EU imports were the Middle East and the EFTA countries, meaning Norway and Iceland.

While several primary smelters in the EU have closed or reduced output, the 10 Norwegian and Icelandic producers have maintained stable output at a total of about 2 million tonnes annually, for the last ten years. Their stable production allows them to export the majority of their primary production to the EU.

3.6 Semi-fabrication and process scrap generation

The next step in the aluminium value chain is fabrication of semi-finished products. Semi-finished fabricators purchase aluminium ingots, slabs or molten aluminium from smelters or recyclers, as the inputs to semi-fabrication can be primary or secondary aluminium. This material will then be rolled, extruded or cast into the desired fabrications, which are not yet ready for final use by an end-consumer.

Figure 10: Global production of semi-fabricated products



Source: IAI Global Aluminium Cycle Model

During the semi-fabrication process, surplus material is generated, which is known as **process scrap**, but also as internal scrap or runaround scrap. This material usually stays within the semi-fabrication installation and is reused directly within the same process. However, it may be traded in some instances, especially if a semi-fabrication installation does not have integrated recycling capacity. Because of this distinction, there is no industry consensus as to whether process scrap is material recovered from a waste stream – where remelting it results in a secondary material, or just a co-product of the semi-fabrication process.[14]

[14] International Aluminium Institute (2023). Reference document on how to treat scrap flows in carbon footprint calculations for aluminium products. Available at: https://international-aluminium.org/wp-content/uploads/2022/09/Carbon-footprint-of-recycled-aluminium-IAI-Document-Public-Review-Final.pdf

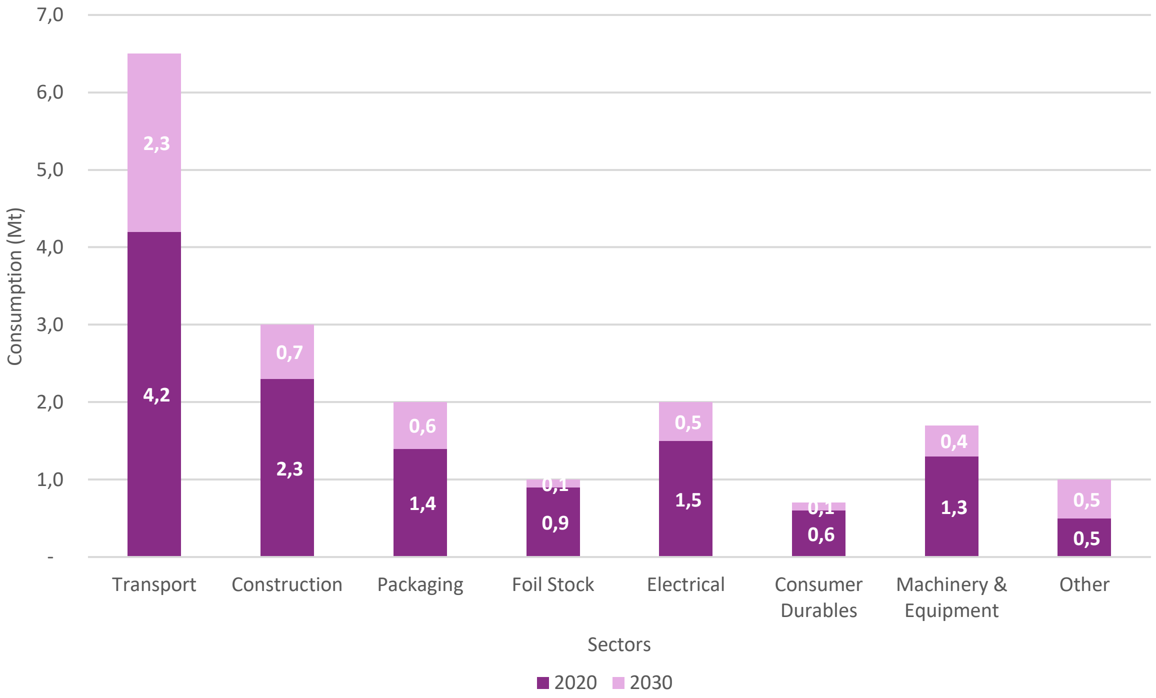
The IAI estimates a consistent level of process scrap generation across regions, although it varies between the type of semi-fabricated product. On average, for every 4 tonnes of semi-fabricated product, 1 tonne of process scrap is generated.

3.7 Manufacturing and manufacturing scrap

Aluminium semi-fabricated products are used as material inputs for manufacturing of final goods. Consumption of semi-fabricated products is split across the sectors transport, electrical, construction, machinery & equipment, packaging, consumer durables and other uses.

The global demand of aluminium is expected to grow by 33.3 Mt, going from 86.2 Mt in 2020 to 119.5 Mt in 2030, where 14% of this growth is expected to come from Europe. In Europe, the majority of aluminium is consumed from the transportation sector, which uses 33% of total demand, followed by construction (18%), electrical (12%), and packaging (11%)[15].

Figure 11: Sector distributed consumption of semi-finished aluminium products in Europe, 2020 vs. 2030



Source: CRU Consulting, 'Opportunities for aluminium in a post-covid economy'

The transportation sector is also expected to be the most important source of growth in demand. The lightweight nature of aluminium is considered essential for the transportation sector to improve its energy efficiency[16]. Additionally, the shift to electrical vehicles (EVs), is expected to drive demand in the sector.

[15] CRU Consulting (2022). Opportunities for aluminium in a post-Covid economy. Available at: https://international-aluminium.org/resource/opportunities-for-aluminium-in-a-post-covid-economy/

[16] Al-Alimi, S. (2024) Recycling aluminium for sustainable development: A review of different processing technologies in green manufacturing. *Results in Engineering.* Available at: https://doi.org/10.1016/j.rineng.2024.102566

When final products are manufactured from aluminium, scrap is generated. Examples include clippings, trimmings, offcuts or the skeleton remaining after can lids are stamped. Based on the IAI aluminium model, it is estimated that for every five tonnes of aluminium in manufactured final products, one tonne of scrap is generated, although the amounts generated vary across sectors and geographies. The amount of scrap generation can vary significantly from industry to industry, based on company efficiencies, but also the shape and size of product outputs. For example, a large sheet manufacturer estimates that for every aluminium sheet sold to an automotive manufacturer, about 30-40% becomes scrap. This scrap is valuable material and is often directly transferred back to the semi-fabricator under specific agreements and contracts to be remelted and turned into a new sheet. Otherwise, the scrap is sold on an open scrap market. For the purposes of this paper – the term **pre-consumer scrap** will be used to describe this type of scrap, which is material diverted from a waste stream during the manufacturing process[17].

3.8 Aluminium recycling

Aluminium scrap can be generated and recycled several times, before and after use of a final product, resulting in secondary aluminium. The recycling process requires a fraction of the energy that is needed to produce primary aluminium. Industry and scholarly consensus are that secondary aluminium production requires only about 5% of the energy required for primary aluminium[18]. Furthermore, the atomic structure of the metal is not affected by recycling, so it is endlessly recyclable. As a result, aluminium scrap retains a high economic value, and recycling occurs because it is economically advantageous. An estimated 75% of historically produced aluminium is still in circulation today. From an economic perspective, this means that secondary aluminium competes with primary aluminium, and prices are linked[19].

Pre-consumer scrap recycling

Pre-consumer scrap, which consists of scrap arising from the manufacturing process, usually has a known quality and alloy, and can be melted with little preparation, particularly if a closed loop recycling system is in place. These closed loops require the right processes, tools and infrastructure, and the right mindset to ensure the scrap is not mixed with other materials, and to keep the different alloys separate from each other. If there is no closed-loop recycling system with good sorting, the pre-consumer scrap can also be sold to traders. The cleaner the pre-consumer scrap, the more valuable and the closer the price is to the price of primary aluminium[20].

Secondary producers will often make agreements with fabricators and manufacturers to acquire pre-consumer scrap. The exact nature of these agreements depends on the level of integration between different parts of the value chain. We observed three types of secondary aluminium producer, each acquiring pre-consumer scrap through slightly different methods:

- Individual secondary producers, not integrated, will purchase scrap at favourable prices and recycle in their facilities to sell unwrought secondary aluminium.

[17] International Aluminium Institute (2023). Reference document on how to treat scrap flows in carbon footprint calculations for aluminium products. Available at: https://international-aluminium.org/wp-content/uploads/2022/09/Carbon-footprint-of-recycled-aluminium-IAI-Document-Public-Review-Final.pdf

[18]Brough, D. & Jouhara, H. (2020). The aluminium industry: A review on state-of-the-art technologies, environmental impacts and possibilities for waste heat recovery. *International Journal of Thermofluids*. Available at: https://doi.org/10.1016/j.ijft.2019.100007

[19] Blomberg, J. & Söderholm, P. (2009). Essays on the economics of the aluminium industry. *Resources, conservation and recycling.* https://doi.org/10.1016/j.resconrec.2009.03.001

[20] European Aluminium (2018). Environmental Profile Report: Life-Cycle inventory data for aluminium production and transformation processes in Europe. Available at: https://european-aluminium.eu/blog/environmental-profile-reports/

- Some primary producers also have recycling capacity – they have negotiated agreements with their customers to take back their scrap, recycle and return it as unwrought aluminium, or they purchase scrap on the open market to recycle.
- Semi-fabrication companies often have integrated recycling capacity and make agreements to take back pre-consumer scrap from their customers. They might also buy scrap in open markets to make up the balance.

Because agreements between secondary aluminium producers and nearby manufacturers are common, pre-consumer scrap most often stays close to where it was generated. In other words, most pre-consumer scrap does not travel between geographical regions.

In addition to purchasing scrap, secondary producers will purchase some primary ingots, alloying elements and liquid aluminium as inputs, to adjust the recycled mix and produce output with the desired quality and alloy specifications. Recycled aluminium then becomes an input for semi-fabricated products. The exact pre-consumer scrap content in a semi-fabricated product varies between product types and regions. Table 4 contains the estimated amounts of pre-consumer scrap content, by mass, in a semi-fabricated product produced in each region, in 2023.

Table 4: Pre-consumer scrap content in semi-fabricated products

Region	Percentage	Tonnes
EU	14%	1,560,527
EFTA	13%	137,767
Other Europe	16%	286,164
China	17%	7,563,653
Rest of Asia	16%	2,727,632
Middle East	8%	175,141
North America	19%	2,189,046
Oceania	4%	17,705
South America & Caribbean	18%	712,307
Other	14%	381,877

Source: IAI Global Aluminium Cycle Model

Post-consumer scrap recycling

Post-consumer scrap comes back into the aluminium industry from a variety of sources. The process involves a diffuse network of metal merchants and waste management companies that collect, and prepare aluminium from, among others, vehicles, industrial waste and household waste. In contrast to pre-consumer scrap, there is a significant time lag between the manufacturing step and post-consumer scrap recycling. While some manufactured products, such as aluminium beverage cans, are used and become scrap within a few months, aluminium content in buildings and transportation applications are typically in use for decades. Across all uses, industry experts have estimated that there is a weighted average of 25-30 years between manufacturing and post-consumer scrap collection[21].

Currently, the transportation and construction industries are among the best performers when it comes to collecting post-consumer aluminium. In the transportation industry, vehicle parts are shredded, where wrought and cast aluminium alloys are mixed. Due to difficulty of distinguishing and separating the type of alloys, aluminium scrap from vehicles is often only used to produce cast aluminium for new car parts, and not applicable in other industries. Aluminium scrap from the

[21] European Aluminium (2018). Environmental Profile Report: Life-Cycle inventory data for aluminium production and transformation processes in Europe. Available at: https://european-aluminium.eu/blog/environmental-profile-reports/

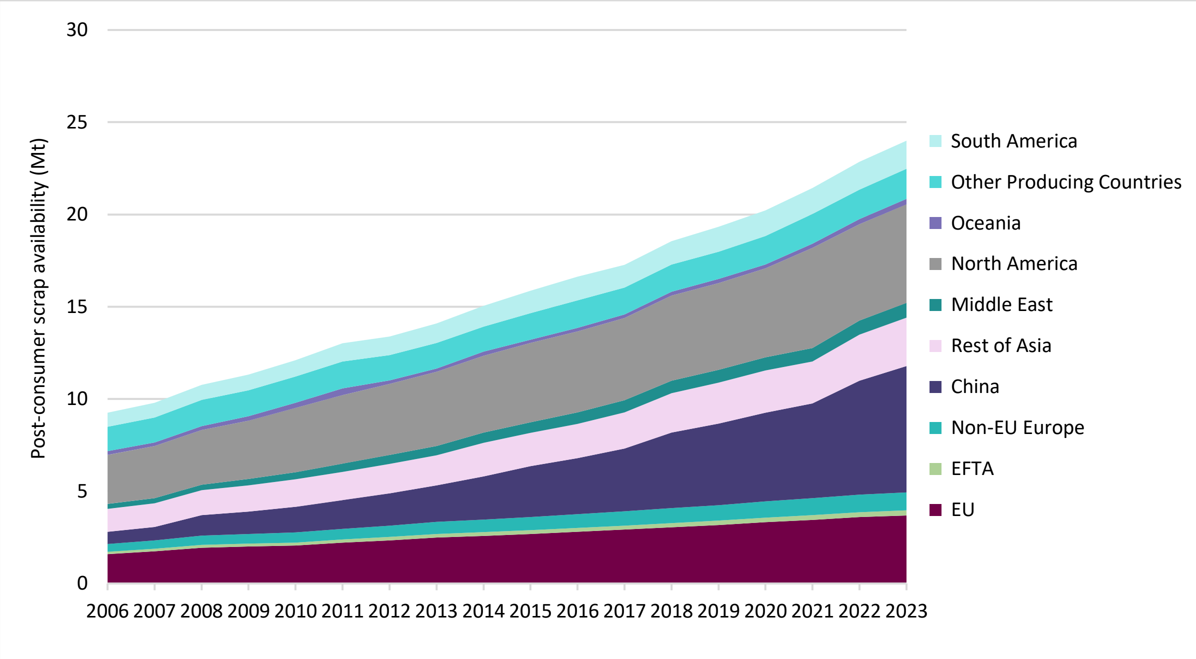
construction industry is mostly dominated by low-alloyed aluminium that can easily be recycled for use in the same applications.

Post-consumer aluminium scrap collection rates have also been increasing in the packaging industry, especially for aluminium cans. In the EU, extended producer responsibility schemes have significantly increased collection and recycling rates for aluminium packaging. However, there are still issues in many countries where sorting and separation are done manually, leading to lower efficiency of recycling[22].

The preparation and efficiency of post-consumer recycling depends largely on the scrap origin and quality. It generally requires a more rigorous treatment before recycling because the composition is more complex and less well-known[23].

Looking at the distribution of post-consumer scrap collection between regions, North America and China generate and collect the most post-consumer scrap, i.e. they have the most available post-consumer scrap.

Figure 12: Global post-consumer scrap availability



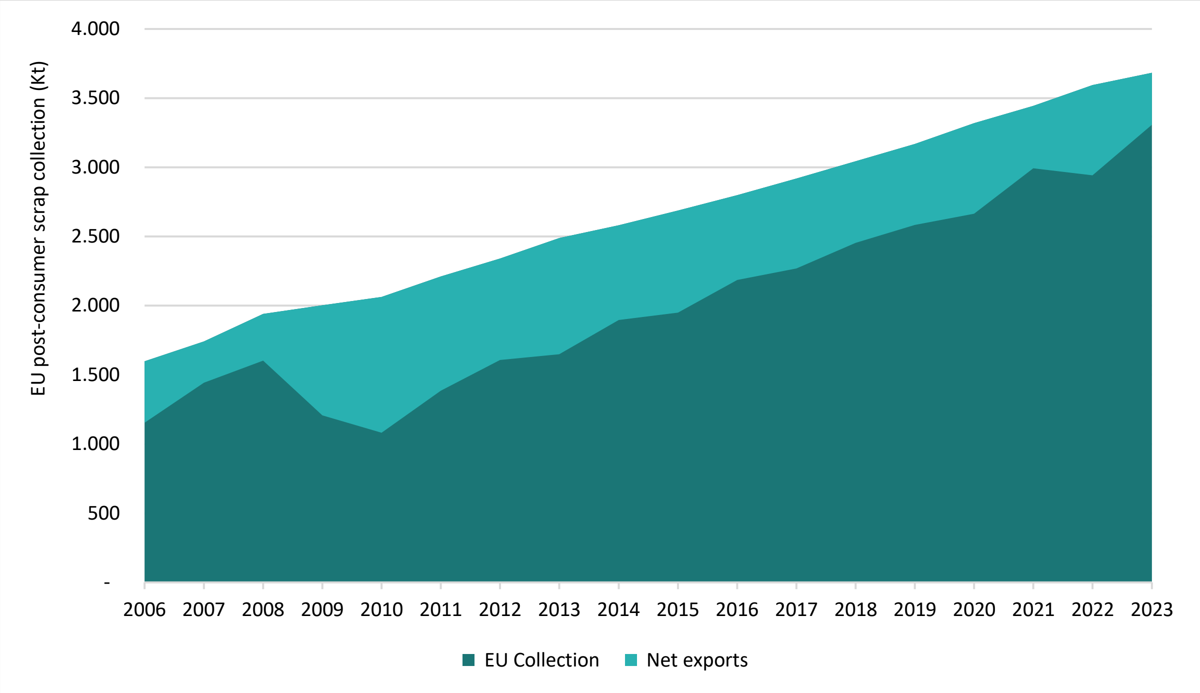
Source: IAI Global Aluminium Cycle Model

Post-consumer scrap is also traded between regions. The international trade code for aluminium waste and scrap – HS 760200, does not distinguish between pre- and post-consumer scraps. Thus, UN Comtrade data does not specify which type of scrap the trade flows consist of. Following discussions with industry experts, it is possible to assume, however, that scrap that is traded between countries is post-consumer.

