



ENVIRONMENTAL PROFILE REPORT FOR THE EUROPEAN ALUMINIUM INDUSTRY

Life Cycle Inventory (LCI) data for aluminium
production and transformation processes in Europe

Full Report

Version 2.0

May 2025

Change log

This edition (May 2025, version 2.0) of the *Environmental Profile Report for the European Aluminium industry* includes corrections to the models for primary aluminium production (Section 4), revision of the life cycle inventory (LCI) of the electrolysis for imported primary aluminium, and a correction to the LCI of aluminium foil production (Section 6), as detailed below.

These updates aim to improve the accuracy and consistency of the environmental modelling and are based on updated datasets and internal validation checks.

While these revisions affect the environmental impact results for primary aluminium (Section 4.6), they do not affect the overall conclusions of the report. Nevertheless, we encourage readers to refer to this updated version for the most accurate information.

Version 2.0 – May 2025

Primary aluminium production (Section 4):

- The inventory values for the electrolysis process of imported primary aluminium (Table 4-6, column labelled “European Aluminium 2019”) were corrected. While the values were correctly implemented in the model, they were not correctly reported in the report due to an issue during data extraction.
- The modelling of electricity and thermal energy demand from heavy fuel oil for imported alumina production was revised. While the correction on the electricity contribution applies to both direct and indirect (via primary ingots imports) alumina imports, the correction to thermal energy demand from heavy fuel oil concerns only directly imported alumina into Europe.
- Transport distances related to the direct imports of bauxite and alumina into Europe were revised in the transport modelling.

Aluminium foil production (Section 6):

- A correction was made to the electricity demand reported in the life cycle inventory for aluminium foil production (Table 6-1).

Version 1.0 – November 2024

Initial release of the *Environmental Profile Report for the European Aluminium industry*.

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List of Abbreviations

ADP	Abiotic Depletion Potential
AP	Acidification Potential
CO ₂	Carbon dioxide
CPC	Calcined Petroleum Coke
EFTA	European Free Trade Association
EP	Eutrophication Potential
EU	European Union
GJ	Gigajoule
GLO	Global
GWP	Global Warming Potential
IAI	International Aluminium Institute
IPCC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
LCA FE	LCA for Experts software (fka. GaBi)
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MJ	Megajoule
Mt	Million tonnes
NO _x	Nitrogen oxides
ODP	Ozone Layer Depletion Potential
PEF	<i>See</i> Product Environmental Footprint
PFC	Perfluorocarbons
POCP	Photochemical Ozone Creation Potential
RU	Russia
SPL	Spent Pot Lining
UAE	United Arab Emirates
UV	Ultra-Violet rays
ZA	South Africa

Preface

The European aluminium industry promotes life cycle thinking and supports the use of Life Cycle Assessment (LCA) which contributes to further environmental improvements in aluminium product development in a life cycle concept. Whenever organisations are doing LCA for aluminium products in which it is appropriate to use European data, European Aluminium contributes to supplying information and data, making it best to provide information in line with the study goal and scope.

The European aluminium industry is striving to improve the environmental performance of its processes and products by promoting:

- efficient use of resources and energy,
- reduction of emissions to air and water,
- reduction of waste
- high recycling rates at the end of the product life cycle.

After use, aluminium products are a valuable re-usable resource which is efficiently recycled through well-established collection schemes, scrap preparation technologies and refining processes. The European recycling rates for end products are currently over 90% for the automotive sector and the building sector (EA, 2022). The recovery rates of used aluminium packaging vary depending on the specific products and the collection practices operated in the different countries. Concerning aluminium cans, the official European collection rate reached 76% in 2021, without considering informal recycling routes (Metal Packaging Europe & European Aluminium, 2024). Since the current aluminium product range is extremely wide, the end-of-life recycling rates can vary significantly.

When addressing the full life cycle assessment (“Cradle to Grave”), the aluminium industry recommends using the end-of-life recycling approach which is the methodology best describing the environmental aspects related to the recycling performances of the final products. The end-of-life recycling approach is based on a product life cycle and material stewardship perspective. It considers the fate of products after their use stage and the resultant material output flows.

This environmental report provides up-to-date life cycle inventory data (LCI) for aluminium production and transformation processes in Europe. This report and the associated LCI data have been developed in full reference to the 2 relevant ISO standards ISO 14040 and 14044 (ISO 14040:2006/Amd 1:2020, 2020; ISO 14044:2006/Amd 2., 2020). This document is based on environmental data related to the year 2021. It updates the previous datasets which were published in February 2018 with the reference year 2015 (EA, 2018), April 2013 with the reference year 2010 (EA,2013), May 2008 with the reference year 2005 (EA, 2008) and September 2005 with the reference year 2002 (EA,2005).

1 The Aluminium Product life cycle

The standard life cycle of an aluminium product system can be represented by a series of distinct process steps, as illustrated in the flow chart presented in Figure 1-1. The delineation of the specific system boundaries for European Aluminium datasets is detailed in Figure 2-1.

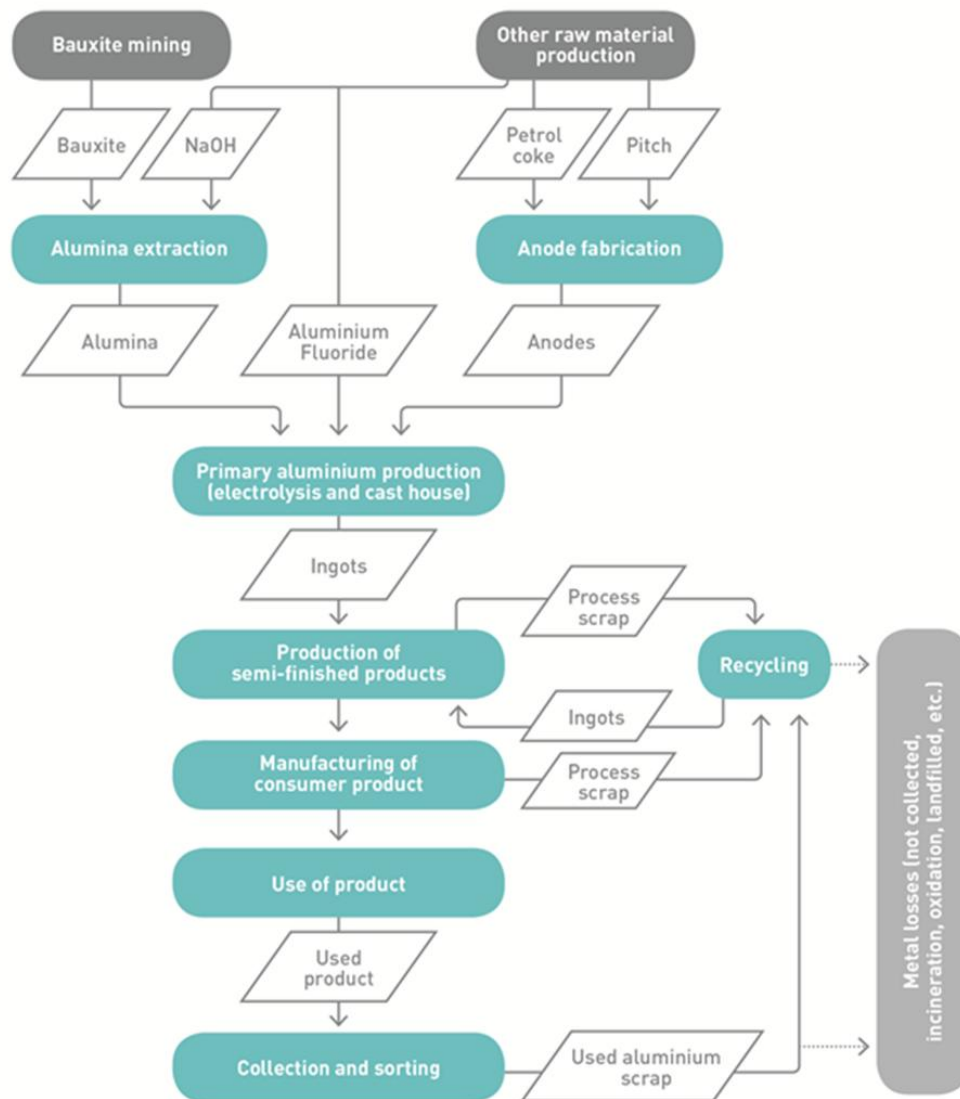


Figure 1-1 Simplified life cycle material flow chart of an aluminium product

The main raw material for aluminium is bauxite, which is extracted from bauxite mines and processed into aluminium oxide at alumina plants. Aluminium metal is produced from aluminium oxide by an electrolytic process.

In addition to alumina, the main raw materials are carbon anodes and aluminium fluoride. In a cast house, aluminium from the smelters, aluminium scrap and alloying elements are mixed to reach the appropriate composition and then cast into ingots for rolling, extrusion or product casting.

Wrought aluminium products are fabricated from ingots by hot working (mainly a rolling or an extrusion process) which is normally followed by cold working and /or finishing operations.

Aluminium castings are manufactured by the solidification of molten alloys, followed by finishing operations.

Aluminium production scrap is generated throughout the diverse stages of aluminium production. This scrap is either directly reintegrated into a closed loop within the originating plant or sent to specialized remelters for external recycling. A significant portion of aluminium scrap formed from products at the end of their service life is extensively reclaimed and recycled to manufacture new aluminium products.

2 Goal and scope of the LCA

2.1 Goal

The updated environmental data and associated LCI datasets annexed to this report should be used for:

- Life cycle assessment (LCA) studies related to aluminium products fabricated in Europe, i.e., products made of aluminium or containing aluminium.
- Updating the environmental and LCI databases related to aluminium processes in Europe.

Therefore, these datasets **are designed to serve as reference materials for LCA studies focusing on products made of or incorporating aluminium**. To complete the product system under study, users should gather the following supplementary data and information:

- Inventory data on the production of components not made of aluminium,
- Inventory data on the production and assembly of the final product system from semi-fabricated aluminium components and possibly other material pieces,
- Inventory data related to the use phase of the product system,
- Inventory data associated with the end-of-life treatment, with a particular emphasis on the collection and recycling processes for aluminium.

The data provided by the European Aluminium members relating to their process steps are the most up-to-date industry average data for these processes. It is therefore recommended to utilize this data for LCA purposes, whenever generic aluminium data for Europe is required. Older literature data should be discounted as they may no longer be representative due to advancements in technology, improvements in operational efficiency, changes in raw materials or waste treatment practices.

In this context, this report is mainly targeting LCA practitioners (e.g. consultants, database providers, etc.), companies belonging to the aluminium value chain (i.e., aluminium producers, consumers, or suppliers), research entities (e.g. universities or environmental agencies) or any other stakeholders interested in having accurate environmental information related to the aluminium industry performance in Europe.

This study is not intended to support comparative assertions intended to be disclosed to the public. However, the study/data may be used to support comparative assessments (related to products made of or containing aluminium) to be disclosed to the public based on a functional unit and the full life cycle as well as an additional critical review.

2.2 Scope

2.2.1 Product system and system boundaries

2.2.1.1 Products system

In total, this report presents 8 life cycle inventory (LCI) datasets based on the years 2021 to 2023. The system boundaries for these diverse datasets are depicted in Figure 2-1.

- 2 datasets related to primary production (cradle-to-gate): one for primary aluminium “produced¹ in Europe” (A) and one for primary aluminium “used² in Europe” (B).

The LCI dataset related to **primary aluminium “produced in Europe” (A)** corresponds to 1 tonne of primary aluminium ingot, i.e., from bauxite mining to the sawn aluminium ingot ready for delivery. This dataset includes all environmental impacts of the different process stages and raw materials necessary to deliver 1 tonne of sawn primary ingot produced by European smelters. Since electricity consumption is the main contributor to the environmental aspects, a specific electricity model has been developed based on the electricity consumed by European smelters.

The LCI dataset related to **primary aluminium “used in Europe” (B)** is similar to the previous one but takes also into account the primary aluminium imported into Europe, which represents 48% of the European consumption in 2021 (see Section 3.5). The modelling of primary aluminium production outside Europe is based on regional data sourced from the (IAI, 2012). Additionally, a dedicated electricity model for the electrolysis process was developed, as detailed in Section 4.4.3, considering the origins of the imports.

- 3 datasets on semi-finished aluminium products fabrication (i.e., gate-to-gate) respectively, sheet, foil and extrusion (i.e., profile) production.

The LCI datasets for '**semi-production**' processes (**sheet, profile**) depict the conversion of a sawn aluminium ingot into a semi-product—either a profile or sheet—prepared for delivery to the end-user. These datasets encompass the recycling of scrap and chips generated in this semi-fabrication stage, along with the recycling of dross. The datasets specifically represent the production of 1 tonne of profile, sheet.

The LCI dataset relating to foil production was developed by EAFA (the European Aluminium Foil Association) and covers the entire process, i.e. production of foil stock (both hot rolling and continuous casting routes), foil rolling, plus recycling of process scraps. The dataset represents the production of 1 tonne of aluminium foil.

¹ Produced by smelters located in Europe (i.e., without imports of primary aluminium ingots).

² Including imports of primary ingots from outside Europe: 48% of primary aluminium used in Europe is imported (Source: Eurostat for EU27 and national customs data for EFTA countries)

- 3 datasets on scrap (pre- and post-consumer scrap) recycling

The LCI dataset for the ‘**remelting**’ process corresponds to the transformation of the aluminium scrap (pre- or post-consumer) into a wrought alloy ingot³ ready for delivery to the end user. Moreover, it encompasses the recycling of dross and skimming. This dataset should be utilized for the recycling of process scrap and the recycling of some specific end-of-life products such as large aluminium pieces used in buildings or aluminium beverage cans collected via specific collection networks.

The ‘**refining**’ process LCI dataset corresponds to the conversion of aluminium scrap (pre-or post-consumer) into a casting alloy ingot⁴ ready for delivery to the end user. The dataset comprises melting, purifying, and casting operations. Moreover, salt slag recycling operations are accounted for. European Aluminium collected environmentally relevant input and output data from refiners for their respective production facilities, covering the years 2017-2019 (EA, 2021). It should also be noted that a scenario with system expansion has been developed to include the benefits related to the recovery of aluminium oxide from the salt slag recycling process (i.e. gate to gate + system expansion). Under the assumption that industry data collected for the years 2017-2019 remains representative of the refining process in 2021, this report maintained the foreground data unchanged and solely updated the background datasets to version 10 of the LCA FE software (reference years between 2022 & 2025) (LCA for Experts, 2023).

Moreover, for aluminium applications or products, it is strongly advised to conduct a more detailed analysis of the recycling scenarios and routes. This approach aims to develop more tailored models and corresponding Life Cycle Inventory (LCI) datasets. European Aluminium members are encouraged to establish dedicated task forces on these subjects. For additional information, please reach out to European Aluminium at LCI@european-aluminium.eu.

For each LCI dataset, the processes and materials within the system boundaries were categorized into five distinct groups: direct processes, auxiliary processes, transport, electricity, and thermal energy. Hence, the LCI data and indicators were allocated to these 5 categories as follows:

- **Direct processes:** Direct consumption or use of materials or direct emissions related to the aluminium processes. The following aluminium processes are considered:
 - **Primary production:** bauxite mining, alumina production, anode/paste production, electrolysis, casting.
 - **Semi-fabrication:** ingot homogenisation, ingot scalping, hot rolling, cold rolling, annealing, finishing, and packaging, extrusion, scrap remelting, and dross recycling.
 - **Remelting:** scrap remelting, scrap refining, dross recycling, salt slag treatment.
- **Electricity:** The processes and materials involved in the direct generation of electricity used in the aluminium processes, including fuel extraction and preparation.

³ Aluminium alloys used for wrought products (e.g., sheet or extrusion) where the shape of the final product is generated by mechanically forming the solid metal.

⁴ Aluminium alloys used for casting where the final product shape is generated by pouring molten metal into a mould

- **Thermal energy:** The processes and materials required to produce thermal energy directly used for the aluminium processes.
- **Auxiliary:** The processes and materials utilized in the aluminium processes. It mainly concerns caustic soda, lime and aluminium fluoride.
- **Transport:** Sea, river, rail and road transport for bauxite and alumina and sea and river transport for imported ingots

This report, based on 2021 and 2022 data collection, was published in 2024 due to an unprecedented energy crisis that severely affected several primary aluminium smelters in the EU in 2022. Consequently, while consolidating and analysing the 2021 data, there was no assurance that the plants considered in the 2021 baseline would still be relevant for a 2023 publication. To provide stakeholders with relevant data, we decided to develop "post-energy crisis" models based on plants still operating in 2023. More details are available in Sections 4.7 and 4.8. This assessment slightly delayed the publication to ensure the delivery of the most up-to-date information to our stakeholders.

2.2.1.2 System boundaries

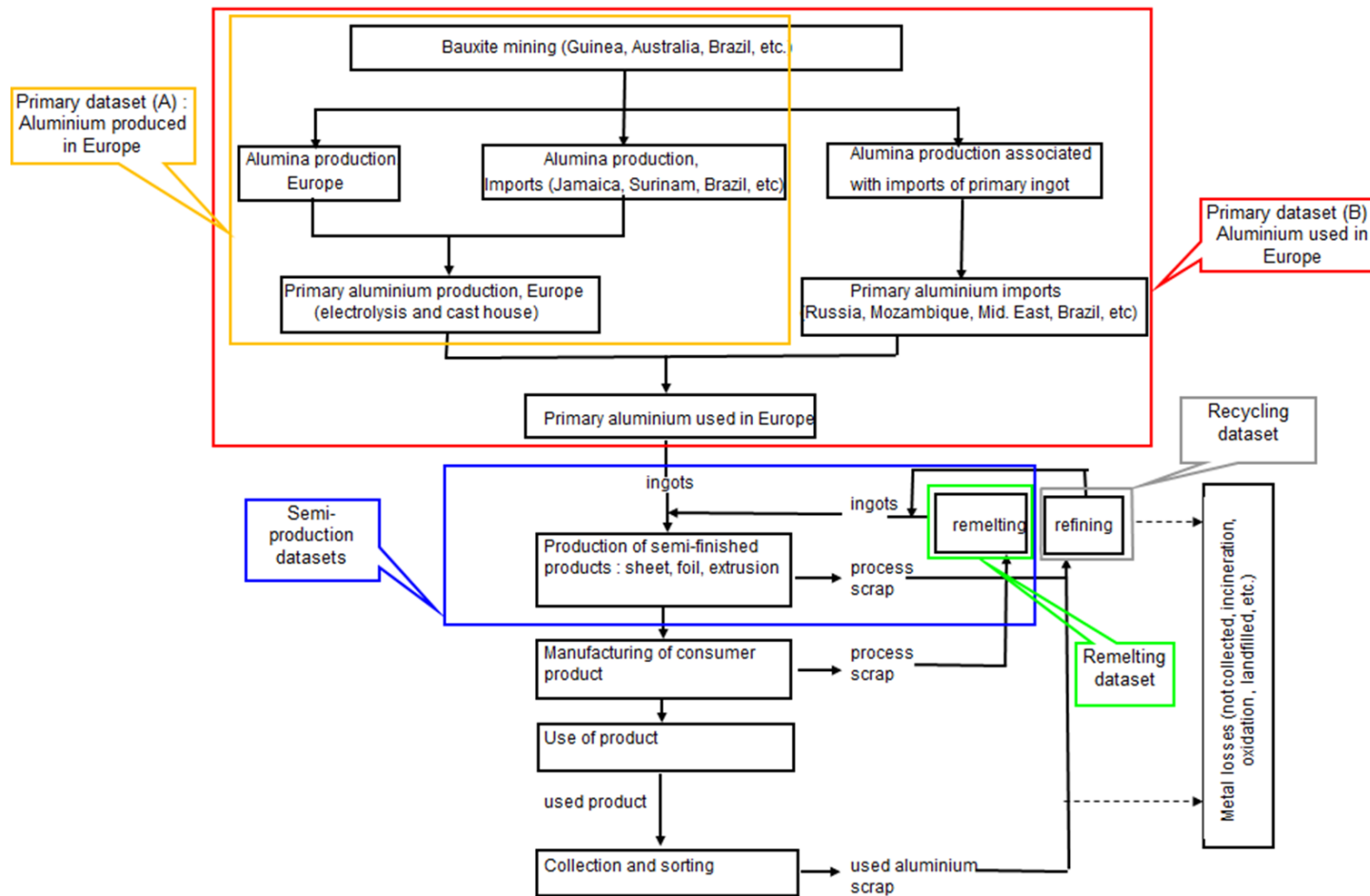


Figure 2-1 System boundaries for the different LCI dataset

2.2.1.3 Cut off rules

Detailed questionnaires were developed to gather input and output figures. In practise, any material flow entering the aluminium process (i.e., inputs) which constitutes more than 1% of the total mass flow (t) or exceeds 1% of the total primary energy input (MJ) is included in the system and modelled for the calculation of elementary flows. Similarly, materials leaving the system (i.e., outputs) which account for over 1% of the total mass flow are incorporated into the system.

All available inputs and outputs, even below the 1% threshold, have been considered for the LCI calculation. The cut-off criteria of the background data were applied as documented in the LCA FE database (LCA for Experts, 2023).

2.2.2 Functional unit

The functional unit and reference flow was specified as “**the production of 1 tonne of aluminium product ready for delivery to the user at the gate** (i.e. out) of the system boundary” across the 8 datasets. For instance, the functional unit considered for the datasets related to primary aluminium produced in Europe was “the production in Europe of 1 tonne of primary aluminium ingot ready-for-delivery to the user”. The report will duly highlight the functional unit outlined above for each environmental dataset.

2.2.3 Allocation procedure

To avoid allocation of the foreground data to the greatest extent, the system boundaries have been expanded. The recycling of scrap and dross has been integrated into each LCI dataset to ensure that only aluminium ingot or semi-products (i.e., sheet, extrusion) exit the system boundaries as valuable products. **In other words, this means that the allocation procedures have been avoided by considering that the process scrap (or dross, skimming) generated within the aluminium processes (e.g. casthouse, rolling mills) are kept in the system boundaries of the LCA model, avoiding accordingly the use of primary materials (i.e. closed loop).** Therefore, these flows have been modelled as “run-around scrap”, as it is very often the case in practice since most aluminium plants recycle directly their production scrap on site via their own casthouse. More details about allocation methodologies for process scrap can be found in the European Aluminium [methodological guideline](#) for the environmental assessment of aluminium intermediate and semi-finished products.

Similarly, energy recovery (both thermal and electrical) has been considered in the incineration of solid waste. To prevent the need for allocation, the recovered energy was reintegrated directly into the LCI model. Consequently, the initial energy input was reduced accordingly. This approach aligns with energetic closed-loop recycling. However, it is worth noting that the energy sourced from incineration remains minimal, accounting for less than 1%.

It should be noted that, for one of the two refining datasets (cradle to gate), a scenario has been developed based on the “avoiding burdens approach” (“aka substitution”). Based on this scenario, the benefits related to the valorisation of aluminium oxide from the salt slag recycling in other systems (e.g. ceramics, cement) have been directly included in the LCA model. This scenario is further explained in the chapter 8.9.

As far as the background datasets, the allocation rules used in the LCA for Experts database (LCA for Experts, 2023) were conserved.

2.2.4 LCIA methodology and types of impacts

Environmental indicators have been computed and reported for each LCI dataset based on a pre-defined set of impact categories (Table 2-1). Each environmental impact category is described in Table 2-2. The corresponding set of impact categories has been defined to be consistent with earlier reporting (EA 2005, 2008, 2013, 2018, 2021). As a result, they may not align with the latest developments, including those that are described in the latest PEF recommendations (Directorate-General for Environment, 2021). Nevertheless, the impact categories considered follow the recommended LCA methodologies for metals (Santero & Hendry, 2016). Further details can be found in Section 9.1.4.

Land use change, human and ecosystem toxicity, and water footprint were not included as impact categories because these characterization factors hold a level III recommendation, meaning they are advised for use but should be applied with caution (European Commission, 2021).

It is important to note that these indicators are solely informative and should not be used to evaluate the environmental aspects of aluminium processes in Europe or to make a comparison between materials. **As emphasized in ISO 14040 and 14044, it is only scientifically sound to consider the environmental aspects of a product or service from a life cycle perspective, i.e., from cradle-to-grave and cradle-to-recycling.**

Table 2-1 Pre-defined set of environmental impact categories

Impact categories	Unit	Methodology
Depletion of Abiotic Resources elements (ADP ultimate reserve)	kg Sb-Equiv.	CML 2001 – Aug. 2016
Acidification Potential (AP)	kg SO ₂ -Equiv.	CML 2001 – Aug. 2016
Eutrophication Potential (EP)	kg Phosphate-Equiv.	CML 2001 – Aug. 2016
Greenhouse Gas Emission (GWP 100 years)	kg CO ₂ -Equiv.	CML 2001 – Aug. 2016
Ozone Layer Depletion Potential (ODP, steady state)	kg R11-Equiv.	CML 2001 – Aug. 2016
Photo-oxidant Creation Potential (POCP)	kg Ethene-Equiv.	CML 2001 – Aug. 2016
Total Primary Energy (from renewable and non-renewable resources)	MJ	net. cal. value
- Primary energy from renewable resources	MJ	net. cal. value
- Primary energy from non-renewable resources	MJ	net. cal. value

Table 2-2 Brief descriptions of the selected environmental impact categories.

Indicators	Short description
Depletion of Abiotic Resources elements (ADP)	Resources are classified based on their origin as biotic and abiotic. Biotic resources are derived from living organisms, whereas abiotic resources are derived from the non-living world (e.g., land, water, and air). Mineral and power resources are also abiotic resources. ADP-elements estimates the consumption of these abiotic resources using the so-called ultimate reserve methodology which refers to the quantity of resources that is ultimately available, estimated by multiplying the average natural concentration of the resources in the earth's crust by the mass of the crust. Similarly, the ADP-fossil measures the consumption of fossil fuels.
Acidification Potential (AP)	AP relates to the increase in acid substances in the low atmosphere, leading to the occurrence of “acid rains” and contributing to the deterioration of surface water and forested areas. This can be either caused directly by the outlets of acids or, indirectly, through the

Indicators	Short description
	outlets of gases that form acids upon contact with air humidity that are subsequently deposited on soil or water. Examples are Ammonia, NO_x, and SO₂. The main sources of emissions of acidifying substances are agriculture and fossil fuel combustion used for electricity production, heating, and transport.
Eutrophication Potential (EP)	Aquatic eutrophication is defined as the introduction of nutrients in the form of phosphates and nitrogenous compounds, resulting in the excessive growth of algae and associated detrimental biological effects. This occurrence can decrease the levels of dissolved oxygen in the water, potentially leading to the demise of aquatic flora and fauna.
Greenhouse gas emission (GWP 100 years, IPCC 2013)	The greenhouse gas effect is a natural process that warms the Earth's surface by trapping outgoing longwave radiation emitted by the sun. Certain gases (e.g., CO ₂ , CH ₄ , etc.) play a crucial role in this process. Human activities have intensified the greenhouse gas effect by releasing these gases in high concentrations, contributing significantly to global warming.
Ozone Layer Depletion Potential (ODP, steady state)	The breakdown of the stratospheric ozone layer is mainly attributed to catalytic reactions with atomic chlorine and bromine. The photodissociation of chlorofluorocarbon (CFC) compounds, commonly known as “freons”, and Bromo fluorocarbons, referred to as “halons”, is the primary source of halogen atoms. These compounds are transported to the stratosphere after being emitted at the Earth’s surface.
Photo-Oxidant Creation Potential (POCP)	Tropospheric ozone is primarily formed when nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs), such as xylene, react in the presence of sunlight in the atmosphere. NO_x and VOCs are called “ozone precursors”. There is substantial evidence indicating that elevated concentrations of ozone (measured in parts per million or ppm), resulting from high pollution levels and exposure to daylight UV rays at the Earth's surface, can adversely affect lung function and cause irritation to the respiratory system.
Total primary energy	Primary energy refers to energy that has not been converted or transformed, e.g., energy contained in crude oil.
Primary energy from renewable resources	Primary energy refers to energy that has not been converted or transformed. Renewable energy comes from naturally replenished sources such as sunlight, wind, water, and biomass. Hydropower is the main renewable energy source for generating electricity in the production of primary aluminium.
Primary energy from non-renewable resources	Primary energy refers to energy that has not been converted or transformed. Non-renewable energy refers to energy derived from finite resources. Examples of non-renewable energy sources include fossil fuels like coal, oil, and natural gas. Once these resources are depleted, they cannot be readily replenished

Normalization, grouping, and weighting were omitted due to their subjective nature. LCIA results are relative expressions and do not forecast impacts on category endpoints, surpassing thresholds, safety margins, or risks.

2.2.5 Types of data sources

2.2.5.1 *Foreground and background data*

- Foreground data

This report is based on foreground data collected by European Aluminium and EAFA members in each production process. For example, data related to anode/cathode production, electrolysis, and the cast house process have been collected for primary production. In practice, this data is a mix of measured, calculated, and estimated values as required in data collection surveys. The data collected for each aluminium segment is available in this report (e.g. see Table 4-6 for the electrolysis process).

The total number of reporting plants, their production volumes and their share of this production in the total European output are detailed in Table 2-3. Specifically, data was gathered from 4 plants producing 5.7 Million tonnes (Mt) of alumina in Europe, representing 81% of European production. Furthermore, 18 smelters provided environmental data related to the electrolysis and casting of primary aluminium. The report covers only the anode production integrated within European smelters, with collected data representing about 95% of this in-site production. No direct data was gathered for anodes produced at facilities separate from the smelters where they are used.

In terms of cold sheet output, 27 European rolling mills reported a total production of 4.5 Mt, achieving 86% coverage of the estimated 5.3 Mt European FRPs production in 2021. Finally, data on 1.2 Mt of extrusion, accounting for about 35% of the total annual European production, was consolidated. This level of coverage aligns with previous reports, which also indicated approximately 30% coverage. Regarding the foil production, EAFA consolidated data from 17 sites covering 0.7 Mt i.e. 83% of the European foil production.

The main aluminium extrusion markets (i.e. 50% building and construction, 22% transport and 12% engineering) are covered by the data considered in this report. However, specific types of alloys (e.g., hard alloys) or highly complex specifications required for the final product may not be adequately represented by the average dataset presented in this report.

Table 2-3 Primary industry data survey coverage per production process.

Production process	Number of reporting sites	Reported production (Mt)	Reporting rate (per total European production)
Alumina production	4	5.7	81%
Anode production ⁵	11	1.3	95%
Electrolysis and cast house	18	3.6	100% ⁶
Rolling mills	27	4.5	86%
Foil production	17	0,7	83%
Extrusion	41	1.2	35%
Remelting	36	5.3	~80%
Refining	26	1.9	61%

European Aluminium and EAFA LCI surveys cover the different direct inputs (e.g., energy, ancillary materials, water, and transport) and outputs (e.g., air and water emissions, waste production) related to the aluminium production processes. These surveys, conducted over the past 20 years, have undergone validation and continuous enhancement by experts, drawing on insights gained from previous exercises. Where applicable, supplementary data on land use have also been gathered, as exemplified in Table 4-2 and Table 4-4.

Additionally, regional-level average process data from a 2019 data collection by the International Aluminium Institute (IAI) have been used for the datasets on primary aluminium (consumed and produced in Europe) to model the aluminium processes, such as bauxite mining, occurring outside Europe (Figure 2-1)(IAI, 2022). To model the European imports of the relevant production, these regional inputs/outputs figures were then weighted according to their proportional share of imports into Europe. Further details on this approach can be found in Section 4.3. These processes together with their relative contributions to the LCI datasets are reported in Table 2-4.

Table 2-4 Respective contributions⁷ of the various processes considered for the two primary aluminium LCI datasets.

Process step	2021		2015	
	Produced in Europe	Used in Europe	Produced in Europe	Used in Europe
Bauxite mining	100% IAI data (no European Aluminium data)	100% IAI data (no European Aluminium data)	100% IAI data (no European Aluminium data)	100% IAI data (no European Aluminium data)

⁵ integrated within European smelters

⁶ Similar to the last report from 2018, the grid mix of the electricity consumption covers all European smelters but hard data for electricity grid mix is based on 86% of the production. The missing data have been estimated by default based on national electricity grid mixes.

⁷ Based on Eurostat (EU27+UK) and national customs data (EFTA countries).

Alumina production	59% European Aluminium and 41% IAI data	33% European Aluminium and 67% IAI data	61% European Aluminium and 39% IAI data	35% European Aluminium and 65% IAI data
Electrolysis including anode production and casting	100% European Aluminium and 0% IAI data	52% European Aluminium and 48% IAI data	100% European Aluminium and 0% IAI data	51% European Aluminium and 49% IAI data

Given that Europe significantly imports alumina and primary aluminium, the premise underlying the "used in Europe" Life Cycle Inventory (LCI) dataset is that all the alumina and primary aluminium manufactured in Europe is solely utilized within its border. This assumption is supported by statistical data, sourced from Eurostat and national customs, revealing that less than 10% of alumina and 15% of primary aluminium produced in Europe is exported, (i.e., outside the EU27 + UK + EFTA).

Regarding the production processes of semis and recycling, only European datasets were considered. The trade of these products in regions outside Europe is also considered negligible (i.e. around 10%). Moreover, there is a scarcity of datasets for other regions or at the global level.

- Background data

Additional inventory datasets, referred to as “background data”, on supplementary processes which are not covered by European Aluminium and/or IAI inventory datasets. have been used. These datasets are included in the LCA FE database version 10 (LCA for Experts, 2023). The most important are:

- Limestone production (DE, 2022)
- Caustic soda production (DE, 2022)
- Aluminium fluoride production (EU28, 2019)
- Calcined petroleum coke production (RER, 2022)
- Pitch production (DE,2022)
- Electricity supply systems (RER, GLO, RME, RU, ZA)
- Fuel supply systems and fuel combustion (EU28, 2019)
- Transportation (GLO, 2022)

In the current LCA methodology, solid wastes are not listed as elementary flow given that they are recycled, incinerated, composted, or legally landfilled. This LCA methodology integrates operations such as incineration, recycling, or landfilling within the system boundaries and models the emissions associated with these operations.

The treatment of solid wastes has been modelled and integrated within the system boundaries for all the LCI datasets included in this report. For most solid wastes which are landfilled, emissions have been computed using average LCI models. This approach was adopted due to the unavailability of specific emission data, or the challenges associated with modelling their behaviour in landfill sites.

2.2.5.2 Focus on specific datasets, processes and production steps

- Focus on: thermal energy used in aluminium processes

Numerous aluminium processes rely on fossil fuels (such as natural gas, propane, diesel, coal, etc.) as thermal energy sources. Although input figures linked to the consumption of these fuels have been

gathered, the data regarding air emissions, primarily linked to the combustion of these fuels, is restricted. Typically, the data only encompasses particulates, SO₂ and NO_x.

To address this limitation and encompass all categories of air emissions associated with the combustion of fossil fuels, the modelling also integrates data for fuel supply systems and fuel combustion sourced from the LCA FE software (reference year 2019 – RER).

As illustrated in Figure 2-2 for the air emissions associated with the process of alumina production, the figures reported in the survey are supplemented with any additional air emissions linked to the preparation and combustion of fossil fuels. Precautions were implemented to prevent any double counting of the reported emissions.

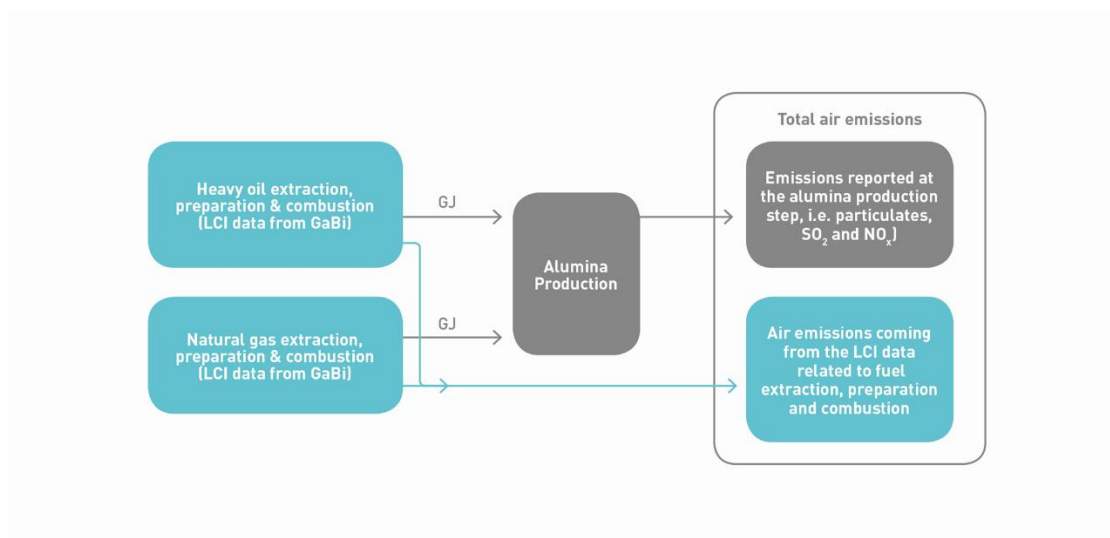


Figure 2-2 Use of background LCI data related to fuel supply systems and combustion (LCA for Experts (fka GaBi) LCA data are presented in blue)

Consequently, the air emissions related to the production of alumina are a combination of reported main emissions and LCI data representing fuel extraction, preparation, and combustion. This approach has been applied to all aluminium processes involving the combustion of fuels.

- Focus on: direct CO₂ emissions in aluminium processes

Direct CO₂ emissions have been determined for different aluminium processes according to their fuel consumption. The CO₂ conversion factors representative of the EU-28 were extracted from LCA FE 10 and are reported in Table 2-5.

Table 2-5 CO₂ conversion factor for various fuels

Fuel type	CO ₂ intensity (kg CO ₂ /MJ)
Heavy oil	8,53.10 ⁻²
Natural gas	6,34.10 ⁻²
Hard coal	9,78.10 ⁻²
Diesel/light oil	8,49E.10 ⁻²

- Focus on: electricity production

The system boundaries encompass electricity production, which plays a substantial role in the electrolysis process where approximately 15 MWh are consumed per tonne of primary aluminium. To this end, two distinct models were developed: one for the electricity used by European smelters and the other for the electricity used by smelters exporting to the European market. Detailed descriptions of these models can be found in Sections 4.4.2 and 4.4.3.

For the other processes, it is assumed that any electricity consumption is reflected by the LCI data related to the EU27 electricity model (reference year 2019⁸) used.