[22] European Aluminium (2020). A strategy for achieving aluminium's full potential for circular economy by 2030. Available at: https://european-aluminium.eu/blog/enabling-the-circular-economy-with-aluminium/

The EU is a net exporter of scrap, primarily to Asia and Turkey. Comparing collection rates to export volumes, about 17% of collected post-consumer scrap is exported from the EU.

Figure 13: EU post-consumer scrap collection & exports



Source: IAI Global Alucycle Model; UN Comtrade HS 760200; Ramboll analysis

Similarly to pre-consumer scrap, amounts of post-consumer scrap content in semi-fabricated products varies between geographies. The IAI Alucycle Model also estimates these values, which are presented in Table 5.

Table 5: Post-consumer scrap content in semi-fabricated products

Region	Percentage	Tonnes
EU	26%	2,916,054
EFTA	32%	332,963
Other Europe	29%	502,825
China	16%	7,318,979
Rest of Asia	30%	5,294,258
Middle East	16%	366,633
North America	31%	3,581,768
Oceania	4%	18,221
South America & Caribbean	41%	1,594,186
Other	57%	1,515,261

Source: IAI Global Aluminium Cycle Model

4. Relevant energy use and emissions along the aluminium value chain

The aim of this chapter is to evaluate the energy use for the production of alumina, primary aluminium and secondary aluminium and resulting emissions in different geographic regions. These values set a baseline for the analysis of carbon costs and potential market prices in Chapter 6.

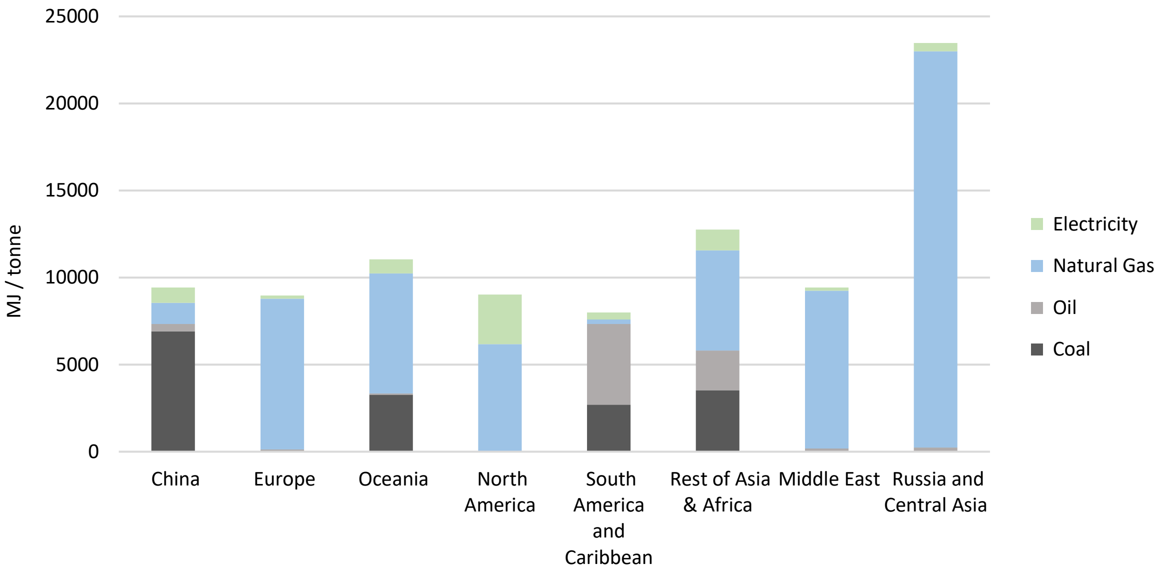
4.1 Alumina

This section describes the main processes, energy requirements, and emissions generated in the global alumina refining industry.

Energy intensity of alumina production

The energy intensity of alumina production varies between regions. The production process requires thermal energy as the main input, although some electricity is also used. The average energy intensity of production for alumina refineries in the EU is about 9 GJ. The fuel inputs to generate energy also varies between regions and refineries. Refineries in most of the world rely on natural gas, whereas most Chinese refineries are producing with coal. Russian alumina refineries stand out in regard to energy intensity, because they produce alumina from a variety of raw materials, also including bauxite. Some refineries are producing from nepheline ore, which requires a different and more energy-intensive process to the more commonly used bauxite ore.

Figure 14: Energy intensity of alumina production

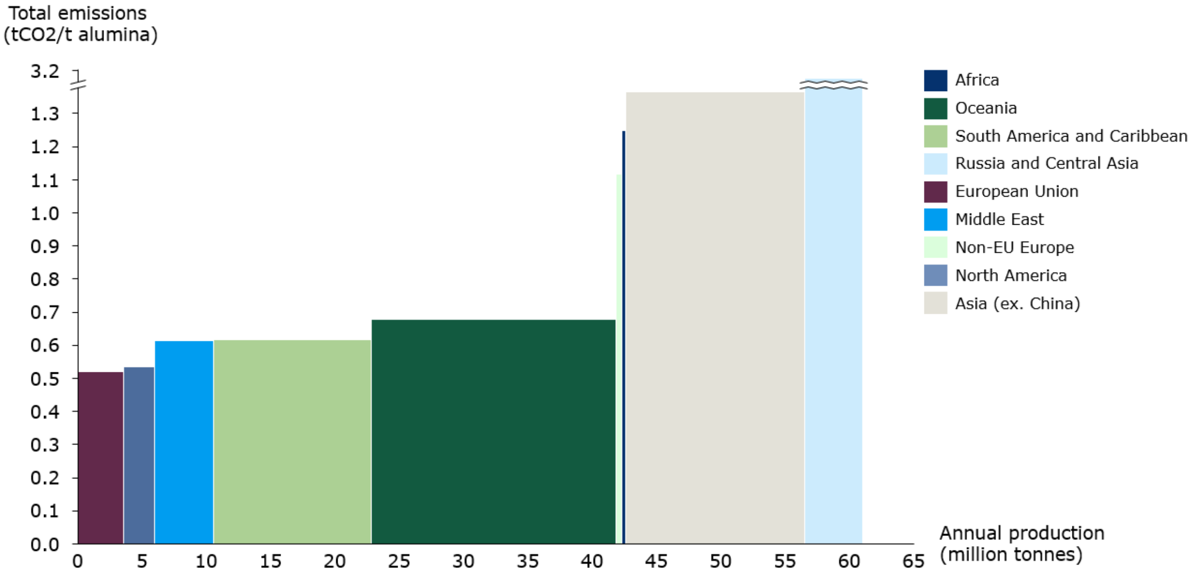


Source: IAI Statistics Database; European Aluminium Environmental Profile Report 2018; Ramboll analysis

Emission intensity of alumina production

The emissions intensity of alumina refining ranges from approximately 0.5 tCO_2e/t alumina to 7 tCO_2e/t alumina, according to data from CRU consulting. The weighted mean emissions intensity is 1.1 tCO_2e/t alumina. Due to their relatively lower energy intensity and the use of natural gas, EU alumina refineries are all on the lowest end of the emissions intensity curve, producing at less than 0.5 tCO_2e/t alumina.

Figure 15: Average emissions intensity of alumina production per region (ex. China)

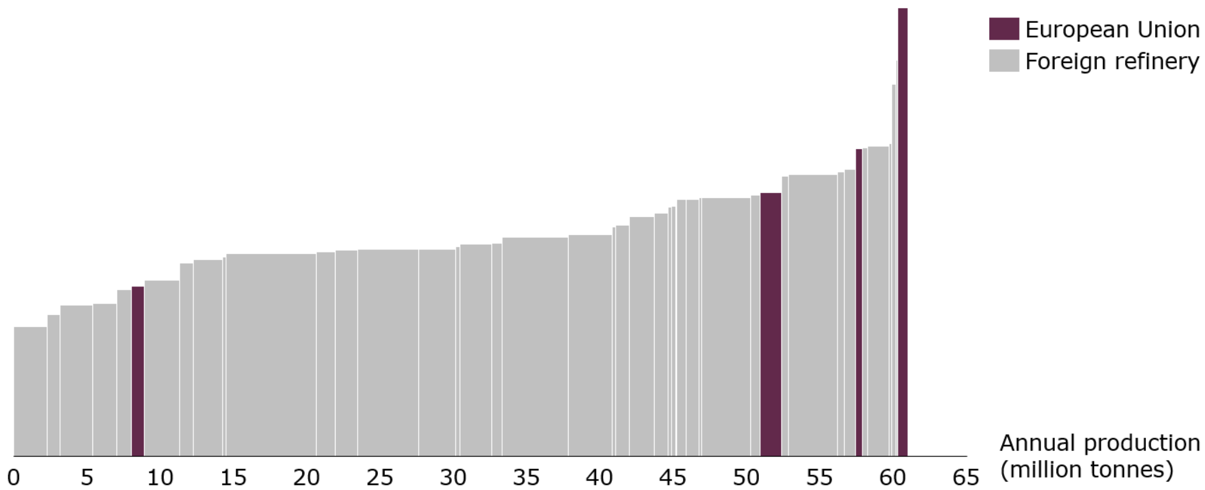


Source: CRU Consulting

Costs of alumina production

The business costs of alumina production range, as of 2023, from EUR 150 to approximately EUR 550 per tonne of alumina. Given the 5-year average alumina price of approximately EUR 300, a number of refineries have tight margins, or likely operate at a loss.

Figure 16: Business costs of alumina production (EUR/tonne; excl. Chinese refineries)



Source: CRU Consulting

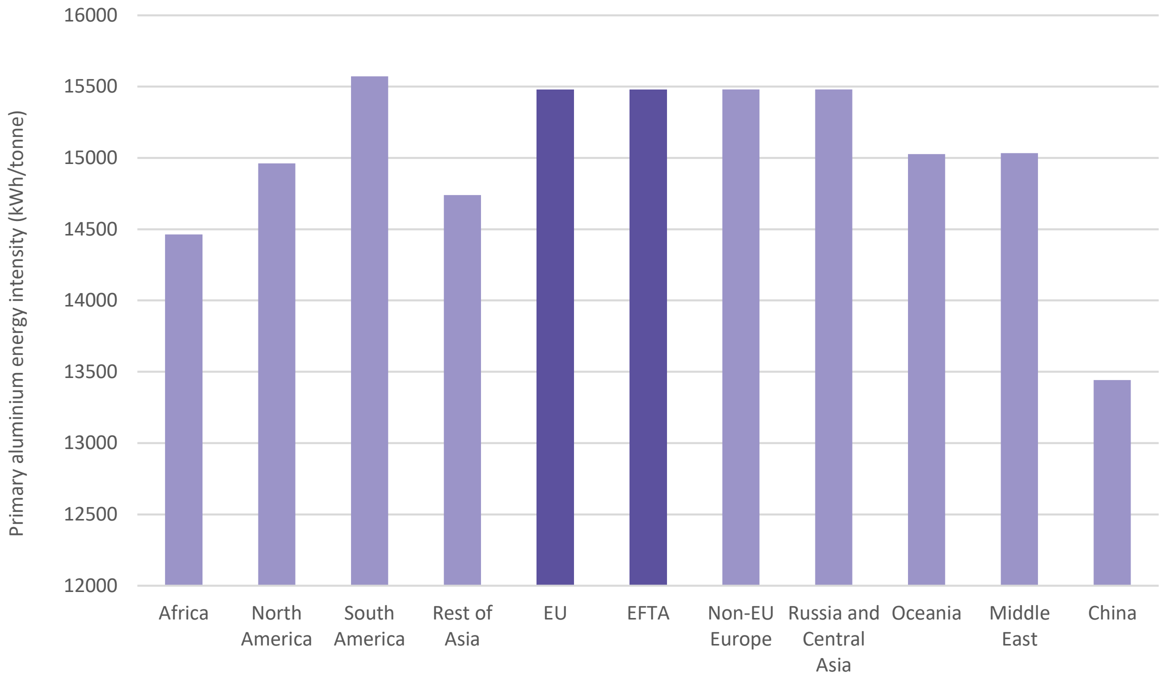
4.2 Primary Aluminium

This section describes the energy intensity, emissions and costs associated with primary aluminium production.

Energy intensity of aluminium production

The electrolysis process to produce primary aluminium from alumina is the same all around the world, so the energy intensity of production does not vary significantly between regions, and the difference in costs is driven by varying electricity costs. The electricity intensity values used in this study are sourced from the IAI's statistics database. The database does not include separate values for EFTA, Non-EU Europe and Russia, so it is assumed in this study, for consistency, that these values are the same as what the IAI reports for overall Europe.

Figure 17: Energy intensity of primary aluminium smelting



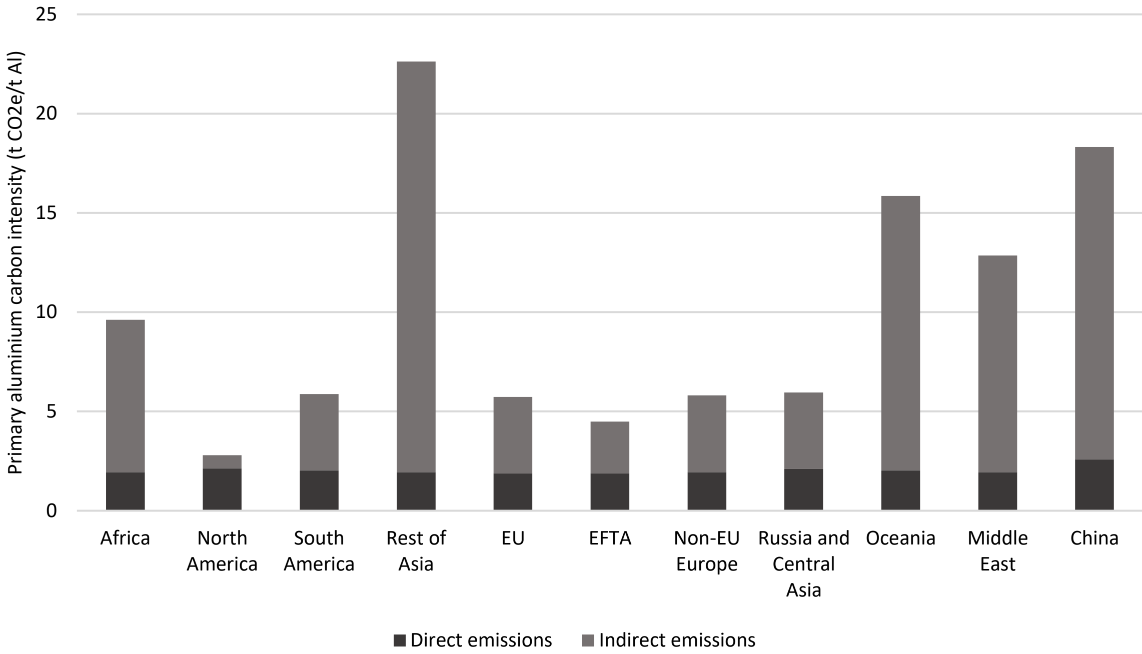
Source: IAI Statistics, Primary Aluminium Smelting Energy Intensity (AC); Ramboll analysis

Emission intensity of aluminium production

Direct emissions from primary aluminium consist of carbon emissions from the consumption of carbon anode in production and the formation of perfluorocarbon gases due to the "anode effect". Estimates of the direct emissions are sourced from the Joint Research Centre's (JRC) reporting[24]. The indirect emissions arise from the production of electricity, which is used in the smelting process. Electricity emissions factors for primary aluminium are sourced from Ecoinvent's database of emissions factors for electricity usage in the aluminium industry for 2024.

[24] Joint Research Centre (2024). Greenhouse gas intensities of steel, fertilisers, aluminium and cement industries in the EU and its main trading partners. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC134682

Figure 18: GHG emission intensity for primary aluminium smelting

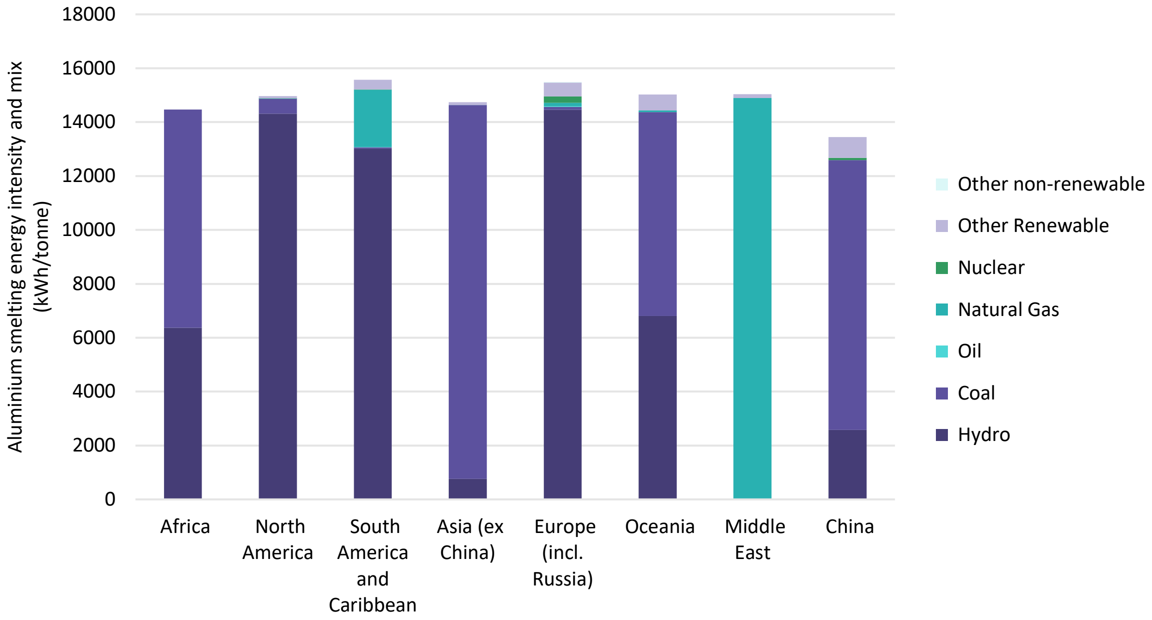


Sources: Joint Research Centre.; IAI Statistics Database; Ecoinvent; Ramboll analysis

Direct emissions vary less between regions than the indirect emissions from electricity production, so the regions with the largest share of renewables have the lowest overall emissions per tonne of aluminium. North America and the EFTA region consequently lead low-carbon production, as a result of the high share of hydroelectricity in production in Canada, Norway and Iceland. The regions relying most on coal for production, including China, the rest of Asia and Australia have the highest indirect emissions.