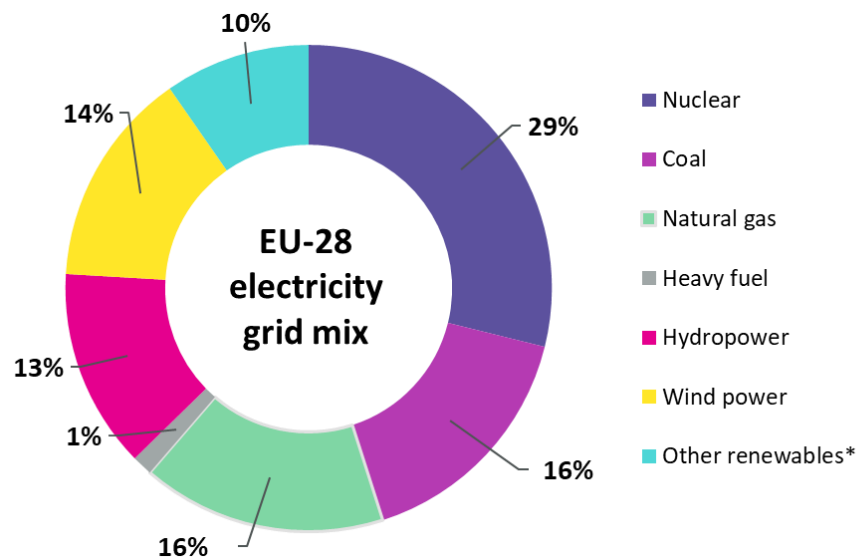


Figure 2-3 Electricity grid mix of EU-27 in 2019 (Source: [Eurostat](#))

*Other renewables: solar, photovoltaic geothermal, biogas, and waste.

Compared to 2015, the EU-27 electricity grid mix in 2019 contained more renewable energy (i.e. 27% in 2015 (EA, 2018) vs 37% in 2019) and less coal (i.e. 27% in 2015 vs 13% in 2019).

⁸ 2019 data were used by default: 2021 data were not available in LCA for Experts 10 software

Table 2-6 Main environmental indicators for the production of 1kWh based on the EU-28 electricity grid mix (reference year 2019)

Environmental indicators per kWh electricity	2019	2015	2019 vs 2015 (in %)
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	7,0E-08	1,8E-07	-61%
Acidification Potential (AP) [kg SO2-Equiv.]	6,8E-04	1,3E-03	-47%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	7,9E-05	1,1E-04	-31%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO2-Equiv.]	3,24E-01	4,46E-01	-27%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	7,0E-12	2,0E-11	-64%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	4,8E-05	8,1E-05	-41%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	1,1E+01	1,0E+01	+4%
Primary energy from non renewable resources (net cal. value) [MJ]	6,8E+00	7,8E+00	-13%
Primary energy from renewable resources (net cal. value) [MJ]	4,1E+00	2,7E+00	+53%

A substantial improvement in all the environmental indicators related to the production of 1 kWh of electricity can be observed in 2019 when compared to 2015 figures (Table 2-6). These changes are mainly related to the electricity grid mix composition as explained above (i.e. more renewable energy and less fossil fuels). For instance, the primary energy demand from non-renewable resources declined by 13%, which can be explained by a reduction in reliance on fossil fuels at the expense of renewable resources (i.e., 53%).

- Focus on: transport

Bauxite, alumina, and primary ingots are predominantly imported into Europe via sea transport and to a lesser extent, by river (barge), road and rail transport. Like previous reports, these transport models have all been included in the European Aluminium LCI dataset for primary aluminium.

Europe imports directly bauxite predominantly from Africa (e.g. Guinea, Sierra Leone, etc) and South America (e.g. Brazil). Hence, the average sea transport distance of bauxite into Europe is 6.900 km by sea (Table 2-7).

Alumina directly imported into Europe originated mainly from Brazil, Jamaica, and Australia in 2021. The average transport distance for imported alumina to Europe is approximately 7.800 km by sea. Additionally, the model assumes an average sea transport distance of 8.400 km for the primary ingots imported into Europe (the main origins of imports are the Middle East, Russia, and Mozambique) (Table 2-7).

Figure 2-4 depicts the average transport distances used in the model for sea, road, and rail transportation of imported bauxite, alumina, and aluminium.

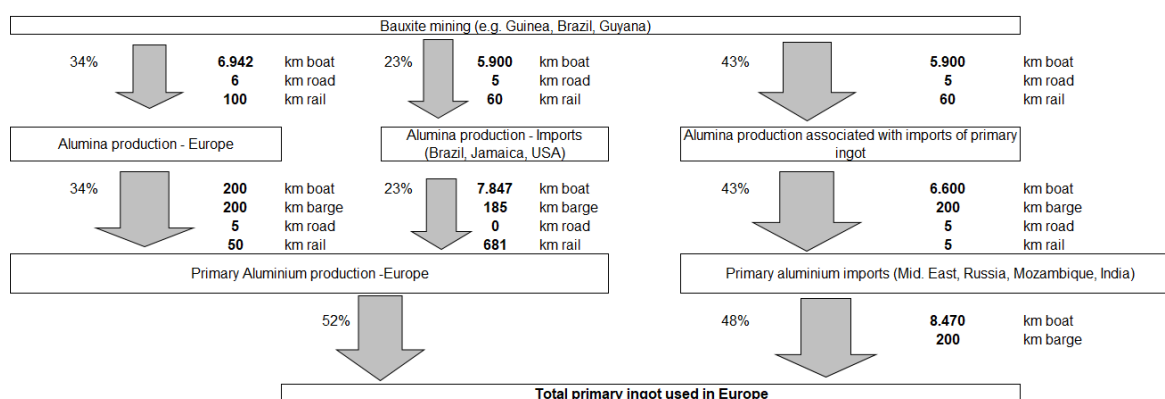


Figure 2-4 Average transport distances of bauxite, alumina and imported primary aluminium

Table 2-7 Average transport distances (direct imports)

Type of transport	Unit	Bauxite	Alumina	Primary
Ocean/Cargo	km	6.942	7.847	8.470
Barge	km	-	185	200
Road	km	6	-	-
Rail	km	100	681	-

2.2.6 Data quality requirements

- Time-related coverage: the datasets considered in this report are all based on the annual average related to **the year 2021** unless otherwise specified (e.g.: foil data are related to the year 2022, refiners data are based on the year 2018).
- Geographical coverage: European Aluminium datasets encompass Europe, comprising **the EU27, the UK and the EFTA countries** (Norway, Switzerland, and Iceland) unless noticed otherwise (e.g. Turkey for foil production).
- Technology coverage: The information outlined in the report **reflects the current technologies employed across all production stages in the aluminium industry**. For instance, the data from European Aluminium on the electrolysis process is 100% Prebake technology.
- Data Precision: The values presented in the report are **production-weighted averages**⁹ for various aluminium processes, ensuring a level of precision in the provided information.
- Completeness: **The identification of outliers and the selection of data to be included in the consolidation were based on expert judgements**. As far as possible, reporting companies were contacted, and outliers were potentially corrected based on the feedback received from these companies.
- Representativeness: Each section below provides an overview of **the representativeness for various steps in aluminium production** (e.g., the alumina process demonstrates

⁹ A production-weighted average involves normalizing the reported input/output data by the facilities included in this report to their respective tonne of product.

approximately 81% representativeness - refer to Table 2-3). When applicable, the representativeness of specific flows, such as seawater inputs/outputs, has been emphasized.

- Consistency: European Aluminium performed data consolidation, averaging, and modelling. The internal environmental reports containing data collection procedures, various questionnaires, and consolidated data have been found consistent and **validated by expert judgments**, specifically the European Aluminium Life Cycle Assessment (LCA) Committee.
- Reproducibility: based on experts' judgement the methodology and data values would allow an independent practitioner to reproduce the results reported in the study. In addition, European Aluminium has been updating its data on a 5-year basis for more than 15 years. Regarding the latest version of the LCI models (see Section 3.4), they have been developed in collaboration with EcolInnovazione (i.e. acting as an external consultant).
- Sources data: foreground data have been reported by the aluminium industry (i.e., via European Aluminium, International Aluminium Institute) whereas background data were provided by the LCA FE version 10 software (LCA for Experts, 2023).
- Uncertainty of Information (e.g., data, models, assumptions):
 - The LCI modelling only reflects pure aluminium mass flow. Alloying elements have been disregarded and replaced by pure aluminium.
 - The substitution principle was employed for scrap generated during the processing, meaning aluminium from process scrap, chips, dross, or salt slag produced during production or transformation is recycled directly into the lifecycle model. In this modelling framework, the only aluminium product exiting the LCI model is either the aluminium ingot or the semi-finished product. This method enhances the modularity of the datasets, allowing for straightforward combination and integration.
 - The modelling includes ancillary processes (e.g. fuel preparation, electricity production, or ancillary materials production) to develop LCI datasets mainly composed of elementary flows (i.e., material or energy directly sawn from the environment without prior human transformation or material or energy directly released into the environment without subsequent human transformation).

2.2.7 Interpretation

The results of the LCI and LCIA are interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Identification of significant aspects,
- Evaluation of completeness, sensitivity, and consistency, Conclusions, limitations, and recommendations.

2.2.8 Critical review by an independent expert

European Aluminium collaborated with Prof. Dr. Matthias Finkbeiner (Technische Universität Berlin, Chair of Sustainable Engineering, Managing Director of the Department of Environmental Technology) to review the previous edition of the report (i.e., in 2015) and has opted to engage his expertise once more for the updated report based on data from 2021.

Considering the previous in-depth reviewing exercise (EA 2005, 2008, 2013), this new review process has been limited to this external report including a plausibility check of the LCI datasets. Hence, the reviewing process has been done "a posteriori", i.e. based on the draft environmental report and the

various LCI datasets. The review has been organised according to ISO TS 14071 (2014) and in agreement with the ISO 14040 and 14044 rules (ISO 14040:2006/Amd 1:2020, 2020; ISO 14044:2006/Amd 2., 2020).

The review is performed as a critical review by an external expert according to paragraph 6.2 of ISO 14044 (ISO 14044:2006/Amd 2., 2020), as the study is not intended for comparative assertions intended to be disclosed to the public. The review is performed at the end of the study and excludes an assessment of the life cycle inventory (LCI) model, as well as an assessment of individual datasets. An individual reviewer was contracted as an independent expert reviewer, not as a representative of his affiliated organizations. The review statement of the reviewer is annexed at the end of this document (see Section 12).

2.2.9 Type and format of the report required for the study

Following the ISO requirements, this document aims to report the results and conclusions of the LCI completely, accurately and without bias to the intended audience (ISO 14040:2006/Amd 1:2020, 2020; ISO 14044:2006/Amd 2., 2020). The results, data, methods, assumptions and limitations are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCI to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study. This report is made publicly available (online) and the full LCI datasets are available on request (lci@european-aluminium.eu).

3 Life Cycle inventory (LCI) phase

3.1 Data collection and calculation

Inventory data of environmental relevance for European Aluminium production have been collected with full reference to ISO standards 14040 and 14044 on Life Cycle Assessment.

In 2022, a comprehensive environmental survey was initiated by European Aluminium, wherein European aluminium producers submitted data on their inputs and outputs with environmental significance for the year 2021 for their respective production facilities.

The plants participating in the data collection delivered absolute figures of process inputs and outputs related to the year 2021 (e.g. in tonnes, GJ, m³, etc.).

The data has been **consolidated at the European level** by performing a horizontal averaging. This technique involves weighting each collected primary data according to the production volume of the related plant. This aggregation approach facilitates a seamless integration of (sub-) processes and provides insights into the contributions of the various process steps.

As mentioned earlier, the procedures followed for data collection and consolidation have undergone validation through experts' assessments (i.e. European Aluminium Life Cycle Assessment (LCA) Committee and/or external consultants).

For each aluminium process step described in the subsequent sections, a dedicated section has been incorporated, which addresses "data collection and averaging". To illustrate, information related to primary production can be found in Section 4.2. The datasets have been systematically collected at the unit process level (e.g., electrolysis for primary production, hot and cold rolling for sheet production, etc.) within the defined system boundaries. When applicable, considerations regarding

data representativeness at the European level (e.g. seawater) have been deliberated upon, with emphasis on discerning the main trends compared to 2015 figures.

Additionally, the report includes, for each main aluminium process step, the following elements:

- A detailed process description (e.g., see Section 7.2 for the extrusion process)
- Geographical mapping of aluminium plants in Europe (e.g., see Section 5.1 for the rolling mills' location)
- A material flow modelling (e.g., see Section 4.3 for primary production from bauxite mining to the primary ingot production)
- Table(s) with the inputs and outputs data (e.g., see Table 7-1 for the extrusion process)
- Table(s) with the list of elementary flows predominantly contributing to the various environmental indicators presented in the report (e.g. see Section 4.5.2 for the primary aluminium consumption and production in Europe).

The section dedicated to primary aluminium production also includes the description of a specific electricity modelling (see Section 4.4).

3.2 Allocation

As discussed in a previous section (see Allocation procedure), allocation has been avoided for the foreground data by expanding the system boundaries. The recycling of scrap and dross has been included in each LCI dataset, ensuring that only valuable aluminium products (like ingots or semi-products) exit the system. This approach avoids allocation procedures by keeping process scrap within the system boundaries, effectively creating a closed-loop model. These flows are modelled as "run-around scrap," reflecting the common practice of aluminium plants recycling their production scrap on-site via their own casthouse.

Energy recovery (both thermal and electrical) from solid waste incineration was reintegrated into the LCI model, reducing the initial energy input and supporting a closed-loop recycling approach. However, the energy contribution from incineration is minimal, at less than 1%.

Concerning background datasets used for the modelling phase, the allocation rules LCA for Experts (LCA FE) (fka GaBi) 10 database (LCA for Experts, 2023).

Furthermore, as previously explained, a scenario using the "avoiding burdens approach" (substitution) has been created for the refining process dataset to incorporate the benefits associated with the recovery of aluminium oxide from the salt slag recycling process (see section 2.2.1).

3.3 How to use these LCI datasets in LCA studies

European Aluminium recommends using these LCI datasets in accordance with methodologies within the framework of the following international standards:

- ISO 14040:2006 Environmental Management - Life Cycle Assessment – Principles and framework
- ISO 14044:2006 Environmental Management – Life Cycle Assessment – Requirements and guidelines

The following key features of these standards are of special importance for aluminium:

- LCA is a technique for assessing the environmental aspects and potential impacts associated with goods and services,
- LCA include the following phases:
 - Goal and Scope Definition
 - Life Cycle Inventory Analysis
 - Life Cycle Impact Assessment
 - Interpretation

LCA covers product systems which comprise the full life cycle of a product, including raw material acquisition, fabrication, transportation, use, recycling/disposal and energy and ancillary material supply operations. Ideally, elementary flows should constitute the sole input and output of such a product system, i.e. material or energy which is drawn from the environment, or which is discarded to the environment without subsequent human transformation. As previously stated, the LCI modelling includes system extension to ancillary processes so that LCI datasets are mainly composed of elementary flows. These LCI datasets are then ready for integration into LCA studies or LCI databases (see Section 2.2.5 on background data).

3.4 Software tool for LCI data modelling

The various datasets related to the year 2021 were developed with the software LCA for expert's version 10 (LCA for Experts, 2023). The LCA for Experts (fka GaBi) software version 7 was used to produce the previous European Aluminium LCI datasets of 2015 and version 9 was for the dataset related to the refining modelling.

3.5 Main differences between the current and previous approach

The same modelling approach (e.g. electricity and transport models) used in the 2018 report was applied to primary aluminium (production and consumption), remelting, and semi-fabrication (extrusion and rolling) in Europe. Furthermore, the model developed for the refining industry in 2021 was integrated to simulate the recycling of dross and salt slag.

However, there were several major updates detailed in Table 3-1. The generic differences between previous and current modelling include updates in the LCIA methodology, LCA software, and background datasets (e.g. EU-28 electricity production). Recognizing that a European average holds little significance for freshwater extraction, given its high dependency on plant location, a first attempt was made to model regional water extraction for all processes, considering each plant's location.

One significant adjustment in the datasets for primary aluminium production and consumption involves accounting for the pre-calcination of petroleum coke, an essential input in the process. In the previous model, petroleum green coke was incorrectly considered by default as the input, leading to an underestimation of the environmental impacts linked to the process.

It should be noted that the current report focuses only on the Prebake technology for the electrolysis process. In 2015, three European plants were still operating under the Söderberg process. However, by 2021, only one plant was still operating with the Söderberg technology. Therefore, for confidentiality reasons, the focus was placed solely on the Prebake technology.

Additionally, the current modelling has improved compared to the 2015 model, by regionalizing the processes related to the production of imported primary aluminium. This improvement was facilitated by the release of regional-level LCI inventory data from the IAI (2021), based on 2019 data collection.

Previously, only global-LCI inventory data (excluding China) were publicly available and used by default for modelling European imports (IAI, 2015). The IAI regional data on thermal energy consumption allowed for allocating thermal energy consumption for subprocesses related to the production of imported primary aluminium by region. However, global-level LCI data from IAI (2021) were used for bauxite mining due to the absence of regional data for this process.

Finally, given the increasing share of renewable energy sources other than hydro power (i.e. solar and wind) in producing electricity for European smelters, these sources were modelled separately from hydropower. Background datasets from Germany were utilized as proxies for the European production of these renewable energy sources.

Table 3-1 Differences between current and past modelling

Generic differences	2017-2018	2023-2024
Data collection reference year	2015	2021
LCIA Methodology	CML 2001 - Jan 2016	CML 2001 - Aug 2016
Modelling tool	Gabi 7 software	LCA FE (fka Gabi) 10 software
Main data sources for ancillary processes	GaBi & ELCD data (ref years between 2013 and 2016)	GaBi & ELCD data (ref years between 2019 and 2021)
Electricity production (<i>excluding electrolysis step</i>)	EU28 grid mix in GaBi (ref year 2015)	EU28 grid mix in LCA FE (ref year 2021)
Refining process (<i>including dross and salt slag recycling</i>)	Use of dataset from 2010	Use of updated dataset from 2021 (European Aluminium, 2021)
Process water from groundwater	EU28 extraction of groundwater in GaBi (ref year 2015)	Regionalization of ground water extraction (ref year 2021)
Specific differences	2017-2018	2023-2024
Anode production	Petroleum coke (ref year 2015)	Calcined petroleum coke (ref year 2021)
Thermal energy for producing imported products*	Use of EU28 production mix, by default (ref year 2015)	Regionalization according to regions of origins (ref year 2021)
Other LCI data on primary aluminum imports** to Europe	LCI data from IAI (2015) averaged at global level (without China), by default	Regionalization according to regions of origins (based on trade and IAI (2022) scenarios)
Cell technology in for electrolysis in Europe	95% prebake technology, 5% Söderberg	100% prebake technology
Electricity grid mix used by smelters in Europe	All Renewable sources modelled as hydropower (main source)	Solar and wind modelled separately from hydro power using DE datasets (ref year 2021)

* Imports of alumina and primary aluminium.

** LCI data for alumina, anode, liquid aluminium production, and casting related to the production of imported aluminium.

4 Primary production

4.1 Process steps descriptions

4.1.1 Bauxite mining

The primary raw material for aluminium production is bauxite which consists of one or more aluminium hydroxide compounds, along with silica, iron, and titanium oxides as the main impurities. Global bauxite mining reached approximately 368 million tonnes in 2021¹⁰. The main deposits are concentrated in a broad belt around the equator, with current extraction activities in Australia, Central and South America (Jamaica, Brazil, Surinam, Venezuela, and Guyana), Africa (Guinea), Asia (India, China), Russia, Kazakhstan, and Europe (Greece). Bauxite extraction is predominantly carried out through open-cast mining.

Environmental data about bauxite mining for the year 2021 has been compiled and developed by the International Aluminium Institute (IAI) (2022).