The IAI statistics database provides estimates of the energy mix that is used to generate electricity for aluminium production, which is presented in Figure 19. Even in the regions where electricity for aluminium is primarily generated through non-renewable sources, such as coal or oil, there is also some low-carbon production with hydro. Thus, while the average emissions intensity of primary production is quite high in these regions, there are likely individual smelters producing with lower emissions, that could become more attractive for export to the EU.

Figure 19: Primary aluminium smelting energy mix



Source: IAI Statistics Database

Energy costs of primary aluminium

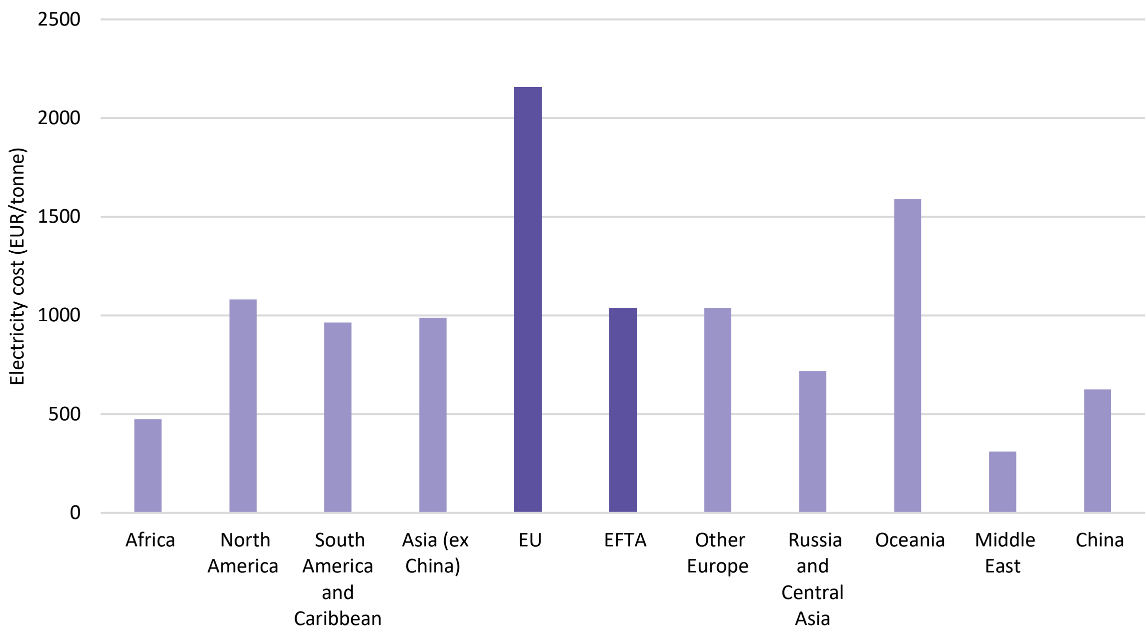
Estimating the electricity prices faced by primary producers is complex, as many companies have self-generation capacity or power-purchasing agreements with electricity companies, that mean they face lower electricity prices than the average industrial consumer. For the purposes of this study, December 2023 industrial electricity prices, as reported by the IEA and Eurostat, are used. To adjust prices to more accurately reflect actual prices faced by producers, industrial electricity prices are reduced by 57%, based on research and analysis done in the report prepared for the European Commission "Study on energy prices and costs"[25]. The resulting electricity costs per tonne of aluminium more accurately reflect real costs as established in interviews with aluminium producers.

Producers in the EU still face the highest electricity costs per tonne of aluminium, followed by producers in Oceania. Producers with the lowest electricity costs are in the Middle East, which is reflected in their growing production volumes. Non-household electricity prices in Norway and Iceland were in 2024 and 2023 about half of the EU average, thus the energy cost of aluminium production is significantly lower[26].

[25] Triconomics (2023). Study on energy prices and costs: evaluating impacts on households and industry - 2023 edition. Available at: https://op.europa.eu/en/publication-detail/-/publication/3b43f47c-e1c5-11ee-8b2b-01aa75ed71a1/

[26] Based on analysis of electricity price statistics from Eurostat. Available at: https://ec.europa.eu/eurostat/databrowser/view/ten00117/default/table

Figure 20: Energy costs for primary aluminium production



Source: Joint Research Centre; IAI Statistics; World Bank Commodity Market Prices; Ramboll analysis

4.3 Secondary Aluminium

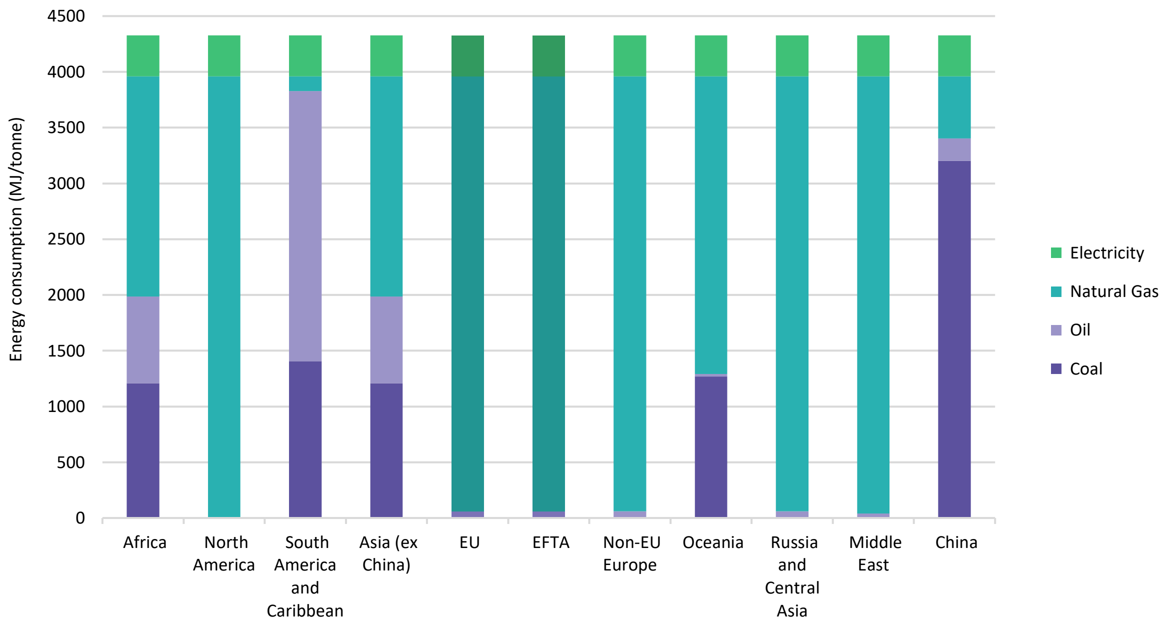
Recycling scrap is much less energy-intensive than primary production but requires a mix of thermal and electrical energy. JRC reporting estimates fixed values for the total amount of thermal energy and electricity required per tonne of recycled aluminium – 3,960 MJ and 102 kWh[27]. These fixed values are also the assumed values in this study. What will vary between regions are the fuels used to generate thermal energy, energy costs, and the resulting emissions.

Energy intensity of scrap aluminium recycling

There are no concrete estimates of the exact fuel input used to recycle scrap in the different regions. For the purposes of this study, it is assumed that the fuel inputs are like those used in alumina, for which there are good estimates from the IAI. While this leads to a rough estimate, the resulting numbers in Figure 21 reflect which fuel types are most readily available in the different regions and what the industry typically consumes.

[27] Joint Research Centre (2024). Greenhouse gas intensities of steel, fertilisers, aluminium and cement industries in the EU and its main trading partners. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC134682

Figure 21: Energy consumption per tonne of secondary aluminium

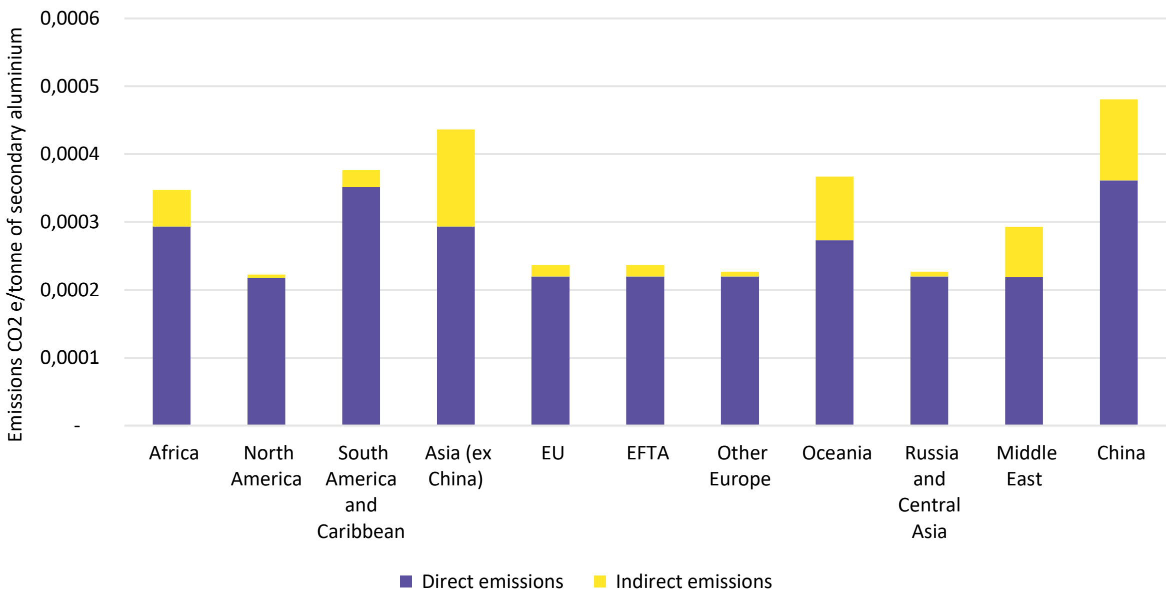


Source: Vidokic et al.; IAI Statistics Database; Ramboll analysis

Emission intensity of scrap recycling

Process emissions from recycling depend on the fuel used. An approximation of the likely emissions per tonne of secondary aluminium can be seen in Figure 23.

Figure 22: Estimated process emissions, secondary aluminium



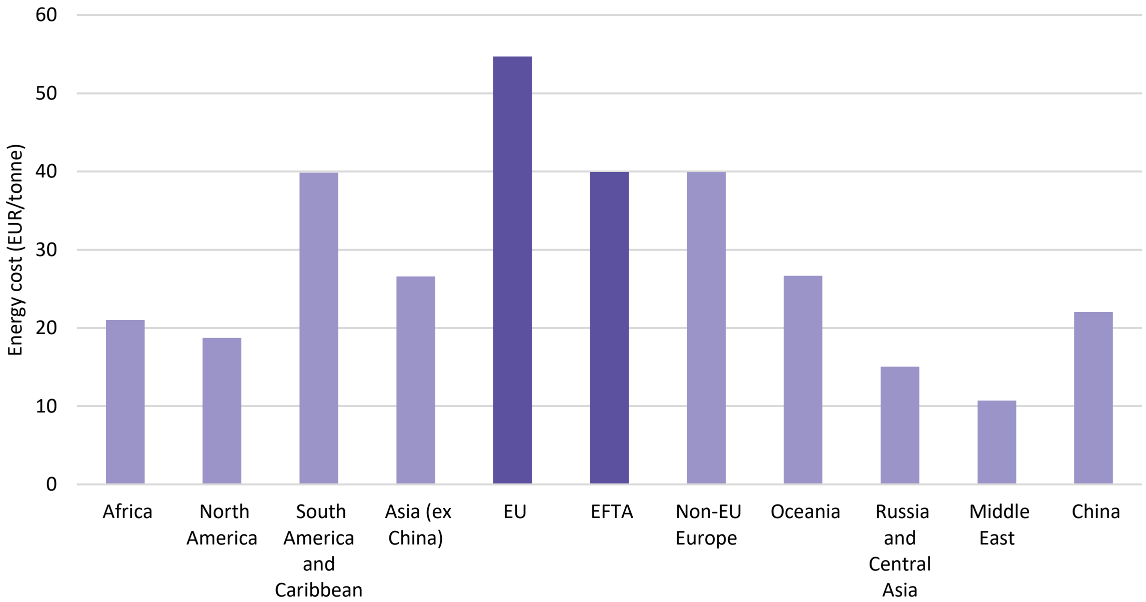
Source: JRC; IAI Statistics Database; Ramboll analysis

Considering whether there are and how to calculate the embodied emissions from scrap content, is a complex discussion that highlights several issues related to scrap. **Post-consumer scrap** is always considered to have zero embedded emissions, because the scrap has had a useful life. However, defining the share of post-consumer scrap content in aluminium can also be complex, as pre- and post-consumer scrap can be mixed during collection and distribution. There is no broad agreement about whether or not embodied emissions should be assigned to **pre-consumer scrap** and harmonising the life-cycle assessment (LCA) approaches to secondary aluminium are out of scope for this report[28].

Energy costs of secondary aluminium production

Using available fuel commodity prices and representative electricity prices for each region, from December 2023 results in the energy costs in Figure 1.

Figure 23: Energy cost of secondary aluminium production



Source: Joint Research Centre; World Bank Commodity Market Prices; Ramboll analysis

[28] RMI (2023). Aluminum GHG Emissions Reporting Guidance. Available at: https://rmi.org/our-work/climate-intelligence/horizon-zero/aluminum-sector/

5. Analysis of alumina in the CBAM scope

This chapter is dedicated to analysing the specific impacts of the EU Carbon Border Adjustment Mechanism (CBAM) on the alumina segment of the aluminium value chain.

This chapter contains the following four study parts:

1. An analysis of the carbon costs faced by alumina refineries under the current ETS.
2. An analysis of the marginal price of alumina in the EU+EFTA market under different CBAM scenarios.
3. An evaluation of the potential effects of the rising alumina price on aluminium smelters.
4. A description of the circumvention risk for alumina.

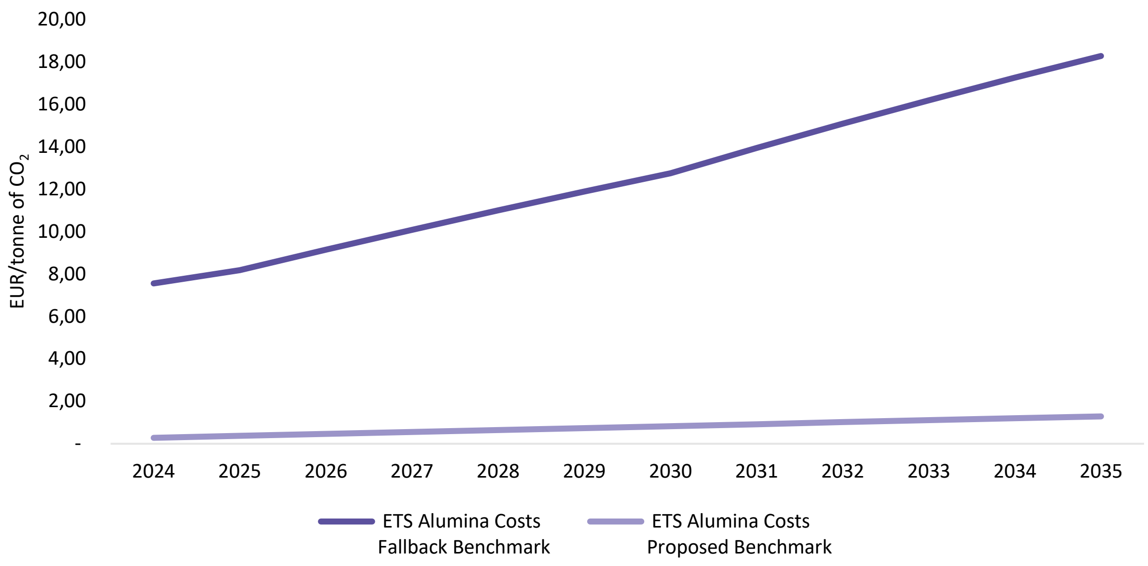
Alumina refineries in the EU pay an ETS price for their emissions. Alumina refineries do not have a product-specific benchmark for free allocation and are instead covered by the non-sector specific heat and fuel consumption fallback benchmarks[29]. This benchmark is set by assessing emissions from a variety of different industries and installations. As a result, it is set to low emission levels that cannot be achieved by an alumina refinery, based on the currently available technologies.

The ETS cost is a cost that EU refineries face, and not their foreign competitors. Because alumina is a globally traded commodity, EU alumina refineries cannot pass this cost onto consumers and must sell at the global market price, which challenges their long-term competitiveness. EU alumina refineries produce at an average energy intensity that is far below the global average (see Figure 15). Thus, their losing ground to foreign competitors would result in carbon leakage.

Figure 24 illustrates the emissions costs faced by an alumina refinery in Europe, per tonne of CO2 emitted, under the current fallback benchmark versus under a separate product benchmark for alumina. As the figure illustrates, a product benchmark that reflected the technologies available to alumina refining, would result in much lower carbon costs, and be a more effective mechanism to prevent carbon leakage.

[29] European Aluminium (2022). CBAM Product Scope: Why alumina should not be included (Annex I). Available at: https://european-aluminium.eu/news_events/cbam-product-scope-why-alumina-should-not-be-included-annex-i/

Figure 24: Alumina ETS cost under current and proposed ETS benchmark



Source: Ramboll CBAM model, based on ETS benchmark forecast based on EU regulatory review

Another option to equalise competition between the EU alumina refineries and foreign refineries is to include them in the CBAM scope. This was proposed by the Commission in internal working documents for the preparation of the initial CBAM drafts[30]. The following section of this report assesses the potential impacts of including alumina in the CBAM scope.

5.1 Determining the price of alumina in the EU and EFTA

The first part of this analysis seeks to determine the potential changes in price of alumina in the European market, were it to be included in the CBAM scope.

Different prices are evaluated for the scenarios listed in Table 6. Demand for alumina in EU + EFTA is assumed to be 6.8 million tonnes per year (compare Figure 7). To determine future prices of alumina, a cost curve has been developed for each scenario, where the price setter is the marginal producer.

To develop the cost curves, the following assumptions are used:

- The marginal producer can be domestic or foreign.
- Foreign producers are 'price takers', and the baseline price they will sell at is the global price – which, in this case, has been set to the global average alumina price from the last five years (2019-2023), normalised to the Pacific. This baseline price has been set to EUR 295 per tonne.
- For producers in the Americas, the alumina market has separate dynamics, so an additional cost is applied, which is known in the industry as the 'Atlantic differential'. The value used here is based on the average differential from the last five years. This additional differential is EUR 9 per tonne of alumina.
- Freight per tonne is added to foreign producers' costs – EUR 20 per tonne from the Atlantic and EUR 40 per tonne from the Pacific.

[30] European Aluminium (2022). CBAM Product Scope: Why alumina should not be included (Annex I). Available at: https://european-aluminium.eu/wp-content/uploads/2022/12/2022-11-18-European-Aluminium-note-on-why-Alumina-should-not-be-initally-included-in-Annex-I-of-CBAM.pdf

- Chinese producers are excluded from the analysis of a European alumina price, because the Chinese alumina market operates separately from the rest of the world, and Chinese alumina refineries do not export.
- Under CBAM scenarios the phase-in curve of alumina follows the phase-in of the current scope (2026-2034), while a later inclusion of alumina under CBAM might lead to a different or delayed phase-in curve. The following scenario analyses are calculated for 2030.

Table 6: Alumina CBAM scenarios

Scenario	Description	Benchmark assumption for 2030
1. "As-Is" CBAM Scope	No CBAM on alumina as a precursor or as a product; Current CBAM scope on primary aluminium and semi-fabricated products	0.34
2. Alumina in CBAM	Alumina included in CBAM product scope, but only paying for direct emissions.	0.34
3. Alumina in CBAM + separate benchmark	Alumina included in CBAM product scope, with a separate benchmark for alumina refineries.	0.37
4. Alumina in CBAM + indirect emissions	Alumina included in CBAM product scope, with both direct and indirect emissions in scope.	0.46
5. Alumina in CBAM + indirect emissions + separate benchmark	Alumina included in CBAM product scope, with a separate benchmark for alumina refineries, and direct and indirect emissions in scope.	0.50

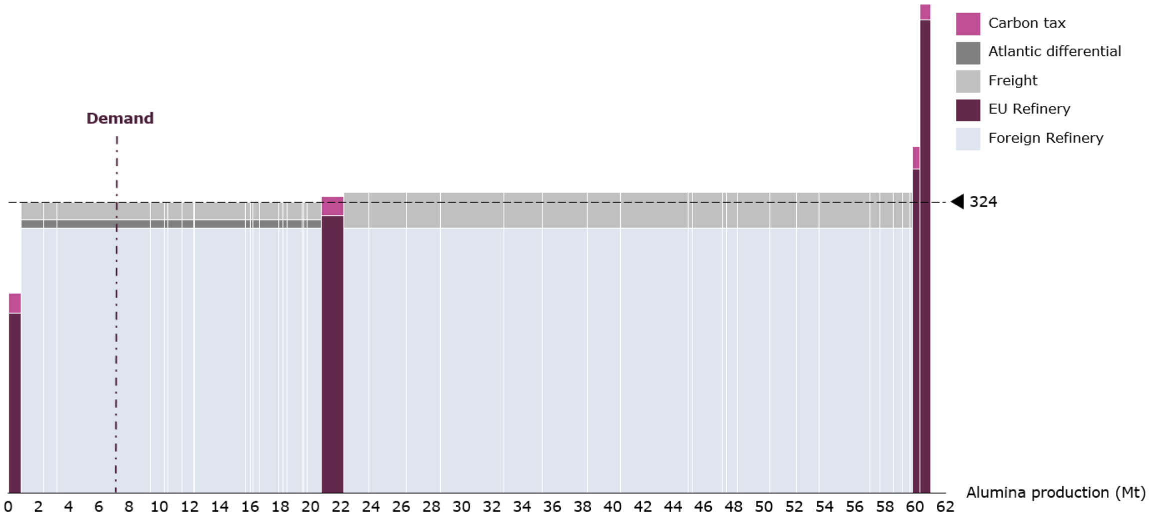
The cost curves illustrated for each scenario reflect the marginal producer pricing structure in the alumina industry. There are a few key points to be able to read each curve:

- All refineries have been ranked according to their total costs, under that specific scenario, given the assumptions listed above. The cost curve illustrates this ranking.
- Each bar in the graph represents a single alumina refinery and the width of each bar represents the production capacity of the respective alumina refinery.
- The marginal producer, which sets the market price, is the lowest cost producer with sufficient production to fulfil market demand. In other terms, the marginal price is where the demand curve meets the supplier cost curve.
- Depending on alumina refinery emissions and the different assumptions in each scenario, the costs of production for each alumina refinery change, so the supplier cost curves change. As a result, the marginal producer and the marginal price differ in each scenario.

Scenario 1: "As-is" CBAM scope – no alumina in scope

Scenario 1 establishes a reference price of EUR 324 per tonne of alumina, when it is outside of the CBAM scope. European producers fall under the ETS, so their carbon costs are considered in the cost curve.

Figure 25: Alumina price scenario 1 [price in EUR/tonne] ***(2030)***



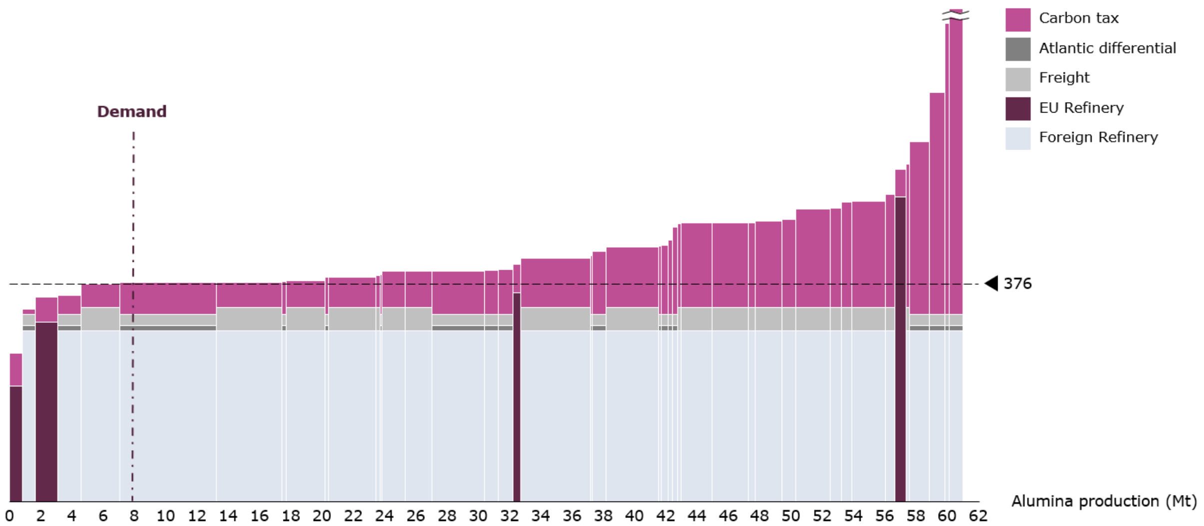
Source: CRU Alumina refinery data; Ramboll analysis

Scenario 2: Alumina in CBAM, only direct emissions in scope

With direct emissions from alumina in scope, the alumina price becomes EUR 376 per tonne in 2030. This corresponds to a price increase of 16%, compared to the reference price in Scenario 1.

If the year assessed in this scenario were 2034, holding all other assumptions the same, the alumina price would be EUR 401 per tonne, or a 24% increase.

Figure 26: Alumina price scenario 2 [price in EUR/tonne] ***(2030)***



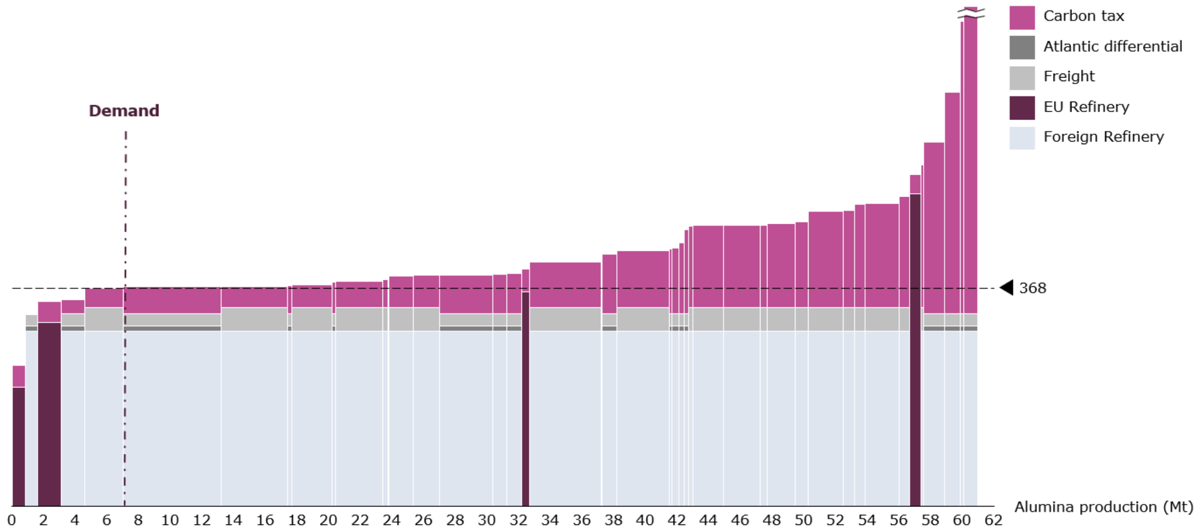
Source: CRU Alumina refinery data; Ramboll analysis

Scenario 3: Alumina in CBAM with a separate benchmark, direct emissions in scope

The creation of a separate benchmark for alumina, based on the emissions-intensity of European refineries, lowers the carbon costs for foreign and domestic producers, resulting in a lower marginal price. The resulting alumina price is EUR 368 per tonne, or 13% higher than the reference price.

If the year assessed in this scenario were 2034, holding all other assumptions the same, the alumina price would be EUR 401 per tonne, or a 24% increase.

Figure 27: Alumina price scenario 3 [price in EUR/tonne] ***(2030)***

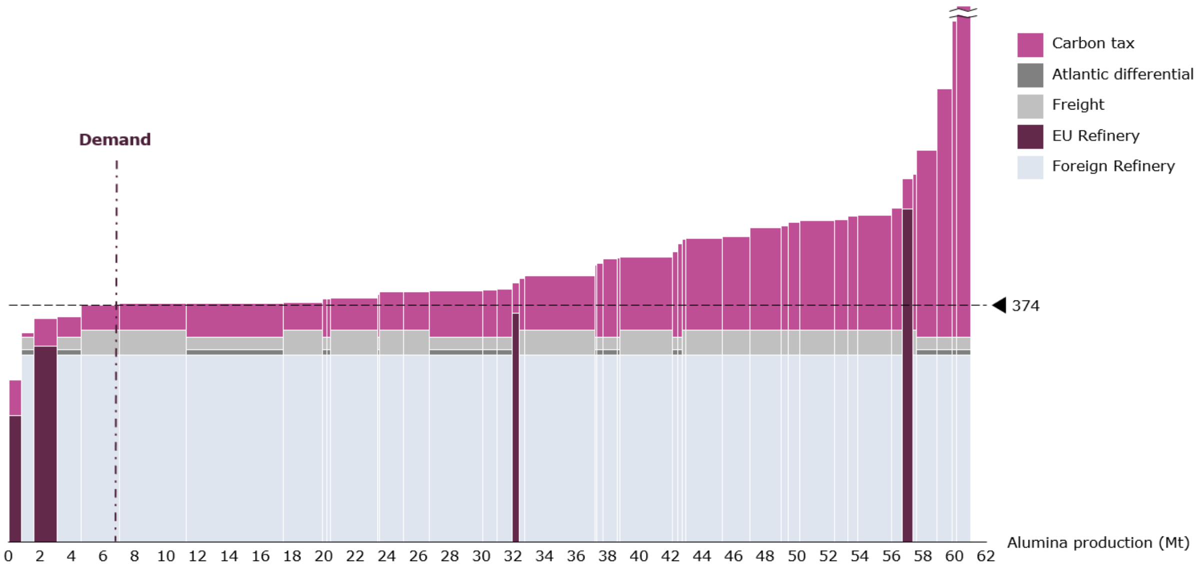


Source: CRU Alumina refinery data; Ramboll analysis

Scenario 4: Alumina in CBAM, indirect emissions in scope

Indirect emissions for alumina refining are insignificant, and in the available data, many foreign alumina refineries report no indirect emissions. This results in a lower marginal price than when the CBAM is only on direct emissions, due to the benchmark adjustment to account for indirect emissions from European alumina refineries.

Figure 28: Alumina price scenario 4 [price in EUR/tonne] ***(2030)***

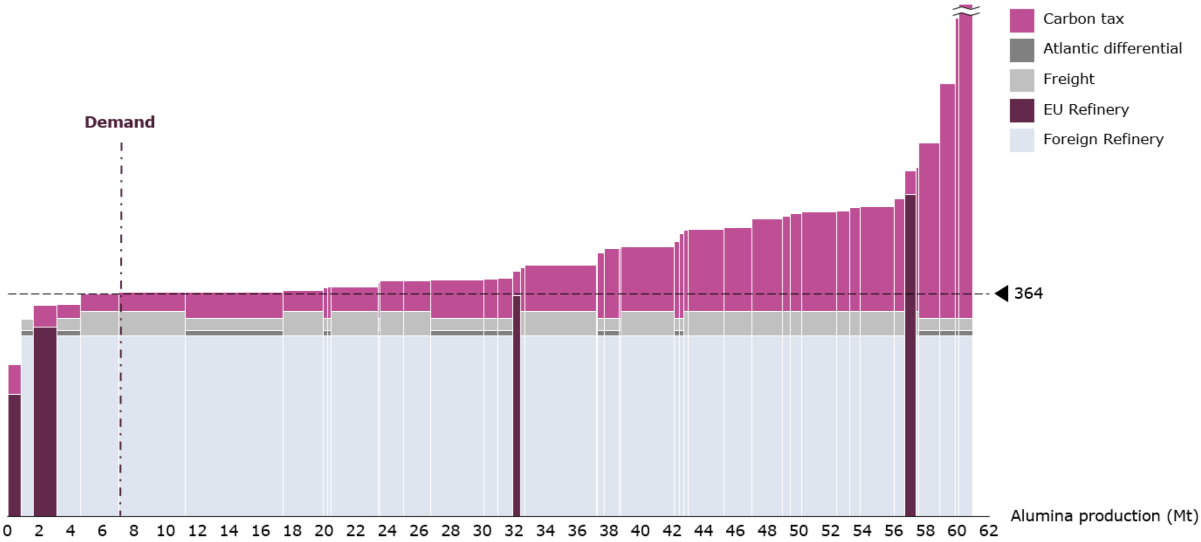


Source: CRU Alumina refinery data; Ramboll analysis

Scenario 5: Alumina in CBAM with a separate benchmark, indirect emissions in scope

A CBAM on alumina with indirect emissions, with a separate benchmark, would result in an even lower marginal price – just 12% higher than the reference price.