4.1.2 Alumina production

Before aluminium can be produced through electrolysis, bauxite must transform into pure aluminium oxide, known as alumina. The Bayer chemical process, conducted in alumina refineries, facilitates this conversion. Within a digester, the aluminium oxide present in bauxite is selectively leached from other substances using an alkaline solution. The leaching process, occurring in autoclaves at temperatures ranging from 100 to 350°C (depending on alumina reactivity), involves caustic soda and lime as primary reactants. Following leaching, the solution undergoes filtration to eliminate insoluble particles, forming bauxite residue, commonly known as "red mud". Upon cooling, aluminium hydroxide precipitates from the soda solution and undergoes washing and drying, while the soda solution is recycled. The aluminium hydroxide is then typically calcined in fluidized-bed furnaces at around 1,100°C. The product, aluminium oxide (Al_2O_3) is a finely grained white powder.

Figure 4-1 provides a comprehensive depiction of the alumina production process. In Europe, approximately 2,5 tonnes of bauxite are utilized per tonne of alumina. The calcination process, and to a lesser extent, the leaching process, predominantly account for the thermal energy consumption. Specifically, around 8,4 gigajoules (GJ) of thermal energy and 227 kilowatt-hours (kWh) of electricity are consumed per tonne of alumina (refer to Table 4-3 for detailed information).

¹⁰ Source <https://www.alcircle.com/news/global-bauxite-production-expected-to-grow-by-2-6-in-2023>. Consulted on May 13, 2024.

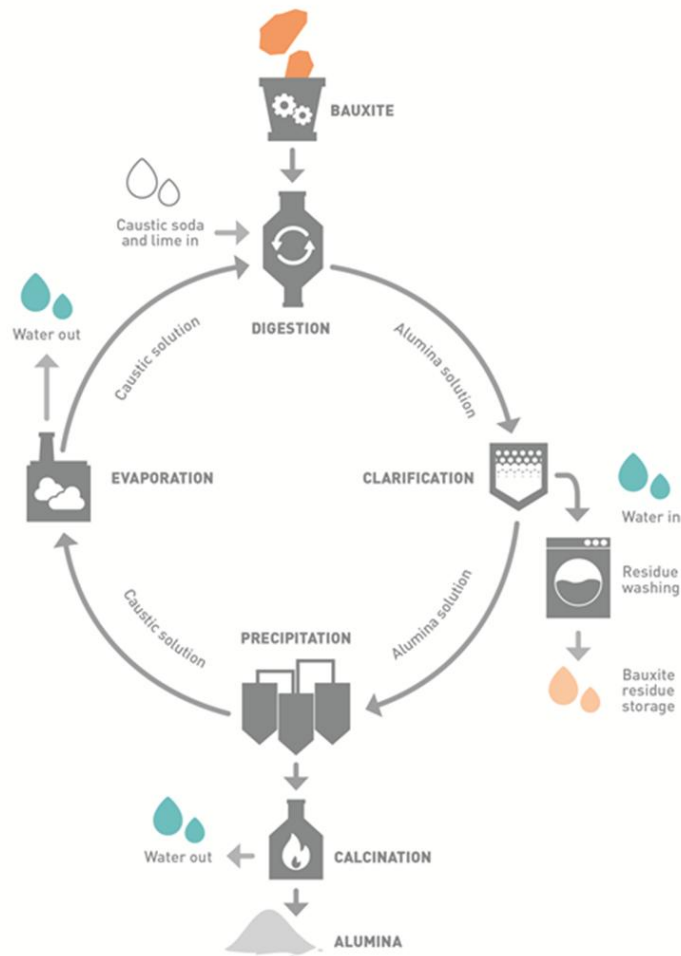


Figure 4-1 Alumina production process (Source: Hydro Aluminium)

Solid wastes generated during the alumina production process originate from two main streams:

- Tailings, inerts and sand which are separated from the bauxite ore before the leaching step
- Leaching process residue (or bauxite residue) which, although comprised of mostly non-toxic and largely insoluble constituents, requires special care due to the residual alkaline content resulting from the extraction process. The alkalinity of the residual solution may vary significantly depending on the bauxite residue filtration and rinsing process. Typically, bauxite residue is deposited on or near the site in specially designed sealed ponds, and excess water is returned to the process. Over time, alkali residues react with carbon dioxide from the air, forming sodium carbonate. Once dried out, bauxite residue disposal sites can be re-cultivated. While the utilization of bauxite residue as filler material for road construction or as an additive in the cement industry is still limited, there is a growing trend in this direction.

4.1.3 Electrolysis

Primary aluminium is manufactured in electrolysis plants commonly referred to as "smelters." In these facilities, pure alumina undergoes reduction into aluminium metal through the Hall-Héroult process. The production of 1 tonne of aluminium requires approximately 2,000 kg of alumina. The reduction of alumina into liquid aluminium occurs at around 950°C within a fluorinated bath, typically cryolite, under a high-intensity electrical current.

This transformative process takes place in electrolytic cells, often called "pots" (refer to Figure 4-2), where carbon cathodes constitute the bottom of the pot and serve as the negative electrode. Carbon anodes, acting as positive electrodes, are positioned at the top of the pot and are consumed during the process as they react with the oxygen emanating from the alumina.

Two primary cell technologies are employed worldwide. Since the early 1970s, all potlines constructed in Europe have utilized the prebake anode technology, where anodes, made from a blend of calcined petroleum coke and coal pitch (serving as a binder), are pre-baked in separate anode plants. In Söderberg technology, the carbonaceous mixture is directly fed into the upper part of the pot, where "self-baking" anodes are produced using the heat released by the electrolytic process. As of 2021, the Söderberg technology was in use at only one operational plant in Europe, in contrast to the three plants recorded in the 2015 data collection. Consequently, this report exclusively addresses the prebake technology, ensuring confidentiality.

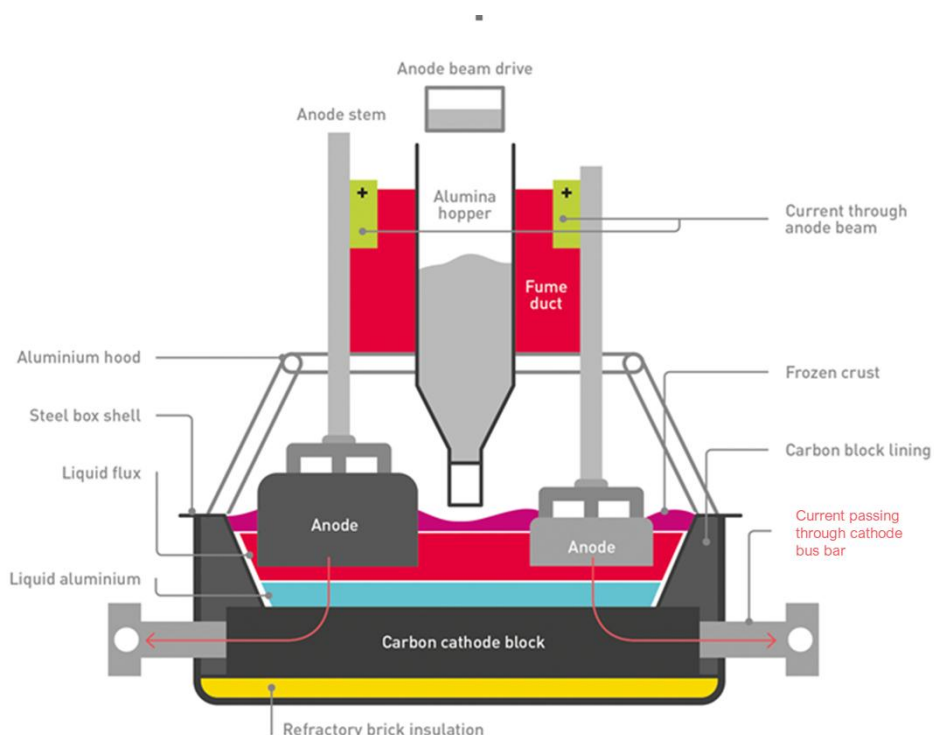


Figure 4-2 Aluminium electrolytic cell - prebake technology

The electrical energy needed during the smelting process is a significant component of the energy consumption in primary aluminium production. Therefore, it has been carefully studied by requiring all smelters' specific consumption figures to compute a precise weighted average. The total consumption encompasses various elements, including:

- Rectifying loss
- DC power usage
- Pollution control equipment
- Auxiliary power (general plant use)
- Electricity transmission losses from power stations to smelters are included in the LCA modelling. Primary smelters receive all their energy through high-voltage lines from nearby power stations and operate their transformer facilities.

In 2021, European smelters, consumed (AC), on average, 14,560 kWh/tonne of electricity for aluminium production. In contrast, the consumption in Europe was 14,850 kWh/tonne of primary aluminium produced in 2015. Regarding imported primary aluminium, which accounts for 48% of the usage in Europe, the average electricity consumption is 15,216 kWh/tonne whereas it was 15,460 kWh/tonne of imported aluminium in 2015.

In Section 4.4.2, a dedicated electricity model is formulated for generating the electricity required during the electrolysis process.

4.1.4 Cast house

Periodically, molten aluminium extracted from the pots is conveyed to the cast house, where it undergoes alloying (depending on the user's specifications) in holding furnaces. This alloying process involves the incorporation of other metals and cleaned aluminium scrap, free from oxides and gases. Subsequently, the alloyed material is cast into ingots. Cast houses are versatile in generating a diverse range of products and alloys. Given the impracticality of creating a dataset for each product and alloy variation, average data has been compiled for a generic aluminium ingot, encompassing those intended for rolling (slabs), extrusion (billets), or remelting. The production of rolling slabs and extrusion billets, depicted in Figure 4-3, employs Direct Chill (DC) casting technology, wherein liquid metal is poured into short moulds on a platform and cooled as the platform descends into a water-filled pit.



Figure 4-3 DC-cast extrusion billets (cylindrical) or rolling slabs (rectangular)

Before leaving the cast house, the extremities of rolling slabs and extrusion bled are generally sawed off and directly recycled in the holding furnace. In the current model, the product exiting the cast house is either a sawn rolling ingot, a sawn extrusion ingot or an ingot for remelting.

Additional treatments related to extrusion and rolling ingots, including homogenisation or scalping, are addressed in the sections relating to semi-finished products.

4.2 Data collection and averaging

Comprehensive datasets encompassing yearly input and output variables of 2021 were acquired using questionnaires which focused respectively on alumina production, anode and paste production, electrolysis, and casting.

Upon consolidating the individual data collected, European averages were derived using the following reference flows:

- For alumina: the total tonnage of alumina produced.
- For paste and anode: the total tonnage of paste production plus the total tonnage of baked anode production.
- For electrolysis: the total tonnage of liquid aluminium produced through the electrolysis process.
- For cast house: the total tonnage of sawn produced.

More details regarding the direct inputs and outputs of each process are given in the following sub-sections.

4.2.1 Bauxite mining

Data for input and output related to bauxite production have been sourced from the International Aluminium Institute (IAI) survey for the year 2019. The information, presented in Table 4-1 pertains to both the extraction and preparation processes involved in producing 1 tonne of bauxite, ready for delivery to the alumina plant.

The use of coal and electricity increased to the expense of heavy oil for the extraction and preparation of bauxite in 2019 vs 2015. This trend, highlighted by the IAI, is mainly attributed to an increase in the number of facilities relying on coal between the two reporting years (IAI, 2022). However, the IAI emphasized that bauxite mining accounts for a relatively small share of thermal and electrical consumption compared to the subsequent processes involved in primary aluminium production.

Table 4-1 Comparison of the direct input and output data for the extraction and preparation of 1 tonne of bauxite in 2021 vs 2015.

Bauxite production – <i>relative figures per tonne of bauxite</i>	Unit	IAI	
		2015	2019
Inputs			
Water used			
Fresh water	m³/t	0,5	0,5
Sea water	m³/t	-	0,3
Energy			
Coal	MJ/t	0	22
Heavy oil	MJ/t	21	6
Diesel oil	MJ/t	78	79
Natural gas	MJ/t	0	1
Total thermal energy	MJ/t	99	108
Electricity	kWh/t	1,5	6,3
Outputs			
Air emissions			
Particulates	kg/t	0,11	0,18
Water discharge			
Fresh water	m³/t	0,03	0,08
Sea water	m³/t	-	0,2
Solid waste			
Mine solid waste	kg/t	0,1	0,06

N.B.: Seawater data were not collected in 2015 by IAI (2022).

In addition, IAI datasets also include information regarding land occupation and rehabilitation conditions¹¹ related to the bauxite mining production processes.

Table 4-2 Land occupation and land rehabilitation in bauxite mining (source: IAI).

Focus on land use	Unit	2019	2015
Land occupation	km ² /t product	3,42E-07	1,65E-07
Land use type before	/	Other forest	Other forest
Land use type after	/	Forest	Forest

¹¹ The topsoil, extracted during mining operations to access bauxite ore, is stored, and subsequently reused in the later stages of mining rehabilitation operations.

Table 4-2 suggests a theoretical requirement of approximately 6,8 km² of land occupation for bauxite production to meet the annual primary aluminium production in Europe¹².

4.2.2 Alumina production

Table 4-3 contrasts the European average input and output values for the years 2015 and 2021, and the global average figures from IAI for 2015 (IAI, 2015). In addition, the table includes weighted average figures that account for the relative contribution of different regions to the total European imports of alumina, calculated by European Aluminium using the IAI regional LCI inventory survey (IAI, 2022). It should be noted that these data are not directly comparable to the global average figures from IAI for 2015, as they were not calculated on the same basis. More details regarding the approach followed to compute these figures for European imports can be found in Section 4.3.1.1.

An average of 2 545 kg of bauxite is consumed in Europe to produce 1,000 kg of alumina. Bauxite consumption increased by about 18% compared to 2015 figures. European alumina producers consume 79 kg of caustic soda (as 100%) and 21 kg of calcined lime as reactive chemicals. The increase in raw materials (e.g. bauxite, caustic soda) could be explained by a lower aluminium content of the bauxite.

The thermal energy consumption decreased in 2021 by 6% in comparison with 2015. In contrast, electricity consumption increased by 61%. Natural gas represents almost 100% of the thermal energy used by alumina refineries. As a result, data collected by European Aluminium indicate that the total (electricity + thermal) energy consumption decreased by 2.5% in 2021 vs 2015 i.e., to 9 242 MJ/tonne.

The share of electricity consumption in the total energy used increased from 5% to 9% between 2015 and 2021. **This trend illustrates the aluminium industry's efforts to switch, when possible, with current technologies, from fossil energy fuels to electricity in view of decarbonising the process.** More details related to industry's decarbonisation strategy can be found in the European Aluminium [Net-Zero by 2050 pathway report](#).

¹² Calculated as land occupation factor* primary European production* conversion factor bauxite/ primary aluminium: $3,42\text{E-}07 * 4\,000\,000 * 5 = 6,8 \text{ km}^2$

Table 4-3 Direct input and output figures to produce 1 tonne of alumina (Al₂O₃).

Alumina production – <i>relative figures per tonne of alumina (Al2O3)</i>	Unit	European Aluminium		IAI	European Aluminium
		2015	2021	2015	2019*
Inputs					
Raw materials					
Bauxite	kg/t	2.156	2.545	2.847	2.557
NaOH (as 100%)	kg/t	48	79	73	95
CaO	kg/t	30	12	32	22
Fresh water used	m3/t	3,6	3,6	2,0	3,3
Sea water used	m3/t	-	-	0,2	0,3
Energy					
Coal	MJ/t	0	0	8.564	2.989
Heavy oil	MJ/t	32	31	1.065	3.795
Diesel oil	MJ/t	3	2	46	6
Natural gas	MJ/t	8.942	8.392	2.637	1.646
Total thermal energy	MJ/t	8.976	8.425	12.312	8.436
Electricity	kWh/t	141	227	218	109
Outputs					
Air emissions					
Particulates	kg/t	0,01	0,25	0,47	0,17
SO2	kg/t	0,25	0,14	1,14	1,61
NOx	kg/t	0,29	0,38	0,61	0,93
Hg	g/t	-	1,68	0,12	-
Water discharge					
Fresh water	m³/t	3,6	2,9	2,0	1,3
Sea water	m³/t	-	-	0,20	0,26
Suspended solids	kg/t	0,16	0,11	0,04	0,01
Oil	kg/t	-	0,01	1,7	0,06
Hg	g/t	-	-	4,70E-04	7,57E-06
By-products					
Bauxite residue	kg/t	10,9	19,0	29,5	4,6
Other	kg/t	-	9,6	-	-
Solid waste					
Bauxite residue	kg/t	791	909	1.231	913
Any other industrial waste	kg/t	48,0	9,4	19	26,5
Of which any other landfill wastes	kg/t	37,4	8,7	-	-
Of which any other hazardous waste according to local legislation	kg/t	2,7	3,2	7,7	9,2

N.B.: Missing data are shown in the table as "-".

*Based on a weighted average of IAI 2019 regional-level data, weighted by countries share in alumina imports into Europe

Table 4-4 Land use and rehabilitation in alumina plants (source: IAI)

Focus on land use	Unit	2019	2015
Land occupation	km ² /t product	6,75E-07	6,54E-07
Land use type before	/	Pastureland	Pastureland
Land use type after	/	Treated and vegetated	Treated and vegetated

4.2.3 Anode production

Direct input and output data for producing 1 tonne of anode are reported in Table 4-5. The European average of 2021 can be compared with the data of the year 2015 for Europe, as well as with worldwide figures from 2015 (IAI, 2015). Additionally, the table includes weighted average figures for anode production for smelters outside Europe, reflecting the relative contribution of various regions to the total European imports of primary aluminium ingots (i.e., indirect imports of anode). These values were calculated by European Aluminium using the IAI regional LCI inventory survey (IAI, 2022). It should be noted that these data are not directly comparable to the global average figures from IAI for 2015, as they were not calculated on the same basis. For more details on the methodology used to compute these figures for anode production at non-European smelters, please refer to Section 4.3.2.

In 2021, the consumption of the total raw carbon material increased by approximately +5% in comparison with the 2015 assessment. Specifically, 1 066 kg of raw carbon inputs were used to produce 1000 kg of baked anode. It should be noted that, in contrast to the 2015 assessment, 2021 figures include as well additional raw materials inputs such as steel or refractory materials. Overall, the total solid inputs amount to 1074 kg of material per tonne of baked anode. There has been an increase in both thermal energy and electricity consumption in 2021 when compared to 2015 energy consumption. Moreover, it appears that the consumption of heavy fuel oil shifted to natural gas consumption.

It should be noted that 2021 datasets refer to 100% anode production while a mix of 95% anode and 5% paste production was used in the 2015 datasets. Therefore, the scope of the 2015 and 2021 datasets are not fully comparable. Finally, 2015 baseline data provided by IAI have been corrected in comparison with the previous report.