Figure 29: Alumina price scenario 5 [price in EUR/tonne] ***(2030)***



Source: CRU Alumina refinery data; Ramboll analysis

5.2 The effect of the alumina carbon cost on aluminium smelters

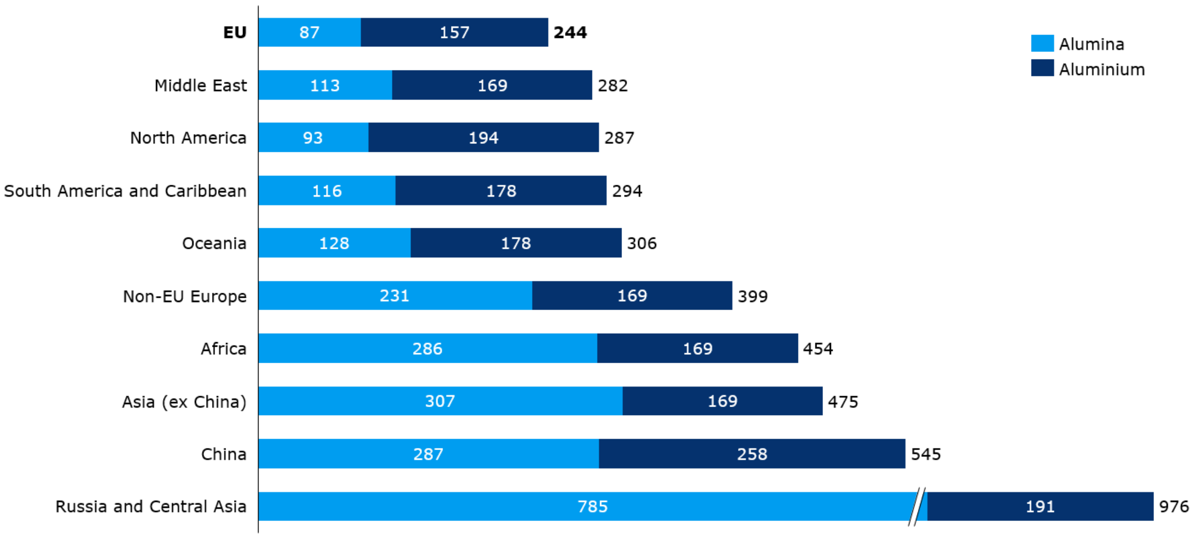
If alumina is included as a product in the CBAM scope, it would also become a precursor to primary aluminium and the downstream products in scope. Unwrought aluminium thus shifts from being a 'simple good' within the CBAM regulation to a 'complex good', where the calculation of the carbon tax for importers must include emissions from its precursor.

This analysis looks at the carbon costs per region and assumes that aluminium smelters are sourcing alumina within their region. In other terms, while the price analysis in the previous section, Section 5.1, accounted for alumina trade, the analysis in this section does not, for simplicity. While the mentioned assumption is a simplification, because alumina is globally traded, the following analysis does provide an indication of the regional differences between primary aluminium carbon costs.

To produce 1 tonne of aluminium, 1.91 tonnes of alumina are needed[31]. Using this conversion and the data in Figure 15 and Figure 17, results in the carbon costs for primary aluminium that can be seen in Figure 30.

[31]European Aluminium (2018). Environmental Profile Report: Life-Cycle inventory data for aluminium production and transformation processes in Europe. Available at: https://european-aluminium.eu/blog/environmental-profile-reports/

*Figure 30: Primary aluminium carbon costs (EUR/tonne), when alumina is a precursor and smelters source alumina from local producers **(2030)***



Source: Ramboll CBAM fee model, CRU data

In conclusion, if direct emissions from alumina and direct emissions from primary smelting are considered, European producers face the lowest combined carbon costs, if they source alumina from European refineries. However, Figure 30 also illustrates that alumina as a precursor can more than double the carbon cost added to primary aluminium, when it is imported into the EU. This further raises the marginal price of aluminium in the EU, increasing the price premium, with detrimental effects on producers further downstream.

5.3 CBAM circumvention risk for alumina

For imports of alumina as a product, circumvention of the CBAM fees is possible. Circumvention would require the importer to falsely report the refinery where the alumina originates – claiming alumina from a lower carbon refinery or using lower carbon energy sources to reduce the fee. The importer will still sell at the marginal price in the European market, allowing them to claim a higher profit.

For imports of aluminium products, where alumina is a precursor, the risk of circumvention rises. Firstly, the traceability of the alumina input becomes more complex when there are more steps of production. A producer of semi-fabricated products would have to account for the alumina used by the smelters where it receives its aluminium. This could potentially be several smelters, who each purchase from several alumina refineries, meaning that traceability and verification of alumina origin would require constant monitoring and strong cooperation between producers.

6. Aluminium scrap under CBAM

The following sections investigate how aluminium scrap may influence the effectiveness of the CBAM regulation. Utilizing aluminium scrap might be used to deliberately lower CBAM fees due. Furthermore, non-European producers may redirect production from low-carbon installations (e.g. hydro-powered smelter facilities) for their exports into Europe. This shortfall is especially relevant for aluminium, due to its high energy intensity (and correlated carbon intensity) and high tradability. This CBAM design flaw has been clearly outlined in the 'Draghi report' on the future of European competitiveness, published by the EU Commission in September 2024:

> *"**CBAM is potentially easy to circumvent**. As an example, as it is structured, exporters to the EU will not be taxed if they serve the European market from their low-emission plant segments and sell CO2-intensive steel on domestic or other third-country markets instead. Similarly, the zero-emissions assumption for recycled material, including industry scrap, could provide incentives for deliberate scrap generation to export the secondary material (exempt from CBAM) instead of the primary one (within CBAM) to Europe (relevant, notably, for aluminium where recycling costs are low). Moreover, monitoring and verification may be very difficult without strong cooperation."*
>
> The future of European competitiveness Part B | In-depth analysis and recommendations *(page 104)*

This policy design shortfall creates a significant risk for European aluminium producers, who are also pressured by increasing ETS costs and loss of free allocation. Foreign exporters can, by circumventing CBAM fees, directly undercut the European market.

Because of the high value chain complexity, aluminium products' carbon intensities (including scrap contents) should be defined by national default values when they are imported into Europe. This would create a more equal playing field between European producers and imports. Default values would have two main advantages:

1. The CBAM reporting methods and calculations would be significantly simplified.
2. CBAM would more effectively encourage industry decarbonisation in regions outside Europe.

As currently designed, CBAM covers i) the direct emissions from primary aluminium smelting, ii) the direct emissions from the recycling process, and iii) the direct emissions from semi-fabrication. Scrap (pre- and post-consumer scrap) is currently not a product or a precursor in the CBAM scope. As primary aluminium is covered and emissions intensive, the usage of scrap makes it possible to significantly reduce the overall CBAM charge. The results of our CBAM fee model are explained below in greater detail and illustrate the circumvention risk.

6.1 The creation of a European market premium

For domestic producers and importers, the implementation of CBAM is expected to significantly elevate the price level in the European aluminium market. This will create a distinct higher premium Europe-internal market, driven by CBAM import fees and ETS-influenced production costs, set by the marginal importer or producer, adding to the existing premium over the global LME price, where already today European premiums are above premium paid in other global regions. Third-country importers can be expected to adjust their prices to match the elevated European prices, rather than reflecting their own actual costs. Thus, efforts to circumvent or reduce CBAM will primarily enhance the margins of third-country producers, without reducing costs for European buyers.

Figure 31: Illustrative ETS and CBAM impact on European premium market for aluminium

Scrap prices are highly correlated to the primary aluminium market price. Scrap can be considered a primary replacement. The aluminium scrap price is also dependant on available recycling capacities, which will increase with a widening spread to the primary aluminium price for post-consumer scrap. Therefore, if the European market price for aluminium increases, scrap prices will also rise, regardless of whether embedded emissions are assigned to aluminium scrap. Under CBAM, scrap will become a more attractive option to reduce overall carbon costs, especially if scrap is excluded from CBAM fees.

Consequently, the market dynamics will negatively impact recyclers who will face higher prices for their raw scrap material inputs, regardless of whether scrap is included or excluded under CBAM. Furthermore, the overall increase of the European aluminium premium based on the marginal producer or importer will lead to an increase in raw material costs for all European downstream manufacturers processing aluminium.

6.2 Circumvention methods for scrap – resource reshuffling and false claims

Globally, there is an ample supply of aluminium scrap that foreign producers could utilise to modify the material flows in their processes. Products predominantly utilising higher scrap volumes could be sold on the European market, while products made from primary aluminium could be reserved for markets without a carbon price. Such resource reshuffling could involve shifting production routes between different installations and allocating production from low-carbon installations for export to the EU, in order to maximise global profits.

In addition to splitting high- and low-carbon businesses over separate installations, the CBAM Regulation (EU) 2023/956 does not explicitly prohibit the division into sub-installations or sub-products for aluminium. In practice, this means that a foreign producer using both primary aluminium (high emissions) and recycled aluminium (low emissions) within a single installation, could selectively declare only the scrap-based production for EU exports.

A simple approach to understanding the potential scale of this issue is to compare the globally available amounts of scrap to the European demand for aluminium. The expected European demand for aluminium semi-fabricated products in 2030 is 17.5 million tonnes[32]. In China alone, in 2023, 7.6 million tonnes of manufacturing scrap and 6.8 tonnes of post-consumer scrap were generated. 2.5 million tonnes of manufacturing scrap and 5.3 million tonnes of post-consumer scrap were generated in North America. These volumes on their own are more than enough to fulfil European aluminium

[32] CRU Consulting (2022). Opportunities for aluminium in a post-Covid economy. Available at: https://international-aluminium.org/wp-content/uploads/2022/03/CRU-Opportunities-for-aluminium-in-a-post-Covid-economy-Report.pdf

demand, and marginal prices in the EU under CBAM will ensure that companies making use of scrap will make a windfall profit.

When process scrap is also considered, the scale of the potential problem increases. Process scrap is generated in the semi-fabrication process. It is valuable material that tends to remain within an installation for remelting and use. As such, process scrap is not usually traded and does not appear in trade or production statistics, so actual amounts are difficult to estimate. There is no consensus as to whether process scrap should be considered "secondary material recovered from a waste stream" or "a co-product of the production process". The relevant ISO standards do not explicitly require one or the other interpretation[33].

The IAI estimates that about 1 tonne of process scrap is generated for every 4 tonnes of semi-fabricated product. In China, the IAI estimates for 2023 that more than 18 million tonnes of process scrap are generated. To circumvent the CBAM, foreign producers could claim process scrap as scrap content in the products they export to Europe, abstain from deducting the process scrap they generate in their fabrication and in this way reduce their CBAM fee. The same is true for post-consumer scrap.

Whether through resource reshuffling or falsely claiming scrap content in their products, circumvention is problematic for several reasons. Firstly, it puts European producers at a disadvantage, because they still must pay the ETS cost for their entire installation and not just for a part of their production. Additionally, it means that the CBAM will not incentivise foreign producers to lower their carbon emissions, thus it will not effectively reduce the risk of carbon leakage, if scrap can be exploited to significantly decrease CBAM fees.

6.3 Calculations of CBAM fees in unwrought aluminium and semi-fabricated products

The modelled scrap and scrap circumvention scenarios combine the different input materials (primary, pre-consumer, post-consumer scrap) and different production steps, in order to calculate the potential CBAM fee applicable in the respective CBAM phase-in years up until 2034. Additionally, the increasing ETS costs for European (EU and EFTA[34]) producers have been modelled.

For this study, emissions intensities are aggregated to regions. For production steps with a dedicated product benchmark (e.g. aluminium smelting) the dedicated benchmark has been assumed based on product benchmark reduction curves. For steps not applicable to a dedicated product benchmark (e.g. recycling, semi-fabrication) energy intensity compared to ETS fallback benchmarks have been assumed, based on overall process energy intensities. Furthermore, as the CBAM is intended to mirror the ETS, it has been assumed that the CBAM benchmarks, which have yet to be published, will also mirror the ETS benchmarks[35]. Those assumptions are necessary to make the current installation-based approach for the ETS comparable with the product-based approach for the CBAM.

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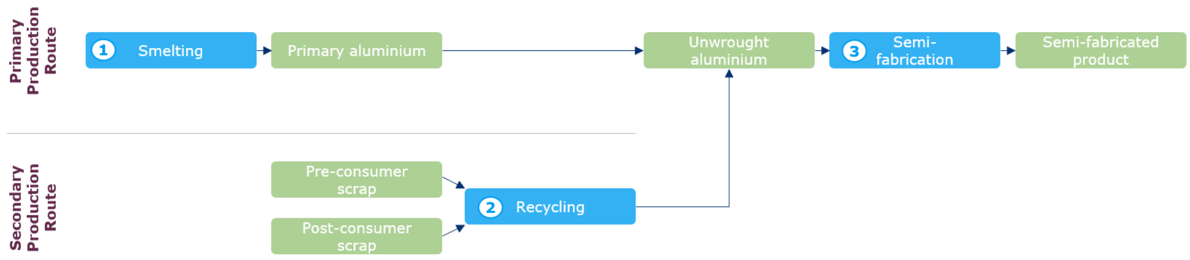
[33] International Aluminium Institute (2023). Reference document on how to treat scrap flows in carbon footprint calculations for aluminium products. Available at: https://international-aluminium.org/wp-content/uploads/2022/09/Carbon-footprint-of-recycled-aluminium-IAI-Document-Public-Review-Final.pdf

[34] EEA countries are assumed to be subject to CBAM in this study. Norway announced a CBAM introduction while an official statement on Iceland is pending. Switzerland has not decided to adopt a CBAM, will resume debate in 2027.

[35] European Commission (2024). Carbon Border Adjustment Mechanism (CBAM) Questions and Answers. Available at: https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en

Figure 32: Emission intensity steps for CBAM in semi-fabricated products

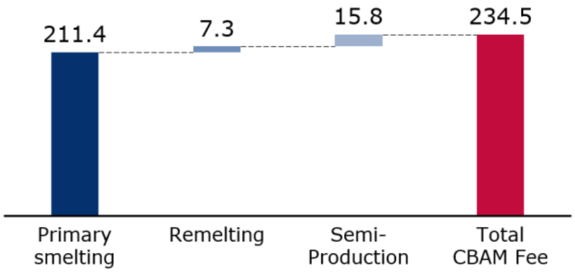


Source: Ramboll analysis

The CBAM fee in the model is calculated based on the split of input material and relative process step emissions. The applied calculation model simplifies the production route and does not account for additional remelting steps, process integration, or multiple loops of scrap elements.

An example calculation is shown in Figure 33 for Chinese imports of cold rolled sheets, based on the average scrap contents observed for this region based on 2030 CBAM introduction.

Figure 33: Combined value chain calculation of CBAM fee for averaged cold rolled sheets from China [EUR/tonne] ***(2030)***[36]



Pre-consumer scrap content	**2%**
Post-consumer scrap content	**16%**

Source: Ramboll CBAM Model

For the average cold rolled sheet, 82% of the material is based on primary aluminium input, where a CBAM fee of EUR 211.40 relative to the tonne is calculated. The remaining 18% of material is based on scrap. Under the current CBAM regulation, this scrap does not carry any embedded emissions. The recycling of scrap material leads to a CBAM fee of EUR 7.30 relative to the tonne. Further, cold rolling 100% of the material leads to another EUR 15.80 relative to the tonne in CBAM fees. As a result, based on current regional scrap content averages, and assuming a 2030 scenario (48.5% CBAM factor), the total CBAM fee sums up to EUR 234.5 per tonne. In a 2034 scenario the total fee would stand at EUR 334 per tonne.[37]

Additionally, an example with unwrought aluminium is given in Figure 34, with a total CBAM fee in 2030 of 185.5 EUR per tonne.

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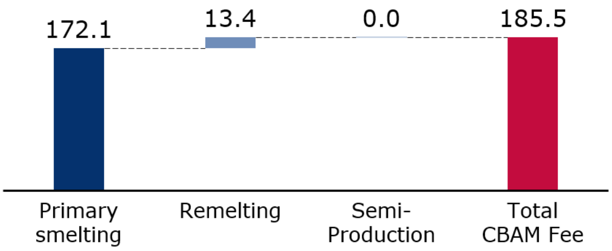
[36] China has been chosen as an example geography, due to high exports, large aluminium industry and high amounts of available scrap volumes; **Model settings**: 2030 assumptions for ETS/CBAM phase-in; EUA price at 140 €; considering full product scope in current CBAM policy design; no further decarbonisation efforts of industries

[37] Emissions for primary aluminium in the applied model are comparatively high for China based on assumed smelting emission driven by high PFC emissions in that region. Data is based on JRC report for primary direct emissions as can be seen in Figure 18.

Figure 34: Combined value chain calculation of CBAM fee for unwrought aluminium from China [EUR/tonne] ***(2030)***[38]



Pre-consumer scrap content	**17%**
Post-consumer scrap content	**16%**

Source: Ramboll CBAM Model

6.4 Increasing the scrap percentage to reduce CBAM emissions

The above calculations already indirectly show the significant CBAM fee advantage that can be achieved, by utilising higher shares of scrap in aluminium and aluminium semi-fabricated products. High-quality scrap or pre-consumer scrap with known alloying elements can be used almost interchangeably with primary aluminium. Post-consumer scrap may be more difficult to use across recycling processes, mostly due to potential contamination and unknown alloying elements.

Scrap contents differ significantly across semi-fabricated product types. As such, scrap volumes for pre- and post-consumer scrap can be increased, especially under described circumvention methods that allow for a rapid change of scrap contents in imported materials. Scrap gives importers an opportunity to undercut domestic producers and creates a significant risk of domestic production being partially or fully replaced by producers that are subject to less strict carbon taxation schemes or decarbonisation targets. It should be highlighted that most foreign producers already have an economic cost advantage, mostly driven by cheaper energy cost, but also other economic factors.

The above cost examples clearly showcase that CBAM circumvention would be so lucrative for importers, that foreign producers can be expected to very quickly adopt practices of global resource reshuffling. This renders CBAM inefficient to reduce the risk of carbon leakage or reduce emissions.

For the further analysis of the impact of utilising different scrap contents, the sensitivity analysis outlined in Table 7 is applied to the CBAM fee model on the example of a Chinese extruded profile (see subsequent figures). The "Actual Case" represents the reported national average for Chinese extruded profiles based on IAI data.