Table 4-5 Direct input and output data for the production of 1 tonne of anode/paste

Anode production – relative figures per tonne of anode	Unit	European Aluminium		European Aluminium
		2015	2021	2019*
Inputs				
Materials				
Calcined coke	kg/t	692	667	941
Pitch	kg/t	160	155	193
Butts used	kg/t	164	244	
Green anodes imported on site	kg/t	1,3	0,2	
Total raw carbon inputs	kg/t	1.017	1.066	NA
Steel	kg/t	-	1,4	-
Refractory material	kg/t	-	6,1	-
Total inputs	kg/t	-	1.074	-
Energy				
Coal	MJ/t	0	0	0
Heavy Oil	MJ/t	636	166	593
Diesel and light fuel Oil	MJ/t	0	0	5
Natural Gas	MJ/t	1.507	2.250	1.918
Other	MJ/t	601,6	497	-
Thermal energy (i.e. fuels)	MJ/t	2.745	2.913	2.517
Purchased electricity	kWh/t	127	230	109
Total energy	MJ/t	3.203	3.743	2.909
Water input				
Fresh water used	m³/t	3,9	3,8	-
Sea water used	m³/t	9,7	12,6	-
Outputs				
Air emissions				
Particulates	kg/t	0,21	0,07	0,49
SO2	kg/t	0,92	0,19	0,98
NOx	kg/t	0,35	0,71	0,82
Particulate fluoride	kg/t	2,2E-03	8,2E-04	1,6E-03
Gaseous fluoride	kg/t	0,03	4,6E-04	1,9E-02
PAH	kg/t	0,12	1,0E-02	8,40E-05
Water discharge				
Fresh water	m³/t	3,7	3,4	0,01
Sea water	m³/t	9,7	12,2	-
Suspended solids	kg/t	0,12	0,14	-
Fluorides (as F)	kg/t	3,5E-03	1,5E-03	-
PAH (6 Borneff components)	g/t	5,90E-01	6,96E-01	8,40E-05
Oil and grease/total hydrocarbons	kg/t	2,31E-05	3,88E-05	5,43E-02
By-products or solid waste				
Waste carbon or mix	kg/t	11,8	17,7	7,40
Steel to be externally recycled	kg/t	1,3	0,4	0,40
Refractory material that is externally recycled	kg/t	4,6	5,6	2,90
Refractory material that is NOT recycled	kg/t	8,9	2,3	2,40
Scrubber sludges	kg/t	0,2	0,0	0,10
Other externally recycled by-product	kg/t	7,3	2,8	0,50
Other landfilled waste	kg/t	7,0	1,4	0,30

N.B.: Missing data are shown in the table as "-".

*Based on a weighted average of IAI 2019 regional-level data, weighted by countries share in ingots imports into

4.2.4 Electrolysis (smelters)

Table 4-6 contrasts the European average input and output values for the years 2015 and 2021, and the global average figures from IAI for 2015 (IAI, 2015). In addition, the table includes weighted average figures that account for the relative contribution of different regions to the total European imports of primary aluminium ingot, calculated by European Aluminium using the IAI regional LCI inventory survey (IAI, 2022). It should be noted that these data are not directly comparable to the global average figures from IAI for 2015, as they were not calculated on the same basis. More details regarding the approach followed to compute these figures for European imports can be found in Section 4.3.2.

Comments on input trends

Alumina and (gross) carbon anode consumption per tonne of liquid aluminium produced in European smelters increased slightly in 2021 compared to 2015. Aluminium fluoride consumption in European smelters (16.4 kg/t) is slightly lower than in smelters exporting to Europe (17.6 kg/t).

European electricity consumption in smelters in 2021 reached 14 564 kWh/t, whereas the electricity consumption in smelters exporting to Europe was 15 216 kWh/t.

Fresh water is mainly used for cooling and, in some cases, for wet scrubbing. The use of freshwater highly depends on the locations of the smelters, with notable discrepancies between water-stressed areas, unstressed areas and coastal regions. The data presented in Table 4-6 are simple arithmetical averages for Europe, without accounting for the water stress index of each plant location. Hence, these averages have limited significance, and freshwater use should be assessed more accurately at the local level. An attempt was made for the current modelling to model freshwater extraction locally according to plant locations as highlighted in Table 3-1.

Seawater is used for wet scrubbing in smelter air cleaning systems. This process is relevant to a limited number of coastal plants, but significant quantities are reported (i.e. 61 m³/t in 2021) because the method involves absorbing smelter air emissions into seawater at harmless concentrations. The data presented in Table 4-6 correspond to an arithmetical average on all reporting plants. Hence, seawater use has limited significance and should be better considered at a local level.

Comments on output trends:

Air emissions: An increase in perfluorocarbons (PFC) emissions is recorded for European smelters (CF₄ up by 2% and C₂F₆ by 12% compared to 2015). SO₂ emissions declined by 18% and NO_x emissions declined by 15%.

Water emissions: Emissions to water decreased for most parameters. Fluoride emissions declined by 51% compared to 2015. Figures for fluoride emissions in water are influenced by the smelters with wet scrubbing technologies. Wet scrubbing is mainly used by Scandinavian smelters located along the sea and using seawater.

Spent Pot Lining (SPL): The volume of Spent Pot Lining (SPL) generated in 2021 is in the same order of magnitude as in 2015. However, the share (%) of SPL deposited increased from 51% in 2015 to 70% in 2021.

Table 4-6 Direct input and output data to produce 1 tonne of liquid primary aluminium.

Production of liquid aluminium at the electrolysis (smelter) step – relative figures per tonne of liquid primary aluminium	Unit	European Aluminium		European Aluminium
		2015	2021	2019*
Inputs				
Raw materials				
Alumina	kg/t	1.908	1.917	1.903
Anode (gross)	kg/t	503	510	540
Anode (net)	kg/t	413	398	449
Aluminium fluoride	kg/t	16,4	16,7	18,1
Cathode carbon	kg/t	5,5	6,8	6,6
Other raw material				
Fresh water used	m³/t	12,7	24,5	0,5
Sea water used	m³/t	31,3	65,1	1,7
Refractory material	kg/t	6,70	6,59	6,41
Steel (for cathodes)	kg/t	5,3	3,5	4,5
Energy				
Electricity consumption	MWh/t	14,79	14,56	15,22
Outputs				
Air emissions				
Particulates	kg/t	0,76	0,55	1,92
NOx, as nitrogen dioxide	kg/t	0,42	0,21	0,49
Sulphur dioxide SO2	g/t	7,7	6,3	11,5
Particulate Fluoride	kg/t	0,15	0,14	0,49
Gaseous fluoride (HF)	kg/t	0,30	0,23	0,42
Total PAH	kg/t	7,8E-03	3,4E-04	2,7E-01
CF4	kg/t	1,8E-02	1,8E-02	4,1E-02
C2F6	kg/t	2,0E-03	2,4E-03	1,7E-03
Total PFC	kg/t	2,0E-02	2,1E-02	4,2E-02
Emissions to water				
Fresh Water	m³/t	15,3	20,0	0,9
Sea water	m³/t	31,3	65,1	28,4
Fluoride (as F)	kg/t	0,21	0,10	0,39
Oil/grease	kg/t	5,1E-03	4,5E-05	1,1E-04
PAH (6 Borneff components)	g/t	6,1E-02	1,9E-04	5,5E-01
Suspended solids	kg/t	0,17	0,14	0,26
By products or solid waste				
Waste alumina	kg/t	1,4	0,6	0,1
Waste carbon or mix	kg/t	12,8	3,1	9,6
Steel	kg/t	6,7	7,3	4,6
Scrubber sludges	kg/t	0,53	0,01	2,11
Refractory material for external recycling (excluding spent pot lining, SPL)	kg/t	0,26	0,16	0,20
Refractory material that is not recycled (excluding spent pot lining, SPL)	kg/t	0,16	0,45	0,10
Spent Pot Lining (SPL)				
Spent Pot Lining (SPL) from normal operation	kg/t	22,3	25,0	22,1
SPL for external recycling	kg/t	10,0	6,6	5,4
SPL deposited	kg/t	12,3	17,5	16,6
SPL stored	kg/t	0	0,82	0

N.B.: Missing data are shown in the table as "-" or "NA" when not disclosed.

*Based on a weighted average of IAI 2019 regional-level data, weighted by countries share in ingots imports into Europe.

4.2.5 Cast house

Table 4-7 compares the European average input and output values for producing one tonne of casting ingot for the years 2015 and 2021 with the global average figures from the IAI for 2015 (IAI, 2015). Additionally, the table includes weighted average figures that consider the relative contribution of different regions to the total European imports of primary aluminium ingot, calculated by European Aluminium using the IAI regional LCI inventory survey (IAI, 2022). More details on the methodology used to compute these figures for European imports can be found in Section 4.3.2.

Comments on input trends:

Aluminium input of the cast house is not only composed of liquid aluminium coming from the electrolysis but consists also of solid metals like alloying elements, aluminium scrap and ingot for remelting, mainly for preparing the right alloy composition and for remelting the ends of the extrusion ingot and rolling ingots which are usually sawn at the cast house location. In 2021, the metal input mix was composed of liquid metal (80%), remelt ingot (9%), scrap (9%) and alloy additives (2%).

As already stated for the electrolysis step, water input is highly dependent on the smelter location, so a European average has little significance.

The use of fuels at the European level is higher than the use in cast house for import ingots, due to a higher input of solid aluminium, i.e. scrap and remelt ingot. There was a strong increase in electricity consumption in Europe (+105%) in 2021 versus 2015, whereas the consumption of thermal energy declined by 33%. **Overall, the total energy consumption (i.e. thermal + electricity) for the casting process declined by 9%.** Although more electricity was used at the cast house, the consumption stayed small compared to the use at the electrolysis step.

The share of electricity consumption in the total energy used increased from 18% to 39% between 2015 and 2021. **This trend illustrates the aluminium industry's efforts to switch, when possible, with current technologies, from fossil energy fuels to electricity in view of decarbonising the process.** More details related to the industry's decarbonisation strategy can be found in the European Aluminium [Net-Zero by 2050 pathway report](#).

Comments on outputs:

European averages of air emissions at the cast house are not very significant since, in many cases, such figures are included in the electrolysis step and no specific figures are given for the cast house.

The most significant by-product is the dross (mix of aluminium oxide and entrapped aluminium metal). After mechanical hot pressing to extract most of the liquid metal, the dross is recycled internally or externally in rotary furnaces (see section 8.7). No allocation has been made here as the recycling of the dross is part of the system boundaries as explained in the next section.

Table 4-7 Direct input and output data to produce 1 tonne of cast aluminium.

Aluminium ingot production – relative figures per tonne of casted aluminium	Unit	European Aluminium		IAI	European Aluminium
		2015	2021	2015	2019*
Inputs					
Metal					
Liquid aluminium (from electrolysis)	kg/t	912	848	1.000	1.000
Remelt ingot	kg/t	69	91	NA	NA
Al Scraps	kg/t	23	90	NA	NA
Alloy additives	kg/t	23	23	NA	NA
Total inputs	kg/t	1.026	1.054	NA	NA
Other raw material					
Fresh water used	m³/t	5,0	8,4	2,2	0,5
Sea water used	m³/t	-	1,78	-	11
Chlorine	kg/t	5,3E-02	2,4E-02	1,0E-02	1,3E-03
Argon	kg/t	5,60	1,48	-	0,63
Nitrogen	kg/t	2,0E-02	5,9E-02	-	5,8E-02
Energy					
Coal	MJ/t	0	0	0	0
Heavy Oil	MJ/t	99	0	51	52
Diesel and light fuel Oil	MJ/t	1	47	21	2
Natural Gas	MJ/t	1.504	924	832	728
Total thermal energy (i.e. fuels)	MJ/t	1.604	1.075	905	781
Electricity	kWh/t	95	194	53	89
Total energy consumption (i.e. fuels +electricity)	MJ/t	1.945	1.775	1.095	1.103
Outputs					
Air emissions					
Particulates	kg/t	0,04	0,03	0,04	0,01
NOx, as nitrogen dioxide	kg/t	0,11	0,14	0,08	0,02
Sulphur dioxide SO ₂	kg/t	1,9E-01	5,2E-03	1,2E-01	2,4E-03
HCl (hydrogen chloride)	kg/t	1,5E-02	1,5E-02	3,0E-02	5,4E-03
Emissions to water					
Fresh Water	m³/t	6,5	8,4	1,9	0,1
Sea water	m³/t	-	1,78	-	11
Oil/grease	kg/t	6,9E-02	4,3E-03	3,0E-02	2,3E-03
Suspended solids	kg/t	5,35E-01	2,70E-02	2,70E-01	2,06E-03
By-products for external recycling					
Dross	kg/t	17,2	20,3	13,3	8,6
Filter dust	kg/t	4,16E-01	3,93E-02	5,0E-01	3,3E-01
Refractory material	kg/t	1,0E+00	4,3E-01	3,0E-01	7,5E-02
Scrap sold	kg/t	-	6,5	-	-
Solid waste					
Dross - landfill	kg/t	0,0E+00	0,0E+00	7,0E-01	1,7E-01
Filter dust - landfill	kg/t	8,5E-03	7,5E-02	0,0E+00	1,1E-01
Other landfill wastes	kg/t	3,00	0,52	1,00	0,98
Of which hazardous waste	kg/t	2,67	0,20	0,90	0,58
Refractory material - landfill	kg/t	0,57	0,41	0,50	0,94
Total solid waste	kg/t	3,58	1,01	2,20	2,19

N.B.: Missing data are shown in the table as "-" or "NA" when not disclosed.

*Based on a weighted average of IAI 2019 regional-level data, weighted by countries share in ingots imports into Europe.

4.3 Material flow modelling

4.3.1 European Aluminium models for alumina supply

4.3.1.1 Modelling direct alumina imports into Europe

In 2015, Europe relied on imports for 61% of its alumina, a figure that decreased slightly in 2021 to approximately 59% of the total European alumina consumption. Specifically, Europe's net import of alumina amounted to 4,8 million tonnes in 2021.

Table 4-8 shows the geographic distribution of alumina imports into Europe and their respective shares of total imports. In 2021, Europe mainly sourced its alumina from “Central and South America” (83% of total imports), followed by “Oceania” (9%), “Rest of Europe” (4%) and “Asia” (4%).

To model the direct imports of alumina into Europe, regional-level LCI inventory data from IAI were used, based on the 2019 data collection (IAI, 2022). All inputs and outputs were then weighted according to their proportionate share of imports into Europe. Correspondence between the regions defined by IAI and the one defined in this report can be found in Table 4-9. The results of this weighting can be found in Table 4-3.

Table 4-8 Geographical distribution of the alumina main imports into Europe (2021) and representative countries for LCA modelling (source Eurostat for EU27 and national customs data for EFTA countries)

Regions	Imports share (%)	2021 main countries and imports share for the region (%)	LCA datasets utilized in modeling
Central and South America	83%	Brazil (84%), Jamaica (16%)	Brazil
Oceania	9%	Australia (100%)	Australia
Rest of Europe	4%	Bosnia & Herzegovina (95%), Turkey (5%)	Ireland (<i>by default</i>)
Asia	4%	Indonesia (25%), India (18%), China (17%), Vietnam (15%), Japan (3%)	India
North America	0,4%	United States (100%)	United States
Total	100%		

Table 4-9 Regionalised inventory data name collected by IAI and their corresponding name for this report

IAI abbreviation	IAI full name	EA correspondance
GCC	Gulf Cooperation Council	Middle East and Central Asia
ROE	Russia and Other Europe	Rest of Europe
AFR	Africa	Africa
NAM	North America	North America
SAM	South America	Central and South America
OAS	Other Asia	Asia
CNA	China	Asia
OCA	Oceania	Oceania

For the modelling of the energy used by foreign alumina refiners which supplied European smelters in 2023, representative country datasets were used for each region, as reported in Table 4-8.

4.3.1.2 Modelling indirect alumina imports into Europe

4.3.1.2.1 Countries of origin of ingots imported into Europe

In 2015, 49% of the primary ingots used in Europe came from imports. In 2021, imports of metal into Europe represent about 48% of European consumption (Source: customs statistics – Eurostat). In 2021, Europe's net imports of aluminium were equal to 3.8 Mt. Most primary aluminium imports originated from Russia (24%), the United Arab Emirates (16%) and Canada (10%).

The details of the main importing countries and regions are given in Table 4-10. As an example, the “Middle East & Central Asia” region represented 31% of European imports in 2021. The United Arab Emirates (UAE) represented 50% of the imports from “Middle East & Central Asia”.

Table 4-10 Geographical distribution of the primary aluminium imports into Europe - 2021 (source Eurostat for EU27 and national customs data for EFTA countries)

Regions	Imports share (%) ¹³	2021 main countries and imports share for the region (%)
Middle East and Central Asia	31%	United Arab Emirates (50%), Bahrain (29%), S. Arabia (9%)
Rest of Europe	30%	Russia (81%), Turkey (8%), Bosnia and Herzegovina (6%)
Africa	19%	Mozambique (49%), South Africa (26%), Egypt (16%) Cameroon (5%)
North America	10%	Canada (99%), United States (1%)
Asia	8%	India (74%), Malaysia (10%), China (2%)
Oceania	1%	Australia (55%), New Zealand (45%)
Central and South America	1%	Brazil (75%)
Total	100%	

Highlights:

Compared to the import statistics of 2015, “Middle East and Central Asia” region has seen a significant increase in its import share (i.e., 31% vs 21% in 2015). Conversely, “Rest of Europe”, which held the position of the main importer, experienced a notable decline, in its market share of European imports, decreasing from 43% in 2015 to 30% in 2021. The rankings of other regions in terms of market share remain consistent with 2015, with “Africa” in third place, followed by “North America”, “Asia”, and “Oceania”.

¹³ From the official trade data, some imports data were allocated to no “countries/regions” for various reasons (e.g. confidentiality issues). These volumes represented 5% of the imports and have been re-allocated to the various regions according to their “statistical weight.”

4.3.1.2.2 Alumina supply

A simplified model was developed to reflect the impacts associated with alumina supply within countries exporting ingots to Europe in 2021. The analysis assessed alumina flows in these regions which are presented in Table 4-11. Specifically, for regions such as “Middle East and Central Asia” and “North America”, archetype scenarios based on trade data produced by IAI were employed to depict the inter-regional flows of alumina (IAI, 2022). Based on the scenarios, “North America” was assumed to rely entirely on “Central and South America” for its alumina supply, while “Middle East and Central Asia” depended on “Oceania”. Furthermore, the supply of alumina for “Oceania”, “Rest of Asia”, and “Central and South America” was hypothesised to be entirely sourced domestically. Finally, as no dataset to produce alumina was made available by IAI for “Africa”, it was assumed that there was no domestic production of alumina, and alumina imports were evenly divided between “Oceania” and “Central and South America”.

From these hypotheses, inputs/outputs data related to alumina supply for smelters exporting ingots exporting to Europe were derived by averaging the regional-level life cycle inventory (LCI) data according to each region’s relative share of the overall indirect imports of alumina into Europe (i.e. intrinsic to the direct imports of ingots), as reported in Table 4-11. The results of this weighted average for each input/output relative to alumina production are reported in Table 4-12.

Table 4-11 Alumina supply for smelters in regions exporting ingots to Europe

Alumina supply by region	Regions of the smelters exporting to Europe							Total
	Middle East and Central Asia	Rest of Europe	Africa	North America	Central and South America	Asia	Oceania	
Middle East and Central Asia								0%
Rest of Europe		50%						15%
Africa								0%
North America								0%
Central and South America		17%	50%	100%	100%			26%
Asia						100%		8%
Oceania	100%	17%	50%				100%	47%
Europe		17%						5%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Table 4-12 Direct inputs and outputs for production of alumina used by smelters exporting primary aluminium to Europe -
Figures scaled to 1 tonne of alumina.

Alumina production – relative figures per tonne of alumina (Al₂O₃) indirectly imported into Europe	Unit	European Aluminium 2019*
Inputs		
Raw materials		
Bauxite	kg/t	2.691
NaOH (as 100%)	kg/t	79
CaO	kg/t	44
Fresh water used	m ³ /t	5,0
Sea water used	m ³ /t	3,1
Energy		
Coal	MJ/t	2.792
Heavy oil	MJ/t	1.309
Diesel oil	MJ/t	8
Natural gas	MJ/t	5.737
Total thermal energy	MJ/t	9.846
Electricity	kWh/t	93
Outputs		
Air emissions		
Particulates	kg/t	0,35
SO ₂	kg/t	0,87
NO _x	kg/t	0,69
Hg	g/t	-
Water discharge		
Fresh water	m ³ /t	2,1
Sea water	m ³ /t	3,0
Suspended solids	kg/t	3,8E-02
Oil	kg/t	3,3E-02
Hg	g/t	2,6E-01
By-products		
Bauxite residue	kg/t	15,8
Other	kg/t	-
Solid waste		
Bauxite residue (red muds)	kg/t	1.311
Any other industrial waste	kg/t	24
Of which any other landfill wastes	kg/t	13,1
Of which any other hazardous waste according to local legislation	kg/t	10,5

N.B.: Missing data are shown in the table as "-".

*Based on a weighted average of IAI 2019 regional-level data, weighted by countries share in ingots imports into Europe

For the modelling of the electricity grid mix and thermal energy consumed by alumina refiners which supplied smelters that exported ingots to Europe in 2021, representative country datasets were used for each region. Specifically, energy datasets from Australia, Brazil, Russia, and Ireland were selected as proxies for “Oceania”, “Central and South America”, “Rest of Europe,” and “Europe”, respectively.

4.3.2 European model for anode production, electrolysis and cast house in foreign countries importing ingots into Europe

Regional-level LCI inventory data from IAI were used to derive average inputs/output values for processes after the alumina production and involved in the production of primary ingots imported into Europe. These processes are anode production, electrolysis, and casting, taking place in countries that exported primary ingots in Europe in 2021.

The approach followed was like that employed for calculating inputs/output values associated with indirect alumina supply in Europe. Hence, all inputs and outputs provided at the regional level in the LCI inventory of IAI (2022) were weighted according to each region’s contribution to the total imports into Europe (as shown in Table 4-10). The inputs/outputs resulting from this weighted average for indirect imports are delineated and compared to the 2015 global average of IAI, as well as the European average for 2015 and 2021, for anode production in Table 4-5, for the electrolysis process in Table 4-6 and casting of imported ingots in Table 4-7.

4.4 European Aluminium electricity models for aluminium electrolysis (smelters)

4.4.1 Overview of European smelters localisation

Since 2015, two smelters located in Spain have closed in Europe versus the 2021 assessment (Figure 4-4). Moreover, in 2021, EFTA countries (i.e., Norway and Iceland) represented 54% of the European production while they represented about 50% of the European production in 2015.

Thus, these changes in the industry will affect the average datasets (e.g., electricity mix) of European smelters in comparison with the previous report.

It should be noted that due to the current energy situation, additional smelters in Europe have been recently (or are in the process of being) fully idled (Figure 4-4). However, as the report focuses on the 2021 assessment, the report includes, when possible, data for the plants idled post-2021 (e.g., in the Netherlands and Slovakia).

To address the changes in the European picture since 2021, Section 4.7 presents a model focusing on the plants still operating in 2023. This model aims to evaluate the impacts of the energy crisis on the environmental footprint of primary aluminium ingots produced in Europe, based on the operational plants in 2023 (i.e. plants depicted in green in Figure 4-4).

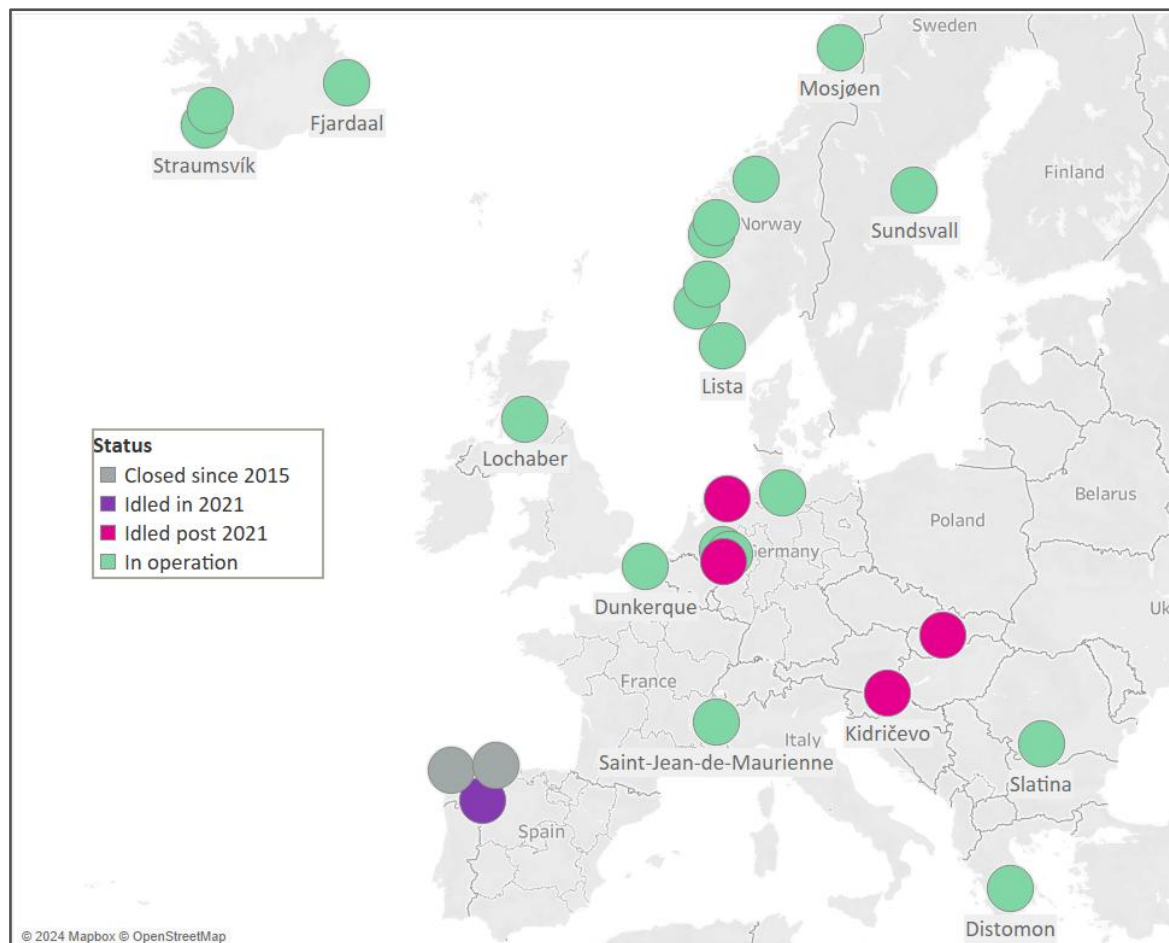


Figure 4-4 Mapping of the European smelters - 2021 vs 2015.

4.4.2 Electricity used by European primary aluminium smelters

The European smelters' electricity model relied on the reported electricity consumption of each smelter, which was then allocated among various energy sources according to data received by the company. The process for building this model is detailed as follows:

1) Consolidation at the level of Europe per energy source

In rare instances where direct data for a plant was unavailable (*about 14% of the primary production*), the national grid mix of the respective country, sourced from the International Energy Agency data, served as a proxy (IEA, 2023). Typically, the national grid mix tends to be more carbon-intensive

compared to the smelter's direct energy sources¹⁴. Therefore, opting for this approach can be viewed as a conservative choice.

2) Calculating the countries' contributions to each energy source

The relative share of each country was subsequently computed per energy source. This step enables the identification of the primary contributors to each electricity source.

3) Modelling the electricity production for each energy source

A simplified model to produce electricity was developed for each energy source (e.g. hydropower, natural gas or coal), focusing on the main contributing countries. This model utilized country-specific and specific energy source LCI datasets available within the LCA FE software. In this report, electricity derived from other renewable energy sources was modelled independently from hydropower¹⁵. To facilitate this, the electricity grid mix of Germany served as a proxy to determine the distribution of various other renewable sources (except hydropower). Consequently, it was defined for the modelling that 2/3 of the total electricity from other renewable energy was sourced from wind energy and 1/3 from solar.

4) Building the European model

The weighting of each LCI dataset was determined according to their respective contribution to the European electricity model. For instance, the LCI dataset for electricity from hydropower accounts for 62% of the total.

The combination of country-specific LCI datasets resulted in a comprehensive dataset detailing the production of 1kWh of electricity in Europe for primary aluminium production via pre-bake smelting. Table 4-13 illustrates the consolidation at the European level of the energy sources to produce electricity, which is used by European smelters, along with the countries that were considered to construct the European model. When only a few countries predominantly utilized a particular energy source for smelters' electricity, the country with the highest usage share served as the representative for modelling purposes. For instance, the EFTA countries (Norway and Iceland) collectively contributed 87% of hydroelectricity, with Norway alone accounting for 52%. Consequently, the dataset on hydroelectricity production from Norway was employed in LCA modelling. Conversely, if multiple countries shared similar usage shares for an energy source, the averaged dataset from EU-28 was utilized (e.g., for natural gas electricity). Lastly, for energy sources with minimal usage (below 5% by default), the European electricity mix for these sources was adopted (e.g., oil and energy from waste).

¹⁴ Direct data collected by the members covering about 86% of the production indicated at European grid mix composed of 67% hydro, 11% nuclear, 6% coal and 7% natural gas, 6% of other renewables, and 1% of energy from waste.

¹⁵ By default, in the previous data collection template, other renewables energy have been assimilated to hydropower as their share in the electricity grid mix used by smelter were limited and few data were available.

Table 4-13 European electricity model - Year 2021

Consolidation at European level		Modelling of the electricity production
Energy source	Share (in %)	<i>LCA datasets used in the electricity model</i>
Hydro	62%	Norway
Nuclear	11%	France
Natural gas	9%	EU-28
Other renewables (2/3 wind and 1/3 solar power)	8%	Germany
Coal	6%	EU-28
Oil	3%	EU-28
Energy from waste	1%	EU-28
Total	100%	

Highlights:

The sourcing of energy for electricity used by European smelters shifted towards greater reliance on renewables between 2015 and 2021 (71% in 2021 vs 67% in 2015). Concurrently, there was an increase in sourcing of electricity from natural gas (9% in 2021 vs 7% in 2015) and oil (3% in 2021 vs 0% in 2015). On the other hand, the use of nuclear energy for smelters electricity in Europe significantly declined in 2021, dropping from 17% in 2015 to 11% in 2021. This drop in the share of nuclear is related to a decrease in the electricity generation from nuclear in some key countries (e.g. France). The environmental indicators related to the production of 1kWh of electricity to produce primary aluminium in 2021, along with the comparison with their values in 2015, are reported in Table 4-14. There was an overall decline in all environmental indicators, excluding the Eutrophication Potential (EP), Ozone Layer Depletion Potential (ODP) and the Global Warming Potential (GWP 100 years). The increase of +8% in the GWP can be explained by the decrease of low carbon energy sources to produce electricity consumed by smelters in Europe (e.g. nuclear).

The apparent strong increase in Ozone Layer Depletion Potential (ODP) is primarily caused by the sensitivity of the data at low values, where small changes can result in large relative differences, despite being nearly negligible.

Table 4-14 Environmental indicators for the production of 1 kWh of electricity used by aluminium smelters in Europe

Environmental indicators per kWh electricity, European model	2021	2015	2021 vs 2015 (%)
Abiotic Depletion (ADP elements) [kg Sb eq.]	3,0E-08	9,3E-08	-67%
Acidification Potential (AP) [kg SO ₂ eq.]	1,6E-04	2,1E-04	-24%
Eutrophication Potential (EP) [kg Phosphate eq.]	2,4E-05	2,5E-05	-5%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	1,5E-01	1,3E-01	+11%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	4,7E-12	1,1E-12	+337%
CML2001 - Aug. 2016, Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	1,5E-05	1,6E-05	-9%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	6,6E+00	6,0E+00	+10%
Primary energy from non renewable resources (net cal. value) [MJ]	2,8E+00	3,1E+00	-11%
Primary energy from renewable resources (net cal. value) [MJ]	3,8E+00	2,9E+00	+34%

4.4.3 Electricity used to produce imported aluminium

The electricity production to produce primary aluminium imported into Europe is illustrated in Table 4-15. The methodology entails several steps and assumptions, detailed as follows:

- Only countries listed in Table 4-17 were considered for building the model. These countries account for more than 90% of European imports of primary aluminium in 2021.
- The IAI regional smelters' electricity grid mixes for these countries based on data provided by aluminium producers were used (available [here](#)). For Africa and North America, IAI regional data have been adjusted to better reflect the exports of the producing countries to Europe. Approximately 99% of European imports from North America (i.e., Canada) are based on hydropower production while the IAI regional mix is based on 95%. For Africa, industry knowledge was used to assess the electricity grid mix from Mozambique, S. Africa, and Egypt. For Cameroon and Ghana, data from the International Energy Agency were used by default (IEA, 2023).
- Weighting and consolidation of the country-specific grid mixes were done at regional and global levels. Consolidated figures are shown in Table 4-15.
- A simplified electricity grid mix using power plant data that is representative of the main sources of imports was produced to model the electricity production of each of the considered regions. For instance, electricity from hydropower for Russia, electricity from natural gas for the United Arab Emirates and hydropower and hard coal for South Africa.
- The consolidation of the energy sources for electricity production used by imported aluminium at a global level is reported in Table 4-15.

Table 4-15 Energy sources for the electricity used to produce imported primary aluminium

Regions	Share of European imported volumes (%)	Energy mix of the European imports						Total
		Hydropower and other renewables	Coal	Oil	Natural gas	Nuclear	Other	
Middle East and Central Asia	31%	1%	-	0%	99%	-	-	100%
Rest of Europe	30%	90%	8%	0%	2%	0%	0%	100%
Africa	19%	54%	26%	1%	19%	0%	0%	100%
North America	10%	99%	1%	-	-	0%	0%	100%
Asia	8%	6%	94%	0%	-	-	-	100%
Oceania	1%	12%	87%	-	1%	-	-	100%
Central and South America	1%	84%	-	-	16%	-	-	100%
Total for Europe	100%	49%	15%	0%	35%	0%	0%	100%

Compared to 2015, the imports supplied by hydroelectricity declined in 2021 (from 69% in 2015 to 49% in 2021). Conversely, imports based on natural gas and coal increased (Table 4-16). The increase in aluminium produced by natural gas can be explained by the strong increase in imports from the Middle East.

Table 4-16 Electricity mix of European imports (2021 vs 2015)

Electricity mix of European imports	Hydro	Coal	Oil	Natural gas	Nuclear	Total
2021 update	49%	15%	0%	35%	0%	100%
2015 update	69%	8%	0%	22%	1%	100%

LCI proxies, derived from representative countries, were utilized to model the energy production from different energy sources within LCA FE software, as illustrated in Table 4-17.

Table 4-17 Representative countries for each energy source for the electricity imports model

Energy source	Hydropower	Coal	Oil	Natural gas	Nuclear
Representative country	Russia	South Africa	South Africa	United Arab Emirates	-

Table 4-18 compares the values of the main environmental indicators considered for this report in 2021 and 2015 to produce 1 kWh of electricity used by smelters exporting aluminium to Europe. Most of the environmental indicators experienced an increase between 2015 and 2021, excluding the Abiotic Depletion Potential (ADP) and Ozone Layer Depletion Potential (ODP).

Table 4-18 Environmental indicators per kWh of electricity used by aluminium smelters exporting to Europe

Environmental indicators per kWh electricity, Imports model	2021	2015	2021 vs 2015 (%)
Abiotic Depletion (ADP elements) [kg Sb eq.]	1,1E-08	9,7E-08	-89%
Acidification Potential (AP) [kg SO ₂ eq.]	2,3E-03	1,8E-03	+27%
Eutrophication Potential (EP) [kg Phosphate eq.]	1,4E-04	1,2E-04	+16%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	3,3E-01	2,7E-01	+23%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	1,1E-14	8,1E-12	-100%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	1,1E-04	9,1E-05	+25%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	6,6E+00	6,8E+00	-2%
Primary energy from non renewable resources (net cal. value) [MJ]	4,5E+00	3,8E+00	+19%
Primary energy from renewable resources (net cal. value) [MJ]	2,1E+00	3,0E+00	-29%

4.5 European Aluminium thermal energy model for anode production and ingot casting

A model was developed to allocate the consumption of thermal energy for sub-processes involved in the production of imported primary ingots, such as anode production and ingot casting. These figures of thermal energy for these processes are reported in Table 4-5 and Table 4-7.

To this end, the 2019 thermal energy data at the regional level related to this process was used. It was hypothesised based on expert judgement that smelters located in regions exporting ingots to Europe are entirely self-sufficient in their production of anode. Therefore, the relative import shares from these regions were used to distribute the thermal energy consumption associated with these processes across the different regions. In addition, datasets of representative countries, which account for 50% of aluminium imports into Europe, were used in the model as proxies for the regions given their availability in the LCA for Experts software, as indicated in Table 4-19. Due to the absence of a dataset for thermal energy from natural gas for the Middle East in the LCA for Experts version 10, the corresponding dataset for Europe was used as a proxy. This decision can be viewed as conservative, given that the smelters in the Middle East have among the best technologies to maximize the energy efficiency of their plant, as highlighted in the previous Environmental Profile Report (EA, 2018).

Table 4-19 Thermal energy modelling for ancillary processes related to the production of imported aluminium ingots

Regions	Imports share (%)	Datasets used in energy models
Middle East & Central Asia	31%	Saudi Arabia*
Rest of Europe	30%	Russia
Africa	19%	South Africa
North America	10%	Canada
Asia	8%	India
Oceania	1%	Australia
Central & South America	1%	Brazil
Total for Europe	100%	

*The EU-28 dataset for thermal energy from natural gas was used by default; no dataset available for Saudi Arabia in the LCA For Experts 10 software

4.6 European LCI datasets and environmental indicators for primary aluminium

The LCA for Experts (fka GaBi) was used to calculate the European LCI dataset for primary aluminium under the modelling hypotheses detailed in Sections 4.3 and 4.3.1, as summarised in Figure 4-5.