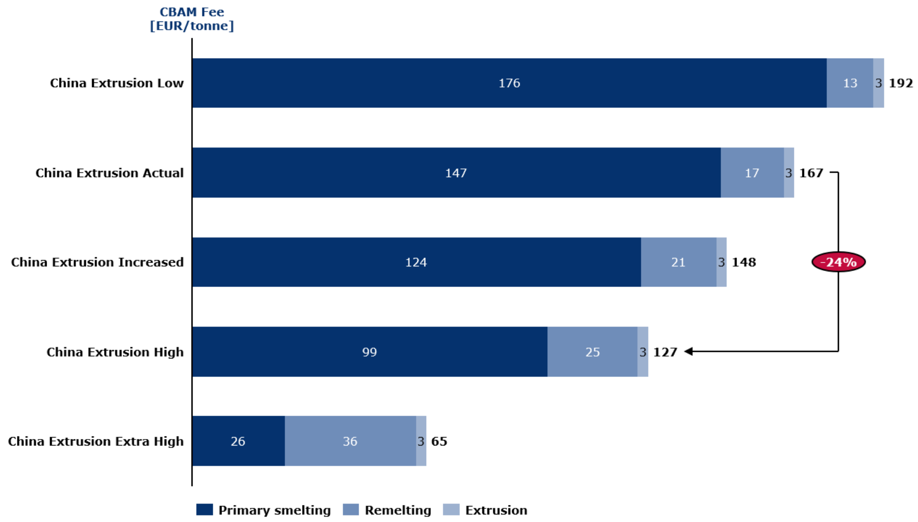
Table 7: Sensitivity on scrap content for extruded profiles from China

Case	Pre-consumer scrap content	Post-consumer scrap content
Low	5%	26.8%
Actual	**16.4%**	**26.8%**
Increased	25%	26.8%
High	35%	26.8%
Extra High	45%	**45%**

Sources: Ramboll CBAM Model assumptions, IAI Material Flow Model tool

[38] **Model settings**: 2030 assumptions for ETS/CBAM phase-in; EUA price at 140 €; considering full product scope in current CBAM policy design; no further decarbonisation efforts of industries

Figure 35: Influence of increasing pre-consumer scrap volumes to circumvent CBAM charges [EUR/tonne] ***(2030)*** [39]



Source: Ramboll CBAM Model

Figure 35 showcases how just a partial increase of pre-consumer scrap by an additional 20% (i.e. from "Actual" to "High") can lead to a reduction of the CBAM fee due, by 24% in a 2030 scenario. The here showcased reduction would directly increase margins of importers on the European market by EUR 40 per tonne. Assuming a current average LME price of EUR 2,260 per tonne, such a EUR 40 reduction in CBAM fees would result in a possible 1.8% savings compared to the LME for of an exemplary Chinese importer under the described "High" case.[40]

The pre-consumer scrap increases are chosen relatively conservatively. Adding additional scrap in an "Extra High" case, increasing pre- and post-consumer scrap content to 45% respectively, would allow to reduce the CBAM fee to EUR 65 per tonne leading to an overall reduction of EUR 102. This would represent roughly 4.5% of LME.

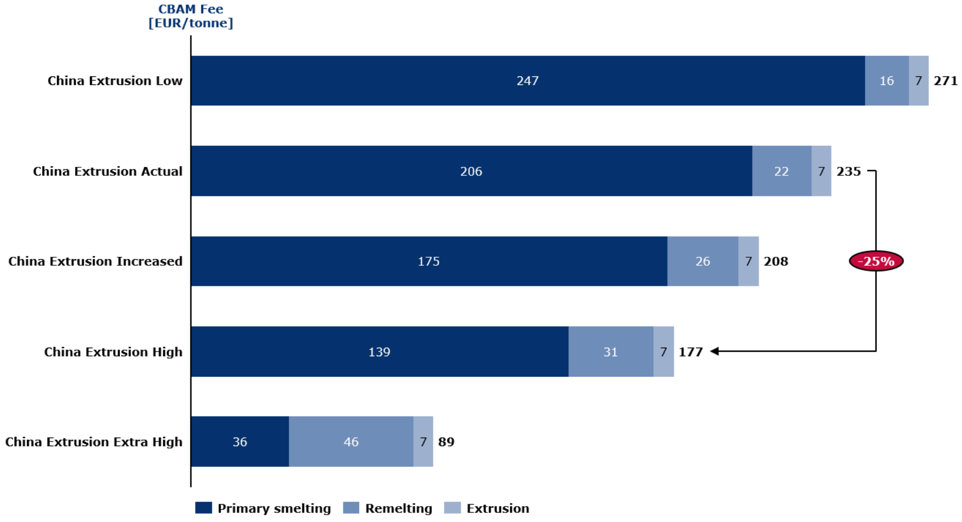
In a 2034 scenario[41], where CBAM fees will be significantly higher, as shown in Figure 40 absolute circumvention risk is consequently higher. The comparison of "Actual" to "High" allows for total cost CBAM fee savings of EUR 58 and compared to the "Extra High" case, allows for saving up to EUR 146. This adds up to approximately 3.6% and 6.5% of current LME price.

[39] China has been chosen as an example geography, due to high exports, large aluminium industry and high amounts of available scrap volumes; **Model settings**: 2030 assumptions for ETS/CBAM phase-in; EUA price at 140 €; considering full product scope in current CBAM policy design; no further decarbonisation efforts of industries.

[40] Disregarding effects of a potentially significant higher LME price in 2030/2034.

[41] 2034 calculations do not account for potential decarbonisation efforts.

Figure 36: Influence of increasing pre-consumer scrap volumes to circumvent CBAM charges [EUR/tonne] ***(2034)***[42]



Source: Ramboll CBAM Model

[42] **Model settings**: 2034 assumptions for ETS/CBAM phase-in; EUA price at 140 €; considering full product scope in current CBAM policy design; no further decarbonisation efforts of industries

6.5 CBAM impacts on aluminium prices and CBAM price scenarios

To outline the magnitude of CBAM fees and highlight the risk of circumvention by utilising higher scrap contents, different sensitivity scenarios have been extracted from the applied CBAM model for unwrought aluminium, as well as extruded and rolled products. In total, six different scenarios have been applied to model the sensitivity of the CBAM scope under different policy settings and calculate CBAM Fees and ETS costs. The six scenarios are outlined in Table 8.

Table 8: Six scenarios for CBAM fee modelling

Scenario	Description
Base Case	No CBAM on unwrought aluminium or semi-products, increasing ETS costs on European producer based on Benchmark reduction curves
"As-Is" CBAM Scope	Current CBAM design, with scrap set at 0 emissions for importers, remaining ETS costs for scrap for European producers[43]
CBAM including embedded emissions on pre-consumer scrap	Enhanced CBAM design, with pre-consumer scrap accounted for at primary emission factors
CBAM including indirect emissions and embedded emissions on pre-consumer scrap	CBAM design including indirect emissions, with pre-consumer scrap accounted for at primary emission factors
CBAM including embedded emissions on all scrap	Enhanced CBAM design, with all scrap accounted for at primary emission factors[44]
CBAM including indirect emissions and embedded emissions on all scrap	CBAM design including indirect emissions, with all scrap accounted for at primary emission factors[44]

Source: Ramboll CBAM Model Scenario Settings

To set increasing CBAM fees and ETS costs into perspective, fees have been set in relation to observed averaged market prices for the specific product group of unwrought aluminium and semi-fabricated products, namely extruded products as well as cold- and hot-rolled products.[45] These costs would partially or fully be passed on to the downstream industry and ultimately to consumers, raising the concern of downstream demand destruction.

Below, the main modelling assumptions to calculate results are described. The CBAM fee forecasts only holds true under these specific assumptions. These assumptions should be considered when comparing results from different studies.

Actual scrap scenario: Using average global values of pre- and post-consumer scrap utilised in specific product types.

High scrap case: Increasing specific regional scrap percentages for all product categories by an additional 20% for pre-consumer scrap and 20% for post-consumer scrap. [46]

[43] Assumed ETS price at embedded emissions of primary production for pre-consumer scrap
[44] All carbon cost assumed at primary for embedded scarp emissions under ETS and under CBAM
[45] Casted products have been excluded in the analysis of market impacts.
[46] Capped at 100% for possible maximum scrap content

Average non-weighted ETS fees and CBAM charges: Outlined calculated averages of CBAM charges are based on non-weighted theoretical CBAM fee averages across all global regions. ETS costs are based on a non-weighted average across EU and EFTA.

Set EUA Price: The average EUA price for calculating the CBAM fees and ETS costs has been fixed at a 2030 assumption of EUR 140 per tonne CO2, to isolate changes in free allocation and benchmarks.

Carbon intensity: Embedded emissions are calculated based on current regional averages; no further decarbonisation has been modelled. [47]

Average price assumptions: For different products different recent average European prices have been used. Prices have not been further forecasted:

- Unwrought: 2,752 EUR/tonne
- Extruded: 3,766 EUR/tonne
- Hot-rolled: 3,782 EUR/tonne
- Cold rolled: 4,593 EUR/tonne

[47] For direct emissions the in hard to abate industries, most decarbonisation efforts will only have a low to medium influence until mid-2030. For the modelled indirect emission scenario disregarding decarbonisation will led to an overestimation of CBAM fees.

Data tables of sensitivity analysis

Below Table 9 outlines relevant modelled product price increases due to CBAM/ETS in the different 2030 scenarios based on the respective scenario settings and assuming "actual scrap" average scrap contents.

Table 9:CBAM fees as percentage of product price - 2030

2030 Actual scrap	Base Case	"As-Is" CBAM Scope	CBAM + emissions pre-consumer	CBAM + indirect + emiss. pre-consumer	CBAM + emissions all scrap	CBAM + indirect + emiss. all scrap
CBAM - Unwrought	-	4.26%	5.10%	39.97%	6,75%	52,54%
ETS - Unwrought	1.74%	4.28%	4.28%	16.07%	5,72%	22,18%
CBAM- Extruded	-	3.39%	4.10%	33.25%	5,01%	39,97%
ETS - Extruded	1.47%	3.63%	3.63%	13.93%	4,26%	16,62%
CBAM – Hot rolled	-	3.40%	3.52%	26.20%	5,02%	39,27%
ETS – Hot rolled	1.39%	3.27%	3.27%	12.14%	4,27%	16,45%
CBAM - Cold rolled	-	3.05%	3.16%	28.29%	4,39%	39,05%
ETS – Cold rolled	1.40%	2.94%	2.94%	12.06%	3,77%	15,62%

Source: Ramboll CBAM Model

Below Table 10 outlines modelled relevant product price increases due to CBAM/ETS in the different 2030 scenarios based on the respective scenario settings and the "high scrap" case.

Table 10: CBAM fees as percentage of product price - 2030

2030 High scrap	Base Case	"As-Is" CBAM Scope	CBAM + emissions pre-consumer	CBAM + indirect + emiss. pre-consumer	CBAM + emissions all scrap	CBAM + indirect + emiss. all scrap
CBAM - Unwrought	-	2.05%	3.96%	29.71%	6,75%	52,54%
ETS - Unwrought	1.46%	3.28%	3.28%	11.79%	5,72%	22,18%
CBAM- Extruded	-	2.55%	3.68%	29.50%	5,01%	39,97%
ETS - Extruded	1.27%	2.91%	2.91%	10.80%	4,26%	16,62%
CBAM – Hot rolled	-	1.77%	2.69%	18.74%	5,02%	39,27%
ETS – Hot rolled	1.18%	2.54%	2.54%	9.02%	4,27%	16,45%
CBAM - Cold rolled	-	1.72%	2.47%	22.14%	4,39%	39,05%
ETS – Cold rolled	1.23%	2.35%	2.35%	9.50%	3,77%	15,62%

Source: Ramboll CBAM Model

Below Table 11 outlines modelled relevant product price increases due to CBAM/ETS in the different 2034 scenarios based on the respective scenario settings and assuming actual average scrap contents.

Table 11: CBAM fees as percentage of product price - 2034

2034 Actual scrap	Base Case	"As-Is" CBAM Scope	CBAM + emissions pre-consumer	CBAM + indirect + emiss. pre-consumer	CBAM + emissions all scrap	CBAM + indirect + emiss. all scrap
CBAM - Unwrought	-	6.54%	7.88%	42.77%	10,55%	56,34%
ETS - Unwrought	1.84%	7.08%	7.08%	18.89%	9,51%	25,97%
CBAM- Extruded	-	5.30%	6.45%	35.76%	7,90%	43,02%
ETS - Extruded	1.44%	6.09%	6.09%	16.55%	7,15%	19,66%
CBAM – Hot rolled	-	5.27%	5.47%	28.25%	7,89%	42,24%
ETS – Hot rolled	1.57%	5.45%	5.45%	14.43%	7,14%	19,42%
CBAM - Cold rolled	-	4.77%	4.93%	30.27%	6,93%	41,78%
ETS – Cold rolled	1.72%	4.92%	4.92%	14.24%	6,31%	18,35%

Source: Ramboll CBAM Model

Below Table 12 outlines modelled relevant product price increases due to CBAM/ETS in the different 2034 scenarios based on the respective scenario settings and the high scrap case.

Table 12: CBAM fees as percentage of product price - 2034

2034 High Scrap	Base Case	"As-Is" CBAM Scope	CBAM + emissions pre-consumer	CBAM + indirect + emiss. pre-consumer	CBAM + emissions all scrap	CBAM + indirect + emiss. all scrap
CBAM - Unwrought	-	3.01%	6.05%	31.84%	10,55%	56,34%
ETS - Unwrought	1.64%	5.40%	5.40%	13.93%	9,51%	25,97%
CBAM- Extruded	-	3.96%	5.78%	31.77%	7,90%	43,02%
ETS - Extruded	1.29%	4.87%	4.87%	12.93%	7,15%	19,66%
CBAM – Hot rolled	-	2.67%	4.13%	20.30%	7,89%	42,24%
ETS – Hot rolled	1.42%	4.23%	4.23%	10.82%	7,14%	19,42%
CBAM - Cold rolled	-	2.63%	3.84%	23.72%	6,93%	41,78%
ETS – Cold rolled	1.60%	3.91%	3.91%	11.27%	6,31%	18,35%

Source: Ramboll CBAM Model

Sensitivity analysis takeaways

The above tables compare the modelled price increases across scenarios and contribute with following main take-aways to the overall analysis:

In the non-CBAM "Base Case", price increases are lower compared to other scenarios but only cover ETS producers: In the base cases, CBAM is not introduced, so there is only a price increase for domestic customers. This is evident in all four tables.

Not accounting for embedded emissions in pre-consumer scrap lowers the CBAM charge: When comparing the "As-Is" scenario and the "CBAM with embedded emissions on pre-consumer scrap" scenario, it can be observed that CBAM fees are generally lower in the "As-Is" scenario, creating a price advantage for importers that is not reflective of actual carbon intensities.

Increasing scrap volumes reduces average CBAM fee increases for importers (increased margin potential): When comparing the "actual" and the "high scrap" cases across tables it is evident that importers can lower their CBAM fee by increasing scrap volumes in the "As-Is" scenario.

Price increases when including indirect emissions reach up to 43% of the unwrought aluminium price under a non-weighted global average by 2034: Primary aluminium production is highly electricity intensive. If indirect emissions are to be included under CBAM, CBAM fees increase significantly.

If scrap content is accounted for, CBAM fees are higher than ETS costs, reflecting the higher average global carbon intensity of aluminium products, compared to aluminium and aluminium semis produced in the EU/EEA. Relative ETS costs are higher than CBAM fees, when scrap is not accounted for under CBAM.

The **additional inclusion of post-consumer scrap under CBAM would** logically further **increase overall CBAM fees**, while **significantly reducing the risk of circumvention.**

Further investigations are necessary, potentially in integrated macroeconomic models, to investigate how cost increases are passed on in the value chain and how the overall creation of a European green premium market might affect macroeconomic supply and demand negatively. Here, multiple effects can create a reduction of aluminium being produced and consumed in Europe. These include, but are not limited to:

1. Reduction of overall demand due to increased prices
2. Substitution to alternative materials (e.g. ones potentially not yet full covered by CBAM or only less carbon intensive)
3. Reduction of supply, as cost increases on the European market will make domestic production and export less attractive

The impacts of these factors could be expressed in market elasticates in an integrated macroeconomic model. Especially for the scenario including indirect emissions, price increases are so significant, that further standard linear elasticates are likely not applicable. Comparison to, e.g. US aluminium and steel tariffs provides insights on how markets might react under additional tariffs[48]. Nevertheless, classical import tariffs are not directly comparable to CBAM, since (1) ETS prices raise at the same rate as CBAM import fees resulting in an equal price increase for domestic production and (2) CBAM fees are highly variable based on the carbon intensity of the specific product, whereas outlined global resource reshuffling and circumvention risks might have significant impacts on how fees will be structured from a macroeconomic perspective.

[48] United States International Trade Commission (2023). Economic Impact of Section 232 and 301 Tariffs on U.S. Industries. Available at: https://www.usitc.gov/publications/332/pub5405.pdf

6.6 Addressing CBAM circumvention through scrap utilisation

Using high volumes of scrap to significantly decrease the overall CBAM fee paid is only an option available to importers. The European aluminium value chain is fully covered by the ETS, where, from a systemic view, no resource shuffling is available, and wrong claims are not feasible due to more strict monitoring of all installations.

It is necessary to effectively address the risk of CBAM circumvention through the utilisation of scrap to maintain the competitiveness of the European aluminium industry and avoid carbon leakage. As described under the overall market effects in section *"The creation of a European market premium"*, lowering the CBAM fees through circumvention will not benefit European firms, but rather increase the margins of importers.

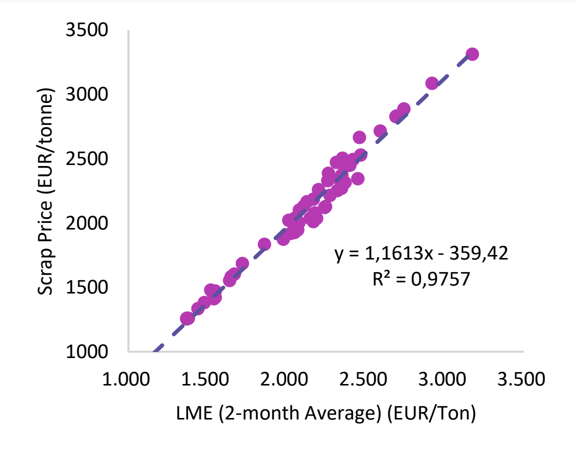
CBAM is not an import tariff, but a mechanism to reduce the risk of carbon leakage. Not assigning embedded emissions to aluminium scrap under CBAM, puts European aluminium producers at a significant disadvantage and does not mirror the paid ETS costs towards importers under CBAM. As a result, scrap needs to have emissions assigned under CBAM. Furthermost, a solution must be practical and applicable to address the complexity of the aluminium value chain. Furthermore, CBAM is not a carbon reporting instrument. As such, its scope is not one-to-one comparable with carbon emissions reporting and LCAs.

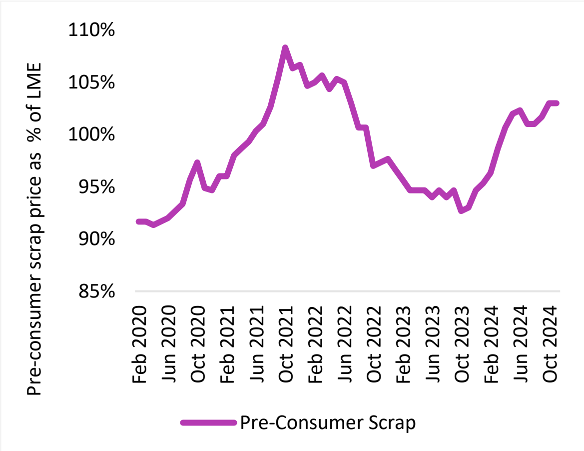
To ensure the effectiveness of CBAM, CBAM should include pre- and post-consumer scrap contents in aluminium (products) with the same embedded emissions as primary aluminium.

Addressing pre-consumer scrap

Pre-consumer scrap is utilised and priced similarly to primary aluminium[49] due to similar properties, except minor alloying components. Scrap flows are often intertwined, as such pre-consumer scrap partially originates from primary aluminium, but could also originate from previously recycled post-consumer scrap. These flows are highly product- and producer-dependent, and limited traceability is a constraint. In contrast to an importer, a European producer would pay an ETS cost for each individual reformation step.

Figure 37: LME versus EU Pre-consumer Scrap Price (EUR/tonne)





Source: CRU; Ramboll analysis

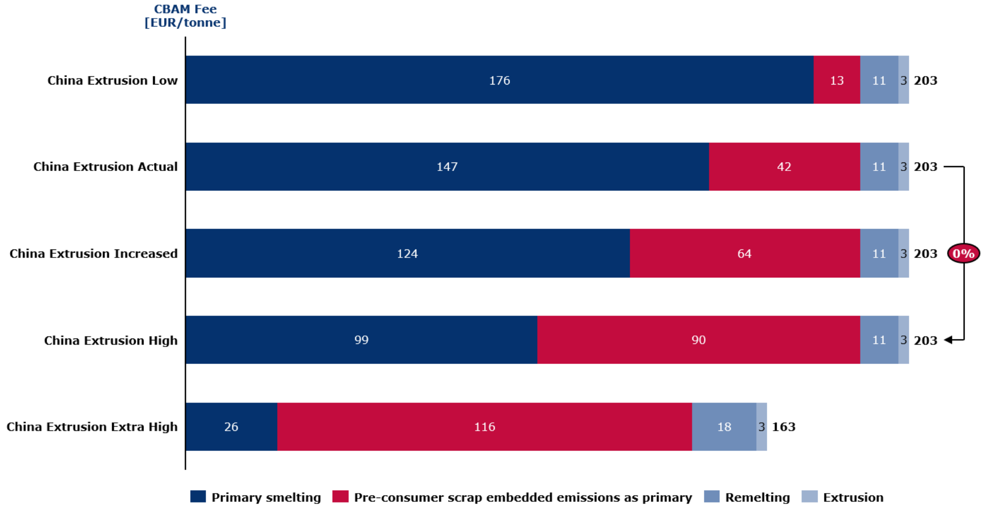
[49] Performed price analysis shows European pre-consumer scrap as being traded at 100% of LME on a 5-year average

To ensure the effectiveness of CBAM, CBAM should include pre-consumer scrap contents with the same embedded emissions as primary aluminium. Assigning primary emissions to pre-consumer scrap, makes sense from a traceability and an economical material value perspective, if pre-consumer scrap should be targeted specifically in potential regulatory changes.

Other methods of assigning embedded emissions to pre-consumer scrap will create additional complexity in the accounting system for primary scrap. For example, pre-consumer scrap would be needed to be traced back to the installations where it has been produced in order to be able to assign very accurate emission information and to define splits between primary pre-consumer scrap and pre-consumer scrap generated from previous post-consumer scrap material.

Assigning embedded emissions at primary aluminium would inhibit CBAM circumvention, as previously described in Section *Increasing the scrap percentage to reduce CBAM emissions.* The same cases for increase of scrap defined in Table 7 are shown below in Figure 38, yet here under the assumption that pre-consumer scrap is assigned the emissions of primary for the specific region. This clearly shows that an inclusion of pre-consumer scrap under CBAM would inhibit CBAM circumvention through pre-consumer scrap.

Figure 38: Influence of increasing pre-consumer scrap volumes to circumvent CBAM charges under embedded emission on pre-consumer scrap scenario [EUR/tonne] ***(2030)*** [50]



Source: Ramboll CBAM Model

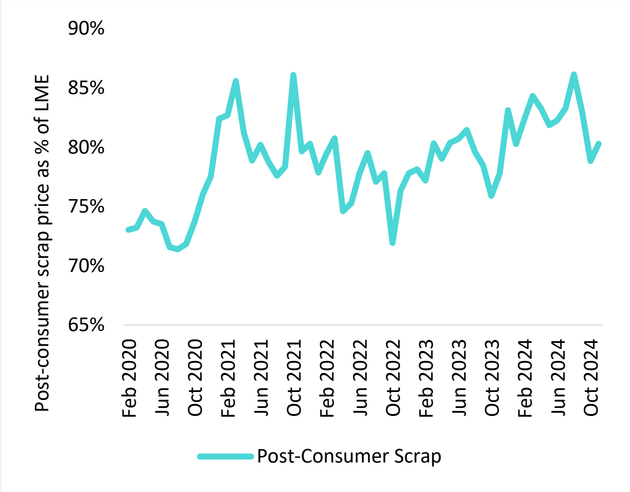
As the risk additionally remains for post-consumer scrap, an additional solution is required for post-consumer scrap. If all scrap in represented in Figure 38 would be accounted at the rate of primary, the total CBAM fee would add up to a total of EUR 258 for a standardised extrusion profile from China in 2030.

[50] **Model settings:** 2030 assumptions for ETS/CBAM phase-in; EUA price at EUR 140; considering full product scope in current CBAM policy design and additional extension with pre-consumer scrap accounted as primary; no further decarbonisation efforts of industries

Addressing post-consumer scrap

Post consumer scrap, due to alloying properties and other impurities, is less interchangeable with primary aluminium. Simultaneously, post-consumer scrap is traded at a lower price relative to the LME. Prices deviations and volatility are generally based on their specific quality and availability.[51]

Figure 39: LME versus EU Pre-consumer Scrap Price (EUR/tonne) – in percent



Source: CRU

Highly complex post-consumer scrap flows, based on different origins, qualities and quantities make an exact consistent tracking of scrap not feasible nor applicable to the CBAM regulation. Not accounting for post-consumer scrap under CBAM leaves a remaining bypass for CBAM circumvention (as shown in the Extra High Scrap case in Figure 36). Considering the phase-in horizon for full CBAM fees by 2034, third countries have a reasonable phase-in period to adjust their material and recycling flows to effectively undercut CBAM fees for exports into the EU. As a result, **also post-consumer scrap contents must be included under CBAM with the same embedded emissions as primary aluminium.**

6.7 Why national default values are needed to reduce the risk of circumvention

In its current design, CBAM is not fully applicable in the realities of the aluminium industries. Created complexities in the regulation, with the intention of creating very accurate global reporting, are not suitable to address the core complexities and objectives of the CBAM from a holistic perspective. **For unwrought aluminium national default values are required that account for overall scrap contents** to mirror the ETS and enable CBAM to work as a mechanism to reduce the risk of carbon leakage, as intended – this is due to seven concrete circumstances:

1. Applying default values significantly simplifies applied data and calculation requirements, while significantly reducing the risk of legal or non-legal CBAM circumvention methods. Simplification of CBAM further significantly simplifies any future CBAM scope extensions, especially, if manufactured final aluminium good should be included.
2. By guarding CBAM import fees against circumvention methods, CBAM is better suited to support global decarbonisation trajectories, as it sets incentives to decarbonise overall national and regional industries, instead of only re-routing lower carbon products towards the European Market.

[51] Price analysis shows a recent average at around 82% of LME, where large deviation depending on post-consumer scrap type and quality exist.

3. The implementation of default values would help prevent the potential misuse of splitting installations into sub-installations under CBAM, which could lead to additional resource reshuffling.
4. A CBAM that addresses the risk of circumvention, would function better as a mechanism to reduce the risk of carbon leakage for European industries.
5. Current required detail of accurate reporting will require a level of collaboration of local authorities and industries that is not seen realistically achievable in the medium-term.
6. Trade codes for aluminium scrap (7602) are not widely monitored, nor are they clearly mutually exclusive on types of scrap or scrap quality. This significantly complicates the monitoring of scrap contents and resulting CBAM fees. The EU needs to develop a more robust monitoring system before scrap contents can be meaningfully reported or distinguished under CBAM.[52]
7. Scrap volumes can be artificially inflated, and different scrap forms lack a consistent method of traceability. As such, different scrap types can be wrongly labelled to further circumvent CBAM (e.g. mixing pre- with post-consumer scrap), if no universal accounting standard is found.

National default values should reflect the overall carbon intensity of the respective third-country primary production of unwrought aluminium. Thereby, all CBAM fees for unwrought aluminium imported from a specific country would be calculated based on the national default value, without making installation-, producer- or scrap-content-based distinctions of the product-embedded carbon emissions. This would mean not accounting for scrap contents embodied in imported products, thus it would entirely avoid the earlier-described problem around scrap.

National default values for the country of origin (country of smelt) can be calculated based on suitable statistics determining smelter capacities, applicable fuel mixes, etc. In case no country-specific default value can be derived, due to missing information or reporting, global average values could be applied.

Semi-fabrication production processes (casting, extrusion, cold- and hot rolling) will be further based on installation-specific reporting, as is currently proposed in the CBAM regulation, where required traceability of industry installations is possible, also in third countries.

In the long term, the industry together with the Commission, needs to develop a more detailed approach to account for decarbonisation efforts in all global regions and allow for a more precise mirroring of the ETS within the CBAM. Such efforts will be more applicable once the impacts of CBAM can be observed in practice, and then a more detailed reporting of CBAM fees can be implemented without risking significant circumvention.

Accounting scrap as primary material could de-incentivise recycling and circularity in third countries in the long term, and CBAM may fail to adequately reward decarbonisation efforts in third countries achieved through increased recycling rates. This is especially true for post-consumer scrap and could be counterproductive to overall global decarbonisation targets. To address this issue, a national mass-balance approach could facilitate the development of more nuanced national default values. For example, national default values could encompass the overall volume of post-consumer scrap generation relative to primary aluminium production. This would allow for the deduction of an average percentage of post-consumer scrap integrated into all aluminium products imported from a specific country. This approach could enhance consistency with the Emissions Trading System (ETS), support

[52] Based on the absence of detailed trade codes and available trade data, the analysis of scrap volumes conducted as part of this report has been based on the detail material flow model provided at the courtesy of the International Aluminium Institute.

general sustainability practices, and incentivise circularity and recycling in third countries but requires more detailed exploration.

The underlying model developed as part of this study – outlining different energy intensities of processes, fuel and electricity mixes, regional capacities, and the different scrap volumes – can be a starting point for deriving national default values for unwrought aluminium imports. Consequently, default values would need an update cycle to account for successful decarbonisation efforts in national industries.

6.8 Recyclers under CBAM and benchmark discussion

Scrap recyclers, like aluminium refineries, do not, in contrast to aluminium smelters, operate under a dedicated product benchmark. They are currently based on the input-based heat- and fuel benchmark. These benchmarks reduce at a faster rate than product-specific benchmarks (annual reduction of heat and fuel benchmark 2021-2026: 1.6%).

Like alumina refineries, recyclers have limited access to commercially available decarbonisation options due to the high heat requirements in the remelting process. This results in a reduction of fallback benchmarks at a level that is neither commercially nor technically viable for aluminium recyclers. Consequently, recyclers under ETS will be subject to significantly higher ETS costs, as their free allocation benchmarks are disproportionally reduced. As such, a lack of a dedicated product benchmark for secondary aluminium has been a design flaw in the original ETS design.[53]

If products are included under CBAM, their free allocation benchmarks get increasingly irrelevant, as free allocation is phased out under CBAM in the medium-term.

CBAM creates an opportunity for recyclers, while being under significantly higher carbon cost after the loss of free allocation, to get the same high carbon costs applied to importers. In the current ETS design, without a dedicated benchmark, recyclers have a cost disadvantage compared to importers not paying any carbon costs.

The average ETS costs for European recyclers are shown below in Table 13, based on basic averaged energy intensities for recycling, assumed split between heat and fuel, natural gas as an energy source, and forecast benchmark reduction curves.[54] The EUA price has been indexed at EUR 100 to highlight the differences in benchmark and allocation developments without the noise of the EUA price development.

Table 13: Scenario ETS cost developments for recyclers in Europe [EUR/tonne], Indexed EUA price at 100 EUR/tonne for better comparison[55]

Scenario	ETS costs 2025	ETS costs 2030	ETS costs 2034
“As-Is”: CBAM and fallback benchmark Covered by CBAM, loss of free allocation, fuel and heat fallback benchmark	5.90 EUR/tonne	14.70 EUR/tonne	22.00 EUR/tonne
CBAM with product benchmark Covered by CBAM, loss of free allocation, dedicated secondary aluminium benchmark	0.10 EUR/tonne	10.80 EUR/tonne	22.00EUR/tonne
No-CBAM with fallback benchmark Only ETS, remaining free allocation, fuel and heat fallback benchmark	5.90 EUR/tonne	7.80 EUR/tonne	9.70 EUR/tonne
No-CBAM with product benchmark Only ETS, remaining free allocation, dedicated secondary aluminium benchmark	0.10 EUR/tonne	0.40 EUR/tonne	0.50 EUR/tonne

Source: Ramboll CBAM Model

[53] The political likelihood of the adoption of a secondary aluminium product benchmark has not been assessed. As CBAM requires dedicated product benchmarks, the inclusion of a secondary aluminium benchmark under the ETS would be reasonable.
[54] For specific installation, resulting ETS cost differ significantly based on installation specific properties. Dedicated benchmark assumptions for actual installation to expected higher as a process efficient benchmark setting installation has been assumed.
[55] To compare recycler costs to other scenarios with a higher price the index can be used for multiplication (e.g. when comparing to a EUA price of EUR 140 prices outlined in the table can be multiplied by 1.4)

6.9 Indirect emissions discussion

Currently, CBAM only covers direct emissions of aluminium production and processing, while indirect emissions are not included. Alumina refining and semi-fabrication processes have limited indirect emissions, which will likely decrease because of decarbonisation efforts. This is particularly relevant for remelting and semi-fabrication, where electrification is more likely.

Conversely, the smelting process of aluminium is extremely electricity intensive, requiring around 14 MWh per tonne of primary aluminium. Including indirect emissions for aluminium would therefore significantly increase the energy and carbon intensity covered by CBAM. This inclusion would have two major effects that would significantly alter the market dynamics described in this analysis:

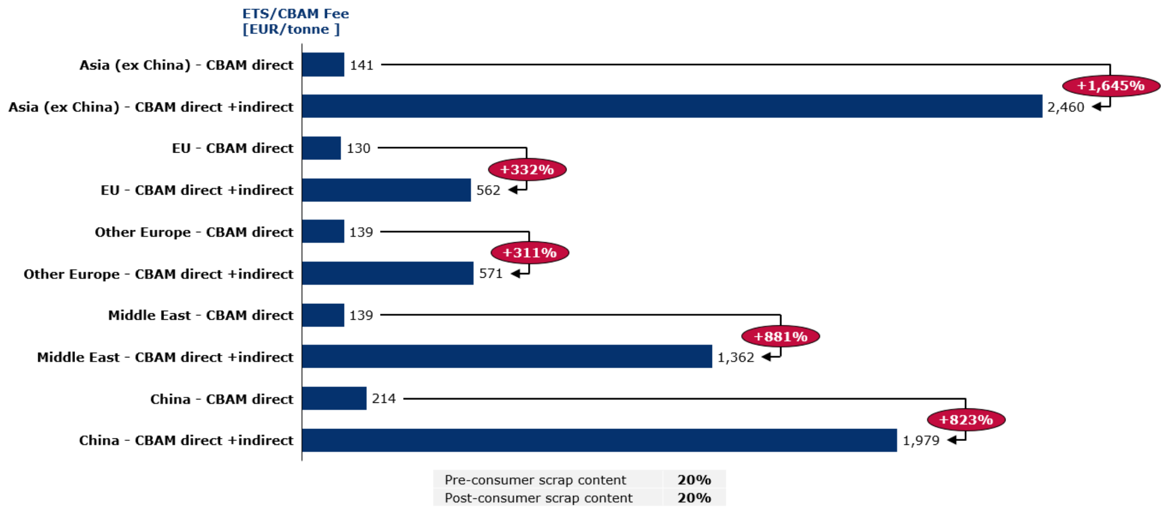
1. **Amplifying global differences in primary aluminium production**: The disparity between the carbon intensity of primary aluminium production across regions would be significantly amplified, because the energy used to generate electricity for smelting processes varies greatly in carbon intensity (e.g., hydro power versus coal-generated electricity). The CBAM fee model demonstrates, that based on regional averages, the indirect carbon intensity for primary aluminium is 2.62 t CO_2 per tonne of primary aluminium in EEA countries compared to an average of 15.27 t CO_2 per tonne of primary aluminium from China. In the current CBAM design, there are no substantial differences between primary aluminium emissions intensities, because direct emissions from the primary production route arise from the chemical reaction (the Hall-Héroult process) and are not related to fuel usage. There are, however, slight differences based on the exact technologies that different smelters have installed.
2. **Increasing attractiveness of secondary production routes**: Using secondary production routes or higher scrap content becomes significantly more attractive as it lowers the emission intensity covered by CBAM. This amplifies the risk of circumvention and increases the demand for scrap. Based on the current CBAM design, this would make resource reshuffling and other circumvention methods even more profitable for importers and further undercut European producers.