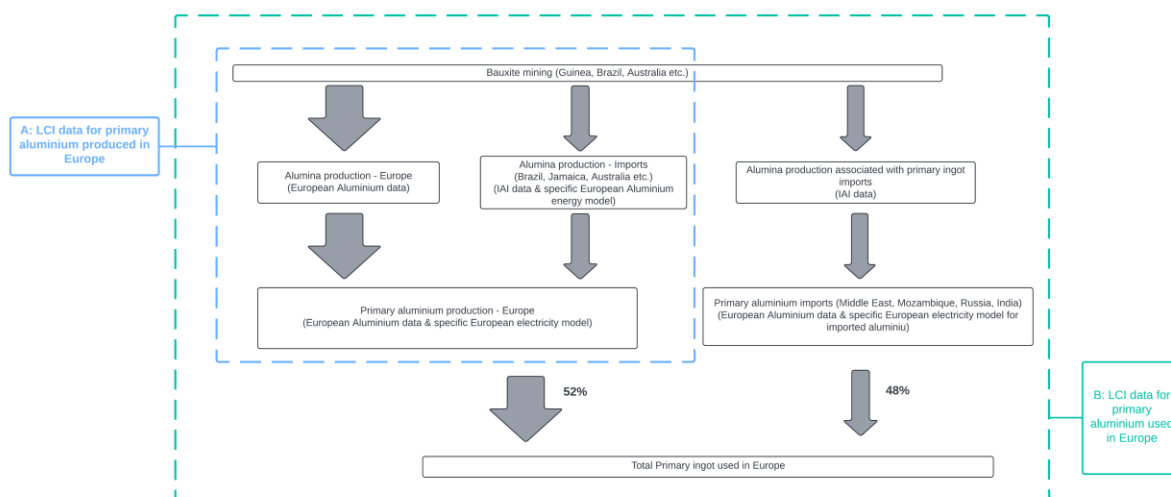


Figure 4-5 Modelling principle for generating the European LCI datasets for primary aluminium

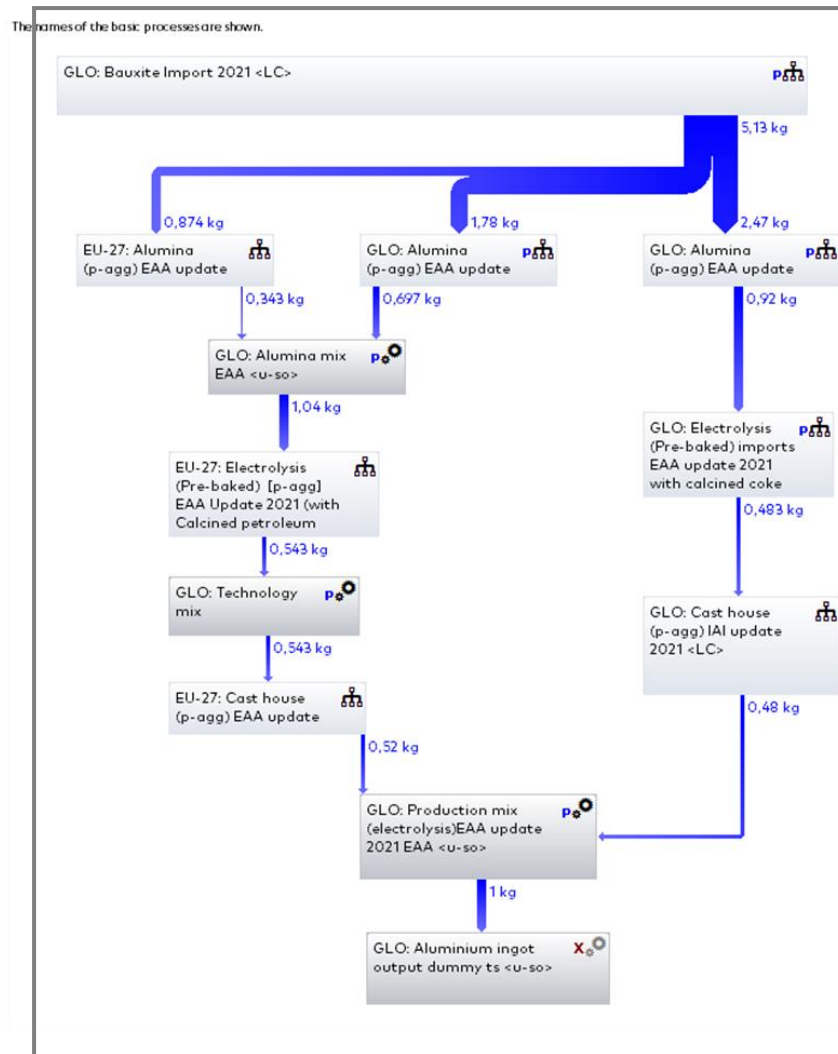
Two types of LCI datasets were created:

- A - LCI dataset for “Produced in Europe” primary aluminium
- B - LCI dataset for “Used in Europe” primary aluminium

For the aluminium ingots used in Europe, a combined model incorporating primary production in Europe and imports was utilized. For each of these models, specific input and output data, along with specific modelling for energy was developed, as previously outlined.

Figure 4-6 illustrates the modelling of primary aluminium in LCA for Experts software.

European Aluminium : primary aluminium ingot used in Europe



European Aluminium : primary aluminium ingot produced in Europe

The names of the basic processes are shown.

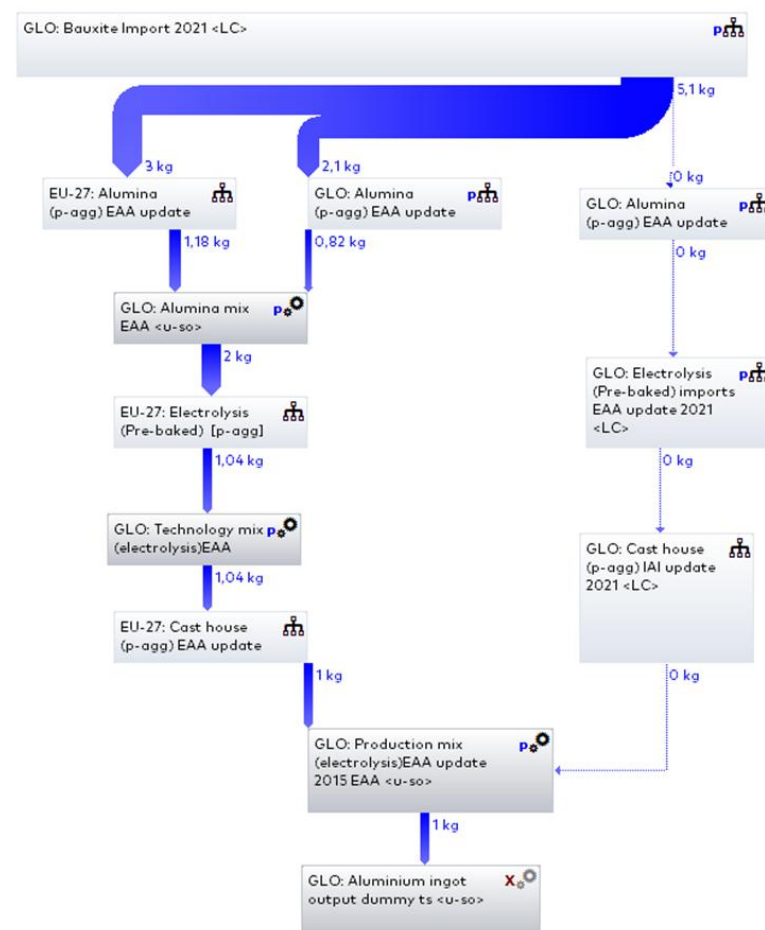


Figure 4-6 Flow diagram for primary aluminium ingot (GLO = Global)

4.6.1 Environmental indicators

The relative contributions of key processes to each environmental indicator are illustrated in Figure 4-7 and Figure 4-8. The values of environmental indicators for the predefined impact categories in 2021 are compared to those from 2015 in Table 4-20 and Table 4-21. **These sets of environmental indicators are purely informative and should not be used for evaluating the environmental impact of primary aluminium in Europe or for comparative purposes between various materials. As highlighted in ISO 14040 and 14044, only the environmental aspects of a product system or a service in a life cycle perspective, i.e. from cradle to grave or from cradle to recycling, are scientifically sound.**

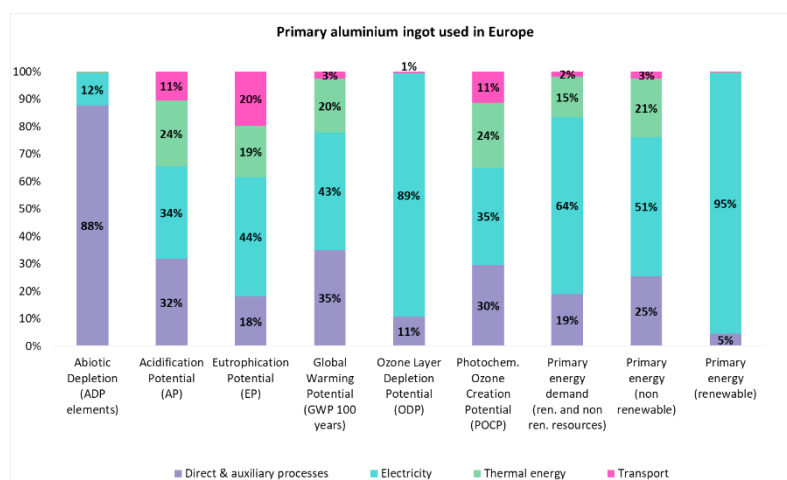


Figure 4-7 Relative contribution to environmental impact indicators values per key process type for primary aluminium ingot used in Europe.

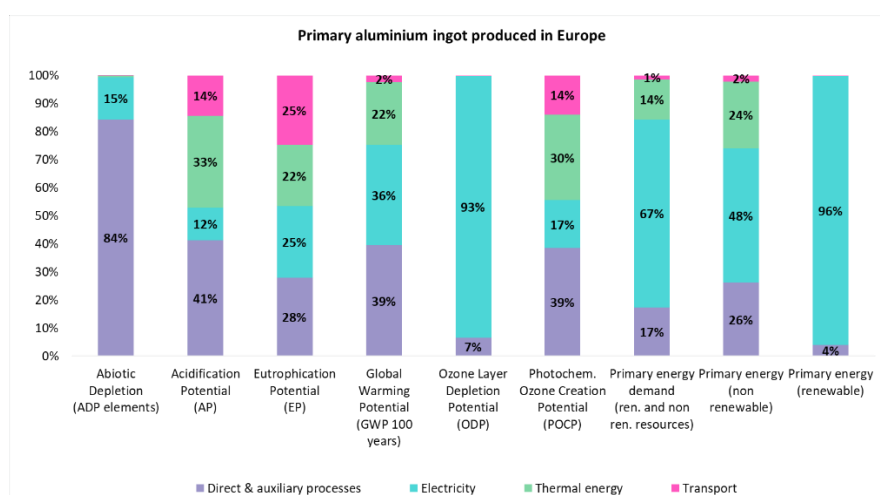


Figure 4-8 Relative contribution to environmental impact indicators values per key process type for the European production of primary aluminium ingot.

Most environmental impacts for both primary aluminium ingots produced or used in Europe are linked to electricity consumption, aluminium production processes, and auxiliary processes, as shown in Figure 4-8. For instance, these categories together contribute to about 78% of the impacts related to the Global Warming Potential (GWP 100 years).

It should be noted that the relative contribution of each subprocess (e.g. transport) in percentage (%) needs to be put in perspective with the absolute value when comparing the 2 datasets (i.e. production and consumption in Europe). For instance, the relative contribution of transport appears to be higher in the primary aluminium produced in Europe. However, the absolute figures for transport in domestic production are lower than the one for consumption (e.g. 4.5E-01 versus 6.1E-01 kg Phosphate equivalent for the Eutrophication Potential, EP).

Table 4-20 Environmental performance of primary aluminium used in Europe (2021 vs 2015)

Environmental indicators (per tonne of primary ingot used in Europe) - Cradle to gate -	2021	2015	2021 vs 2015 (in %)
Abiotic Depletion (ADP elements) [kg Sb eq.]	3,1E-03	4,2E-03	-26%
Acidification Potential (AP) [kg SO ₂ eq.]	5,6E+01	4,3E+01	+31%
Eutrophication Potential (EP) [kg Phosphate eq.]	3,1E+00	2,8E+00	+10%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	9,0E+03	8,6E+03	+4%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	4,9E-08	1,2E-07	-59%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	2,9E+00	2,3E+00	+25%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	1,7E+05	1,6E+05	+9%
Primary energy from non renewable resources (net cal. value) [MJ]	1,2E+05	1,1E+05	+8%
Primary energy from renewable resources (net cal. value) [MJ]	5,2E+04	4,7E+04	+11%

Table 4-21 Environmental performance of primary aluminium produced in Europe (2021 vs 2015)

Environmental indicators (per tonne of primary ingot produced in Europe) - Cradle to gate -	2021	2015	2021 vs 2015 (in %)
Abiotic Depletion (ADP elements) [kg Sb eq.]	3,5E-03	3,8E-03	-6%
Acidification Potential (AP) [kg SO ₂ eq.]	3,1E+01	2,3E+01	+38%
Eutrophication Potential (EP) [kg Phosphate eq.]	1,8E+00	1,5E+00	+20%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	7,2E+03	6,7E+03	+9%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	9,0E-08	9,9E-08	-9%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	1,7E+00	1,4E+00	+27%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	1,7E+05	1,4E+05	+19%
Primary energy from non renewable resources (net cal. value) [MJ]	1,0E+05	9,8E+04	+4%
Primary energy from renewable resources (net cal. value) [MJ]	6,8E+04	4,5E+04	+50%

Most environmental indicators for both primary aluminium produced and used in Europe showed an increase in 2021 compared to 2015 (Table 4-20 and Table 4-21). The deterioration in the

environmental footprint concerning AP, ODP, and POCP, for both domestically produced ingot and imports, is primarily attributed to an increase in direct emissions of SO₂ and NO_x.

Additionally, the rise in primary energy demand, from both renewable and non-renewable sources, can be explained by the increased electrification of aluminium processes and the greater use of renewable energy sources like solar and wind.

The increase in the GWP of primary aluminium produced in Europe is mainly related to the improved modelling in 2021, which includes the preliminary calcination of petroleum coke for anode production used by smelters, and the decline in the proportion of low-carbon energy sources to generate electricity used by smelters. Specifically, the share of low-carbon energy sources declined for electricity generation for European smelters, as detailed in Section 4.4.2. Moreover, there was a significant increase in imports from countries that rely on more carbon-intensive electricity (Table 4-16).

It should be noted that without the changes in modelling for the calcined coke for anode production, the GWP values between 2015 and 2021 would have been rather stable despite the decrease in the low-carbon electricity used by European smelters (see Section 9.2.2.1).

Finally, the decline for both datasets in Abiotic Depletion Potential (ADP) is driven by both a decline in thermal energy consumption from natural gas for alumina refining and a decline in ADP indicators of the European grid mix (refer to Table 2-6), although the volumes of NaCl (rock salt) used as an input for the refining of alumina increased (as shown in Table 4-3).

4.6.2 Main elementary flows

For each indicator presented in Table 4-20 for primary aluminium ingots used in Europe and Table 4-21 for primary aluminium ingots produced in Europe, the main contributing elementary flows are detailed in Table 4-22 and Table 4-23, respectively. **These elementary flows account for more than 80% of the respective indicators.**

For instance, 93% of the Global Warming Potential (GWP 100 years) of primary aluminium ingot used in Europe is attributed to carbon dioxide emissions, while approximately 3% is due to methane emissions, and PFC emissions also contribute around 3% to the GWP. The carbon dioxide emissions are primarily generated during electricity production (45%), followed by processes related to the production of primary ingots (e.g. anode consumption) (30%), and from fuel combustion (19%).

Table 4-22 Main elementary flows and main related processes: primary aluminium used in Europe

Main elementary flows and main related processes: primary aluminium used in Europe				
Abiotic Depletion	Elementary flows	Sodium chloride (rock salt): 83%	Chromium: 3%	
	(Sub) Process	Auxiliary (99%)	Electricity (97%)	
Acidification Potential	Elementary flows	Sulphur dioxide: 77%	Nitrogen oxides: 20%	
	(Sub) Process	Process (32%), Electricity (32%), Fuels (26%)	Electricity (44%), Transport (21%), Fuels (19%)	
Eutrophication Potential	Elementary flows	Nitrogen oxides: 94%		
	(Sub) Process	Electricity (44%), Transport (21%), Fuels (19%)		
Global Warming Potential	Elementary flows	Carbon dioxide: 93%	Methane: 3%	Halogenated emissions to air (PFC): 2%
	(Sub) Process	Electricity (45%), Process (29%), Fuels (20%)	Process (35%), Electricity (32%), Fuels (26%)	Process (100%)
Ozone Layer Depletion Potential	Elementary flows	R 141b (dichloro-1-fluoroethane): 98%		
	(Sub) Process	Electricity (89%), Auxiliary (8%)		
Photochem. Ozone Creation Potential	Elementary flows	Sulphur dioxide: 61%	Nitrogen oxides: 22%	NMVOC (unspecified): 3%
	(Sub) Process	Process (32%), Electricity (32%), Fuels (26%)	Electricity (44%), Transport (21%), Fuels (19%)	Transport (37%), Process (33%), Electricity (15%)
Primary energy demand: total	Elementary flows	Natural gas: 28%	Primary energy from hydro power: 23%	Hard coal: 17%
	(Sub) Process	Electricity (54%), Fuels (33%), Process (9%)	Electricity (99%)	Electricity (69%), Fuels (16%)
Primary energy from non renewable resources	Elementary flows	Natural gas: 40%	Hard coal: 25%	Crude oil: 24%
	(Sub) Process	Electricity (54%), Fuels (33%), Process (9%)	Electricity (69%), Fuels (16%), Process (13%)	Process (58%), Fuels (17%), Electricity (11%)
Primary energy from renewable resources	Elementary flows	Primary energy from hydro power: 73%	Primary energy from solar power: 16%	Primary energy from wind power: 10%
	(Sub) Process	Electricity (99%)	Electricity (82%), Auxiliary (13%)	Electricity (85%), Auxiliary (11%)

Table 4-23 Main elementary flows and main related processes: primary aluminium produced in Europe

Main elementary flows and main related processes: primary aluminium produced in Europe				
Abiotic Depletion	Elementary flows	Sodium chloride (rock salt): 81%	Chromium: 3%	
	(Sub) Process	Auxiliary (98%),	Electricity (97%)	
Acidification Potential	Elementary flows	Sulphur dioxide: 78%	Nitrogen oxides: 20%	
	(Sub) Process	Process (42%), Fuels (36%), Transport (11%), Electricity (8%)	Transport (28%), Fuels (24%), Electricity (22%), Process (21%)	
Eutrophication Potential	Elementary flows	Nitrogen oxides: 88%	Chemical oxygen demand (COD): 3%	
	(Sub) Process	Transport (28%), Fuels (24%), Electricity (22%), Process (21%)	Electricity (84%), Auxiliary (9%)	
Global Warming Potential	Elementary flows	Carbon dioxide: 93%	Methane: 4%	Halogenated emissions to air (PFC): 2%
	(Sub) Process	Electricity (36%), Process (33%), Fuels (23%)	Electricity (38%), Process (31%), Fuels (25%)	Process (100%)
Ozone Layer Depletion Potential	Elementary flows	R 141b (dichloro-1-fluoroethane): 98%		
	(Sub) Process	Electricity (93%)		
Photochem. Ozone Creation Potential	Elementary flows	Sulphur dioxide: 57%	Nitrogen oxides: 20%	Methane: 4%
	(Sub) Process	Process (42%), Fuels (36%), Transport (11%), Electricity (8%)	Transport (28%), Fuels (24%), Electricity (22%), Process (21%)	Electricity (38%), Process (31%), Fuels (25%)
Primary energy demand: total	Elementary flows	Primary energy from hydro power: 25%	Natural gas: 22%	Crude oil: 22%
	(Sub) Process	Electricity (99%)	Fuels (48%), Electricity (36%)	Process (52%), Electricity (20%), Fuels (15%)
Primary energy from non renewable resources	Elementary flows	Natural gas: 36%	Crude oil: 26%	Uranium: 20%
	(Sub) Process	Fuels (48%), Electricity (36%)	Process (52%), Electricity (20%), Fuels (15%)	Electricity (93%)
Primary energy from renewable resources	Elementary flows	Primary energy from hydro power: 63%	Primary energy from solar power: 23%	Primary energy from wind power: 14%
	(Sub) Process	Electricity (99%)	Electricity (89%), Auxiliary (8%)	Electricity (91%)

4.7 Modelling the impact of the energy crisis in Europe post-2021: primary production in Europe

Following the data collection of 2021, Europe experienced a significant increase in energy prices, which substantially affected the domestic production of primary aluminium ingots. Specifically, several smelters were idled, and some plants that continued operating had to drastically reduce their production. Moreover, as explained above, the nuclear capacity in France was running at a low production level which had a significant impact on the electricity grid mix by European smelters.