The inclusion of indirect emissions would significantly increase CBAM fees and further raise the market premium on all aluminium products within Europe, subsequently increasing prices for all off-taker markets. Figure 40 illustrates the potential rise in CBAM fees, if indirect emissions were to be included. CBAM fees could potentially increase by 311% to 1,645% under the set 2030 scenarios. In 2034 scenarios the increase in CBAM fees would be even higher due to a full CBAM phase-in.

For instance, the total price of Chinese unwrought aluminium imports could rise by over 80% in 2030 compared to global LME prices. Such market impacts would result in a substantial decrease in both demand and supply, along with a high rate of substitution that would extend beyond market-comparable elasticities.

These price impacts would be so significant that projections of European demand and supply curves become challenging to predict based on existing market knowledge. Consequently, the immediate inclusion of indirect emissions could critically paralyse the European aluminium industry, as well as all associated downstream industries. The incorporation of indirect emissions into the CBAM scope is only feasible when a broader availability of low-carbon electricity sources is accessible to the aluminium industry, both within Europe and globally. This is necessary because downstream producers are currently incapable of absorbing price increases at such magnitudes.

Figure 40: Comparison of inclusion of indirect emissions for unwrought aluminium [EUR/tonne] ***(2030)***[56]



Source: Ramboll CBAM Model

Figure 40 does not include any potential future decarbonisation efforts and calculates CBAM fees based on current electricity sources of aluminium production. Further it does not account for indirect cost compensation for calculating the ETS costs of domestic producers.

Overall, the inclusion of indirect emissions under CBAM would further create additional circumvention risks through green electricity claims and would create additional flaws when mirroring the ETS costs for CBAM imports. In Europe, the ETS price is directly included in all electricity prices, due to the ETS cost for the electricity producer. [57]. Due to the marginal price setting mechanism on the electricity market, this "baked-in" ETS price cannot be avoided by European producers, even when procuring green electricity through e.g. specific green PPAs.

As a compensation, some European producers receive compensation to the ETS price paid as part of the electricity price (often referred to as "state aid for indirect emission costs"). This compensation is currently applied inconsistently on a national level as per Article 10a of Directive 2003/87/EC until 2030. The inconsistent application of state aid on a national level creates an additional European market distortion and fragmentation, where already today some European producers are not subject to any state aid.[58]

Including indirect emissions under the CBAM would realistically result in the phase-out of remaining indirect cost compensation for European producers. All in all, this would create a significant mismatch under the attempt of mirroring the cost of indirect emissions of European producers onto CBAM importers. By including indirect emissions under CBAM, European producers would have a significant cost disadvantage, if indirect cost were no longer being compensated. A European producer will not

[56] ETS costs excluding indirect cost compensation; 2030 forecast based on current grid emissions potentially overstating the increase in 2030, if indirect emissions are to be included; **Model settings:** 2030 assumptions for ETS/CBAM phase-in; EUA price at EUR 140; considering full product scope in current CBAM policy design plus extension with pre-consumer scrap accounted as primary, Indirect emission scenario to include indirect emissions, Indirect emissions modelled based on process electricity demand and regional grid emission factors; fixed scarp volumes; no further decarbonisation efforts of industries and grids

[57] Draghi, M. (2024) The future of European competitiveness Part A: A competitiveness strategy for Europe. Available at: https://commission.europa.eu/topics/eu-competitiveness/draghi-report_en

[58] European Commission (2024). The future of European competitiveness; Part B | In-depth analysis and recommendations. Available at: https://commission.europa.eu/topics/eu-competitiveness/draghi-report_en

be able to effectively avoid these carbon costs in their electricity price. At the same time, exporters to the EU have a possibility to procure electricity from renewable sources, avoiding any CBAM fees on indirect emissions, as they can procure carbon free electricity in third countries without an included carbon price. Before CBAM can include indirect emissions on aluminium, these complications need to be effectively addressed, especially due to the high electricity demand of aluminium smelting. Failure to address these issues will place European producers at a competitive disadvantage, significantly increase aluminium prices in Europe, adversely impact the downstream industry, and potentially lead to the substitution of aluminium in various applications despite its superior material properties.

7. Conclusions

CBAM is designed as a policy instrument to mitigate carbon leakage, where importers of products should be subject to the same carbon costs as European producers. As such, a thorough assessment of CBAM impacts also requires a nuanced understanding of the ETS system.

The CBAM mechanism should support a holistic development of global carbon taxation schemes to effectively combat climate change at the global level. A global price on carbon is eventually one of the few methods to reach a global equilibrium between climate change impact and carbon emissions reduction.[59]

In its current design the combination of the higher production ETS costs and higher CBAM import costs creates a high premium market in the EU. This has raised concerns of downstream demand destruction, reduced competitiveness of EU producers, an accelerated deindustrialisation in the EU, and without an export support scheme, and inability of European producers to export to the global market. Especially EIIs currently lack commercially feasible technologies and access to low carbon energy to decarbonise at a significant rate.

This study investigated the impact of specific CBAM design elements on the European aluminium industry. These design elements include the future potential inclusion of alumina into the CBAM scope, as well as the risk of CBAM circumvention by using significant amounts of scrap in imported products, currently accounted for at zero emissions in the CBAM regulation. For the accounting of scrap, it could be shown that the current CBAM design puts European producers at a direct disadvantage while the CBAM would miss its overall policy objectives of incentivising global and regional decarbonisation. As part of the analysis other current issues around the CBAM implementation, where future changes can be expected, have been discussed on a holistic level (namely inclusion of indirect emissions under CBAM for aluminium, cost absorption, current exclusion of downstream industries and no export support scheme).

7.1 Impact of the further development of the European ETS and its impact on CBAM

The detailed long-term development of specific ETS policy design aspects for the European aluminium industry is dependent on multiple future changes to the ETS system. Currently the ETS is trading in phase 4 (2021-2030). Significant updates to ETS benchmarks are due by 2026. Updates to the ETS under phase 5 after 2030 are speculative. As result, this analysis often highlights CBAM impacts by 2030 and 2034.

Based on the defined EU ETS allowances cap and the defined liner reduction rate (currently 4,3%; 4,4% from 2028) last EU ETS allowances would be issued around 2040, aligning with overall EU decarbonisation targets. The current banking system of the ETS would enable the usage of allowances at later stages.

This means that free allocation for EU installations will need to be phased out in the medium-term, also for industries and goods not yet covered by CBAM. Further it puts the introduction of CBAM, and the need for a mechanism to prevent carbon leakage into a long-term perspective, as European Industries cannot rely on free allocation under supportive product benchmarks in the long-term.

[59]For example, shown by William D. Nordhaus (Nobel Prize in Economics, 2018)

This creates further uncertainty in the long-term forecasting of ETS and CBAM impacts, specifically after 2030. Main uncertainties relevant for the impacts outlined in this study are:

- Predictable ETS benchmark updates in 2026 and high uncertainty for ETS benchmarks past 2030
- High uncertainty for free allocation past 2030 (currently at 43% of emission cap) exceeding available emission cap, resulting in a further reduction for all ETS benchmarks through the application of a cross sectoral correction factor (CSCF)
- Uncertainty around further national application off state aid for indirect emission costs past 2030

Simultaneously, the CBAM policy will be subject to change. Current discussion indicates that the CBAM definite regime from 2026 will remain on track. Regardless, technical changes to the policy are required as shown in this study. Furthermore, the CBAM scope will extend vertically and horizontally in the coming years, covering more sectors, materials and products[60]. The impact of the CBAM on EU industry should be closely monitored by EU policymakers, and the policy should be reconsidered if the CBAM does not prove to be an effective instrument to prevent carbon leakage.

> *"The EU should **closely monitor and improve the CBAM design** during the transition phase and **consider postponing the phase out of free ETS free allowances** for EIIs if implementation is ineffective."*
>
> The future of European competitiveness Part A | A competitiveness strategy for Europe *(page 51)*

7.2 Wider policy design shortfalls and creation of a high premium market

The above analysis on alumina and scrap as part of aluminium, gives some wider insights into effects of CBAM on the aluminium industry. The underlying scenario model, based on semi-quantitative analysis only addresses these wider CBAM policy effects partially. Impacts are based on a strict set of assumptions and variables. These policy concerns should be addressed in more detail before the CBAM is applied sector wide.

Green premium market

ETS and CBAM will create a premium market for aluminium in the jurisdiction of the ETS/CBAM. Circumvention of CBAM, as widely discussed in this report, must be effectively minimised as it would directly improve the profitability of third country importers on the European Market. Due to the high energy- and resulting carbon-intensity, combined with a high global tradability for aluminium, market effects are at a higher magnitude compared to other materials and commodities covered, or to be potentially covered by CBAM.

Downstream manufacturing must consequently be included in the CBAM scope. Otherwise, there is a significant incentive to offshore remaining European final manufacturing and assembly, so final goods can be imported into the EU without the additional carbon costs.

Further this analysis assumes a significant cost-pass through of carbon costs in the value chain, possible due to the overall creation of a green premium market and the assumption that final products are

[60] Consolidated text: Directive 2003/87/EC

eventually included under CBAM. It predominantly ignores wider risk of overall downstream demand destruction through significantly higher prices for commodity material prices within the EU. Aluminium is an essential material for many European industries including energy, buildings, transport and defence. Especially due to its role in energy and transport, aluminium is an enabler of decarbonisation efforts and the green transition.

Downstream demand destruction might be amplified by cross commodities effects in a complex system, leading to an overall significant economic slowdown within the European Union. This could further reduce demand by European Industries for aluminium and aluminium products.

Lastly, CBAM requires an export support mechanism/compensation for European Industries. Based on the overall higher carbon costs of European production, firms are not able to sell their products on markets that are not subject to a carbon cost premium. This creates a competitive disadvantage for European firms, producing at an overall lower carbon intensity, not being able to diversify and derisk their sales to other geographies.

ETS as absorbed costs vs. CBAM as a variable cost component

The reduction of free allocation for European installation covered by CBAM, leads to an overall increase in their production costs and raw material costs due to additional carbon costs. Parts of these costs can and will be passed on down the value chain, ultimately reaching consumers. However, European producers will always bear these initial carbon cost on their overall production volumes, impacting their available cash flows. In contrast, a foreign producer can export to the European Market based on their own preferences and how attractively they rate this market (disregarding partial vertical integration of aluminium producers), choosing the amount of their production subject to additional variable carbon cost through CBAM. Overall, this may cause uneven effects across companies and could lead, based on current CBAM design, to a dominant reshuffling of resource instead of a global net reduction in emissions.

7.3 Sub-conclusions regarding alumina

The European alumina industry is under considerable strain due to high energy costs and declining domestic demand following aluminium smelter closures. With only four refineries remaining in the EU after recent shutdowns, additional carbon costs under the EU ETS and the asymmetrical implementation of CBAM could further weaken the sector's competitiveness.

Currently, alumina refineries fall under the heat and fuel fallback benchmarks, which do not adequately reflect their emissions levels. As a result, refineries face disproportionately high carbon costs that they cannot pass on to industrial consumers due to alumina being traded globally. This exacerbates the risk of carbon leakage and puts the sector’s long-term viability at risk.

This study has demonstrated that EU alumina refineries are among the most energy-efficient globally. Their closure would likely lead to an increase in emissions through the import of higher-carbon alumina from outside the EU. Introducing an ETS benchmark tailored to alumina refineries, based on the best-performing facility, would provide a more accurate reflection of their emissions reduction potential and mitigate the risk of carbon leakage.

Regarding CBAM, the inclusion of alumina in its product scope would drive up the marginal price of alumina in the EU + EFTA region by an estimated 12-16%, depending on design choices such as whether only direct emissions are covered and whether alumina is assigned a separate benchmark. This would prevent carbon leakage in the EU alumina refining industry, because importers would have to pay a carbon cost at a similar level to EU refineries. This direct effect would improve the competitiveness of EU alumina refineries. The carbon costs associated with alumina as a precursor would raise raw material costs further down in the value chain, especially for recyclers, semi-fabrication production and manufacturing of final goods. Moreover, if alumina demand in the EU falls as a result, the higher costs would make EU alumina exports uncompetitive without an export compensation mechanism.

A balanced approach to carbon pricing and trade policy is critical to maintaining a viable alumina refining sector in the EU. Ensuring an appropriate ETS benchmark and delaying CBAM inclusion for alumina until all downstream industries are also included will help safeguard the industry's competitiveness while maintaining progress toward EU climate goals.

7.4 Sub-conclusions regarding aluminium scrap

Currently, Aluminium scrap is not covered by the CBAM as a product or precursor. As a result, recycled aluminium scrap embedded in finished products is assigned zero embedded emissions when reporting on imports into Europe. This study clearly highlighted, that this practice puts the European producers at a disadvantage, risks significant CBAM circumvention and falls short to incentivise global decarbonisation of the aluminium industry.

This study has analysed aluminium production, trade, and pricing in order to assess the competitiveness impacts, price shifts, and market flows resulting from the exclusion of scrap as an aluminium product and precursor under CBAM. Different CBAM design options were modelled, to identify a policy design that would lead to carbon prices of imports most closely mirroring the ETS costs that EU+EFTA producers face domestically.

Overall, CBAM on aluminium will increase aluminium prices of the metal in Europe, creating an EU+EFTA market green premium. This price increase will cascade throughout the value chain, raising costs for producers and consumers, raising among others concerns around demand destruction. While indirect emissions are currently excluded from the CBAM design for aluminium, their inclusion would further drive-up a green market premium in the EU/EFTA market and due to the high electricity demand in aluminium production, in essence, paralyse the European aluminium industry.

For scrap, the global availability of pre- and post-consumer scrap presents a significant risk of CBAM circumvention through significant resource reshuffling and false claims. CBAM circumvention allows importers to directly improve their margins on an attractive EU market, while directly undercutting European producers. To enhance the CBAM’s effectiveness, maintain market stability, and ensure alignment with the EU ETS framework, this study recommends:

1. No inclusion of indirect emissions for aluminium under CBAM, in order to prevent excessive cost increases and the risk of carbon leakage.
2. Assigning a national default emissions value to all unwrought aluminium at the level of primary with no distinction between the primary or secondary production route in the short- and medium-term, in order to prevent CBAM circumvention, not disadvantaging European producers and ensuring CBAM can incentivise global decarbonisation.

Appendix

Overview of data collection sources for material flows and assumptions

Value chain	Global production	EU Imports	EU Exports
Bauxite	UK Geological Survey Reports US Geological Survey	UN Comtrade – HS 260600 (aluminium ores and concentrates)	UN Comtrade – HS 260600 (aluminium ores and concentrates)
Alumina	UK Geological Survey Reports US Geological Survey	UN Comtrade - HS 281820 (aluminium oxide, other than artificial corundum)	UN Comtrade - HS 281820 (aluminium oxide, other than artificial corundum)
Primary aluminium	UK Geological Survey Reports US Geological Survey Company annual reports	UN Comtrade – HS 7601 (aluminium; unwrought)	UN Comtrade – HS 7601 (aluminium; unwrought)
Semi-fabricated products	IAI Alucycle Model *Assumed EU production as a proportion of Europe based on the number of plants and average plant capacity in Europe.*	IAI Alucycle Model *Assumed EU production as a proportion of Europe based on the number of plants and average plant capacity in Europe.*	IAI Alucycle Model *Assumed EU production as a proportion of Europe based on the number of plants and average plant capacity in Europe.*
Process scrap	IAI Alucycle Model *Assumed EU production as a proportion of Europe based on the number of plants and average plant capacity in Europe*	IAI Alucycle Model *Assumed EU production as a proportion of Europe based on the number of plants and average plant capacity in Europe.*	IAI Alucycle Model *Assumed EU production as a proportion of Europe based on the number of plants and average plant capacity in Europe.*
Manufacturing	IAI Alucycle Model *Assumed EU production as a proportion of Europe based on EU GDP as a percentage of total Europe GDP.*	IAI Alucycle Model *Assumed EU production as a proportion of Europe based on EU GDP as a percentage of total Europe GDP.*	IAI Alucycle Model *Assumed EU production as a proportion of Europe based on EU GDP as a percentage of total Europe GDP.*
Manufacturing scrap	IAI Alucycle Model *Assumed EU production as a proportion of Europe based on EU GDP as a percentage of total Europe GDP.*	IAI Alucycle Model *Assumed EU production as a proportion of Europe based on EU GDP as a percentage of total Europe GDP.*	IAI Alucycle Model *Assumed EU production as a proportion of Europe based on EU GDP as a percentage of total Europe GDP.*
Post-consumer scrap	IAI Alucycle Model *Assumed scrap availability in the EU as a proportion of Europe based on EU GDP as a percentage of total Europe GDP.*	UN Comtrade – HS 760200 (waste and scrap, aluminium) *Assumed that all aluminium scrap imported and exported in the EU is post-consumer scrap.*	UN Comtrade – HS 760200 (waste and scrap, aluminium) *Assumed that all aluminium scrap imported and exported in the EU is post-consumer scrap.*

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