In this context, European Aluminium aimed to create a model to evaluate the environmental footprint of primary aluminium produced in Europe, in smelting plants that were still operating in 2023. For this purpose, it was hypothesized that the input/output figures related to the electrolysis process remained constant, **and only the average electricity grid mix of 2021, as presented in Table 4-13, was adjusted to reflect the mix used by the plants still operating in 2023 (Table 4-24). This model is closer to the current situation as the smelters which closed between 2021 and 2023 are still fully idled. Moreover, the electricity generation from nuclear energy in France is back to its normal level.**

It can be observed from Table 4-24 that in 2023, the share of low-carbon energy sources, namely nuclear, hydropower and other renewables, increased from 81% to 86% compared to 2021. Additionally, there was a decrease in the relative share of oil and coal, both carbon-intensive sources, declining by 1% point and 2% point, respectively.

Table 4-24 Electricity grid mix utilized by primary aluminium smelters in Europe (2023 vs 2021)

Electricity grid mix for primary smelters	2023	2021
Coal	5,0%	6,4%
Natural gas	7,1%	9,2%
Oil	0,7%	2,7%
Nuclear	10,7%	11,2%
Hydropower	68,3%	61,7%
Other renewables (2/3 wind and 1/3 solar power)	7,5%	7,8%
Other non renewables (e.g. waste)	0,7%	1,0%

The changes in environmental footprint related to the change in the electricity grid mix used by European smelters between 2021 and 2023 are reported in Table 4-25. Most environmental impacts notably decreased in 2023 compared to 2021. For instance, the Global Warming Potential (GWP 100 years) declined by 28%. This decrease can be attributed to the increase in the usage of low-carbon energy sources for electricity generation for European smelters in 2023. This trend is also evident in the reduction of primary energy demand from non-renewable resources, which declined by 21% in 2023 versus 2021, whereas primary energy demand from renewable resources increased by 13%, primarily due to the increase in hydroelectric power.

Table 4-25 Environmental indicators comparison related to the production of 1kWh of electricity used by European aluminium smelters (2023 vs 2021)

Environmental indicators per kWh electricity, European model	2023	2021	2023 vs 2021 (%)
Abiotic Depletion (ADP elements) [kg Sb eq.]	3,2E-08	3,0E-08	+5%
Acidification Potential (AP) [kg SO ₂ eq.]	9,5E-05	1,6E-04	-40%
Eutrophication Potential (EP) [kg Phosphate eq.]	1,6E-05	2,4E-05	-33%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	1,1E-01	1,5E-01	-28%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	4,5E-12	4,7E-12	-4%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	9,1E-06	1,5E-05	-38%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	6,6E+00	6,6E+00	-1%
Primary energy from non renewable resources (net cal. value) [MJ]	2,2E+00	2,8E+00	-21%
Primary energy from renewable resources (net cal. value) [MJ]	4,3E+00	3,8E+00	+13%

Table 4-26 presents the environmental impacts of producing primary aluminium ingot in Europe resulting from the adjustment in the grid mix to align with the conditions of 2023 while keeping all other mass flows constant. It can be observed that there was a reduction in the environmental footprint associated with primary aluminium production in 2023 compared to 2021, mainly due to the change in environmental footprint associated with the production of electricity used by European smelters between these two years, as previously discussed.

Table 4-26 Environmental indicators comparison between 2021 baseline and 2023 model for primary aluminium ingots produced in Europe

Environmental indicators (per tonne of primary ingot produced in Europe) - Cradle to gate -	2023*	2021	2023* vs 2021 (in %)
Abiotic Depletion (ADP elements) [kg Sb eq.]	3,5E-03	3,5E-03	-0,5%
Acidification Potential (AP) [kg SO ₂ eq.]	3,0E+01	3,1E+01	-3%
Eutrophication Potential (EP) [kg Phosphate eq.]	1,7E+00	1,8E+00	-7%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	6,6E+03	7,2E+03	-10%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	8,2E-08	9,0E-08	-10%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	1,6E+00	1,7E+00	-5%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	1,6E+05	1,7E+05	-4%
Primary energy from non renewable resources (net cal. value) [MJ]	9,3E+04	1,0E+05	-9%
Primary energy from renewable resources (net cal. value) [MJ]	6,9E+04	6,8E+04	+3%

*Based on a model where only the grid mix used by smelters in Europe is updated to reflect 2023 conditions.

4.8 Modelling the impact of the energy crisis in Europe post-2021: primary consumption in Europe

In addition to adjusting the grid mix used by European smelters to evaluate the environmental impact of primary aluminium produced in Europe in 2023 (as explained in Section 4.7), a similar approach was followed for the electricity production used by smelters exporting primary aluminium ingots to Europe in 2023. This was done to produce a model that evaluates the environmental impacts of primary aluminium ingots used in Europe in 2023, including both locally produced and imported ingots.

The methodology to adjust the modelling of the electricity grid mix used for imported ingots entails several steps and assumptions, as outlined below:

- By default, the same simplified electricity grid mix model using power plant data that is representative of the main sources of imports in 2021 was employed to model the electricity production in 2023. Consequently, the same set of country-level datasets was used for this model (refer to Table 4-17).
- The import share of each region exporting to Europe was adjusted to reflect the 2023 situation as shown in Table 4-27.
- The IAI regional smelters' electricity grid mixes (available [here](#)) for these countries, based on data provided by aluminium producers, were used. Since grid mixes for the year 2023 were not yet available and no major changes were expected between 2023 and 2022, the 2022 power mixes were used by default. For Africa, IAI regional data were adjusted to better reflect the exports of the producing countries to Europe. In detail, industry knowledge was used to assess the electricity grid mix from Mozambique, S. Africa, and Egypt. For Cameroon and Ghana, data from the International Energy Agency were used by default (IEA, 2023).
- Weighting and consolidation of the country-specific grid mixes were done at regional and global levels. Consolidated figures are shown in Table 4-28.
- The consolidation of the energy sources for electricity production used by imported aluminium in 2023 at a global level is reported in Table 4-29.

Table 4-27 Distribution of European imported volumes of primary aluminium ingots by region (2023 vs 2021) and the respective contributions of each country to 2023 imports

Regions	2023 Imports share (%)	2021 Imports share (%)	2023 main countries and imports share for the region (%)
Middle East and Central Asia	33%	31%	United Arab Emirates (54%), Bahrain (29%), Kazakhstan (5%)
Asia	22%	30%	India (74%), Malaysia (19%), China (2%)
Rest of Europe	18%	19%	Russia (75%), Turkey (8%), Bosnia and Herzegovina (8%)
Africa	18%	10%	Mozambique (58%), South Africa (33%), Cameroon (4%), Egypt (3%)
North America	4%	8%	Canada (92%), United States (8%)
Oceania	2%	1%	Australia (51%), New Zealand (32%)
Central and South America	2%	1%	Brazil (51%), Argentina (18%)
Total	100%	100%	

The geographical distribution of imports of primary aluminium ingots in 2023 compared to 2021 is detailed in Table 4-27. The share of imports from “Rest of Europe” (mainly Russia) was reduced by 12

% point between 2023 and 2021. Meanwhile, imports from “Asia” and “Middle East and Central Asia” increased by 14% points and 2% points, respectively. Additionally, imports from “North America” declined from 10% of the total imports in 2021 to 4% in 2023. Finally, there was a slight increase in imports from “Oceania” and “Central and South America”.

Table 4-28 Energy sources for the electricity used to produce imported primary aluminium in 2023

Regions (2023 data)	Share of European imported volumes (%)	Energy mix of the European imports						Total
		Hydropower and other renewables	Coal	Oil	Natural gas	Nuclear	Other	
Middle East & Central Asia	33%	1%	-	0%	99%	-	-	100%
Rest of Europe	18%	87%	10%	0%	3%	0%	0%	100%
Africa	18%	61%	33%	0%	5%	0%	0%	100%
North America	4%	96%	4%	-	-	0%	0%	100%
Central & South America	2%	84%	-	-	16%	-	-	100%
Asia	22%	6%	94%	0%	-	-	-	100%
Oceania	2%	12%	87%	-	1%	-	-	100%
Total for Europe	100%	35%	30%	0%	34%	0%	0%	100%

Table 4-29 Electricity mix of European imports (2023 vs 2021)

Electricity mix of European imports	Hydro	Coal	Oil	Natural gas	Nuclear	Total
2021 update	49%	15%	0%	35%	0%	100%
2023 update	35%	30%	0%	34%	0%	100%

Table 4-29 shows that there was a decline in the use of hydropower for electricity generation by smelters exporting to Europe in 2023 (from 49% in 2021 to 35%). This can be explained by the decline in imports from “Rest of Europe” (e.g. Russia). On the other hand, the use of coal strongly increased between the two years (15% in 2021 to 30% in 2023), mainly explained by the increase in imports from “Asia” (e.g. India) (Table 4-27).

The changes in environmental footprint due to the shift in the electricity grid mix used by smelters exporting primary aluminium ingots between 2021 and 2023 are reported in Table 4-30. Most environmental impacts significantly increased in 2023 compared to 2021. For instance, the Global Warming Potential (GWP 100 years) rose by 50% (from 0,33 kg CO_{2eq}/kWh in 2021 to 0,49 kg CO_{2eq}/kWh). This increase is attributed to the higher usage of carbon-intensive energy sources, such as coal and natural gas, for electricity generation to produce imported ingots. The primary energy demand from non-renewable resources increased by 41% in 2023, whereas the primary energy demand from renewable resources declined by 28%, mainly due to the drop in use of hydropower (49% of the grid mix in 2021 versus 35% in 2023).

Table 4-30 Environmental indicators comparison related to the production of 1kWh of electricity used by aluminium smelters exporting to Europe (2023 vs 2021)

Environmental indicators per kWh electricity, Imports model	2023	2021	2023 vs 2021 (%)
Abiotic Depletion (ADP elements) [kg Sb eq.]	8,4E-09	1,1E-08	-22%
Acidification Potential (AP) [kg SO ₂ eq.]	4,2E-03	2,3E-03	+85%
Eutrophication Potential (EP) [kg Phosphate eq.]	2,4E-04	1,4E-04	+64%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	4,9E-01	3,3E-01	+50%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	1,6E-14	1,1E-14	+40%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	2,0E-04	1,1E-04	+77%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	7,8E+00	6,6E+00	+19%
Primary energy from non renewable resources (net cal. value) [MJ]	6,3E+00	4,5E+00	+41%
Primary energy from renewable resources (net cal. value) [MJ]	1,5E+00	2,1E+00	-28%

The adjustments to the electricity grid mix of smelters exporting primary ingots to Europe in 2023, along with the electricity grid mix adjustments for European smelters (refer to Section 4.7) and the changes in the trade balance from 2021 to 2023¹⁶, were used to create a model reflecting the impacts of primary aluminium used in Europe in 2023 (post-2021 energy crisis). The results of this model, in terms of environmental impacts, can be found in Table 4-31. The environmental impacts of primary aluminium ingots used in Europe based on the 2023 model, increased for all indicators, except for Abiotic Depletion (ADP elements) and Ozone Layer Depletion Potential (ODP), which declined by 2% and 14%, respectively. Finally, primary energy demand from renewable resources declined by 9%, mainly due to the strong decline in the use of hydropower to produce imported aluminium.

¹⁶ In 2023, 49% of primary aluminium used in Europe were domestically produced, 51% were imported.

Table 4-31 Environmental indicators comparison between 2021 baseline and 2023 model for primary aluminium ingots used in Europe.

Environmental indicators (per tonne of primary ingot used in Europe) - Cradle to gate -	2023*	2021	2023* vs 2021 (in %)
Abiotic Depletion (ADP elements) [kg Sb eq.]	3,0E-03	3,1E-03	-2%
Acidification Potential (AP) [kg SO ₂ eq.]	7,3E+01	5,6E+01	+29%
Eutrophication Potential (EP) [kg Phosphate eq.]	3,9E+00	3,1E+00	+25%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	1,0E+04	9,0E+03	+12%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	4,2E-08	4,9E-08	-15%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	3,6E+00	2,9E+00	+25%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	1,8E+05	1,7E+05	+4%
Primary energy from non renewable resources (net cal. value) [MJ]	1,3E+05	1,2E+05	+10%
Primary energy from renewable resources (net cal. value) [MJ]	4,7E+04	5,2E+04	-10%

*Based on a model where only the grid mix used by smelters and the share of imports and European production are updated to reflect 2023 conditions.

5 Aluminium sheet production

5.1 Localisation of aluminium rolling mills in Europe

About 65 rolling mills operate in Europe (Figure 5-1) including Turkey here. This number is relatively stable in comparison with the 2015 survey. It should be noted that all the rolling mills do not include all subprocesses (e.g. hot rolling, cold rolling, finishing processes). A total of 8 companies (with several production plants) represents about 70% of the European production.



Figure 5-1 Mapping of rolling mills in Europe.

5.2 Process steps description

The most prevalent form of aluminium rolled products is aluminium sheet, typically characterized by a thickness ranging from 0.2 to 6 mm. The initial material for the majority of rolled products is the DC (i.e., Direct Chill semi-continuous cast) ingot. The dimensions of the ingot are contingent upon the available DC unit, the capacity of the hot rolling mill, the requisite volume for specific end use, and, to some extent, the alloys being cast. Ingots up to 32 tons in weight, with dimensions of 500 - 600 mm in thickness, 2,000 mm in width, and 9,000 mm in length are usually manufactured.

To prepare the rolling ingot for subsequent operations, machining steps are undertaken. This includes sawing to cut the ends and scalping to achieve even surfaces before initiating the rolling process.

Depending on the specific alloy grade, homogenisation through thermal treatment may be applied (see Figure 5-2). Next, the DC ingot is preheated to approximately 500°C before progressing through a hot rolling mill, which reduces its thickness to approximately 4 – 6 mm. Subsequently to the hot rolling stage, the resulting strip is coiled and stored before being cold rolled. Cold rolling is generally conducted on the same site as hot rolling. A wide variety of types and sizes of cold mills exist; ranging from single-stand to 3-stand and some are 5-stand configurations. The final thickness of the cold-rolled strips falls typically within the range of 0.2 to 2 mm.

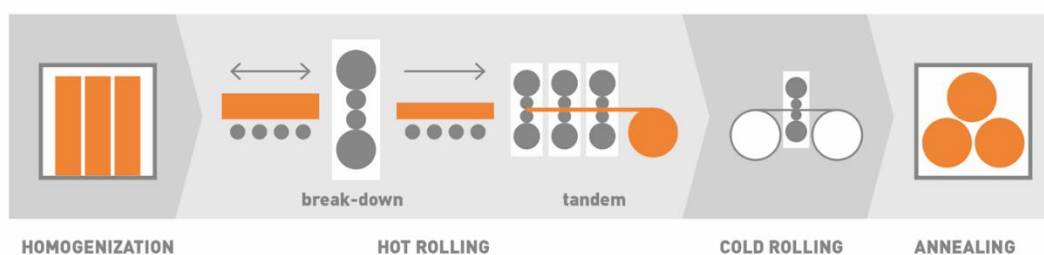


Figure 5-2 Main process steps in aluminium sheet production.

Finishing operations encompass:

- Dimensional adjustments, such as trimming, slitting, and blanking,
- Annealing tailored to specific alloy grades,
- Final surface preparation (excluding coating and/or painting).

On average, 371 kg of scrap is generated during the transformation from a sawn ingot to the final aluminium sheet. These scraps undergo recycling through remelting to create new ingots, typically carried out on-site within integrated cast houses. The LCI dataset on sheet production encompasses this internal recycling of process scrap, as depicted in Figure 5-3.

5.3 Data consolidation, averaging and modelling

The LCI dataset related to aluminium sheet production was created based on a survey conducted by European Aluminium. The survey encompassed European aluminium rolling mills and their integrated cast house, where process scrap is remelted to produce rolling ingots (i.e., slabs).

A total production of 4.5 Mio tonnes of cold sheet output has been consolidated, which represents in total of 27 European rolling mills. Hence, the survey coverage primary industry data coverage reached approximately 86% (Table 2-3). A limited range of details was provided regarding the alloys used in

the process. Hence, the average results presented in Table 5-1 may differ depending on the types of alloys or the specifications needed for the production of a specific final product. Hence, a more in-depth assessment would be required for these specific cases, considering that a mass-based functional unit will highly depend on the product thickness for instance (usually between 0.2 and 6 mm).

Nevertheless, the data reported accurately reflect the main aluminium flat rolled products markets (i.e. 41% of packaging including foil stocks, 22% transport and 11% of building and construction) in Europe.

The LCI datasets for sheet production encompass both the sheet production chain and the recycling processes associated with the generated process scrap at different stages of sheet production. This also includes the recycling process for dross. The flow diagram associated with this LCI is illustrated in Figure 5-3.

European Aluminium : aluminium rolling process in Europe

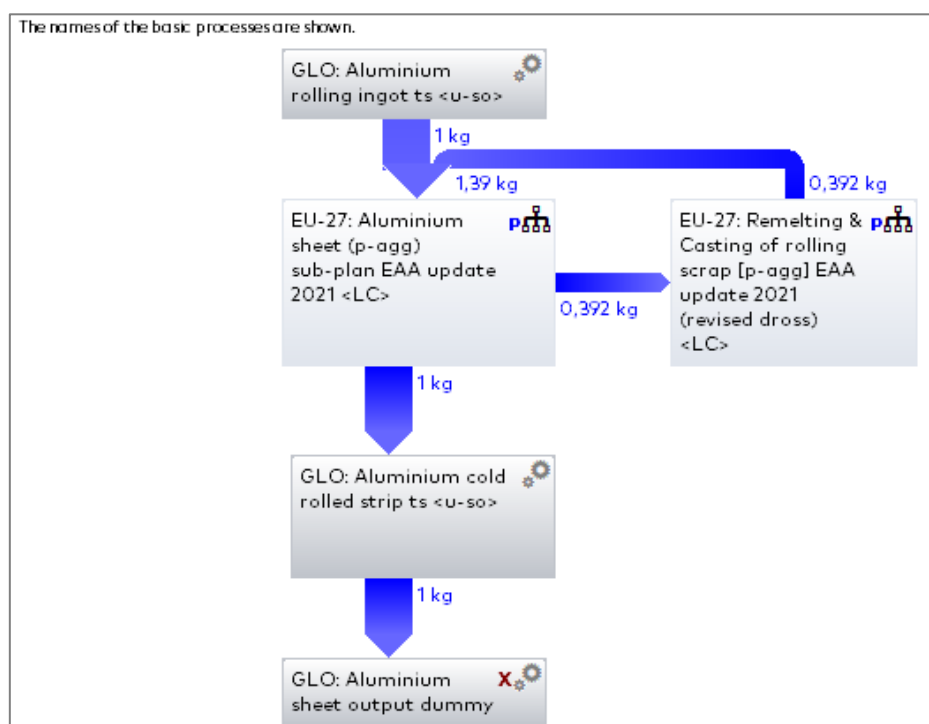


Figure 5-3 Flow diagram for aluminium sheet production

Table 5-1 presents the direct inputs and outputs associated with sheet production and the remelting of the related scrap. The data has been scaled to the production of 1 tonne of finished aluminium sheet.

Table 5-1 Direct inputs and outputs for the sheet production and related scrap remelting - Figures scaled to 1 tonne of finished sheet.

Sheet production and scrap remelting – relative figures per tonne of finished sheet	Unit	Sheet production 2021 data	Scrap remelting 2021 data	Total 2021	Total 2015
Inputs					
Metal					
Scrap	kg/t		371		
Unscalped rolling ingots	kg/t	1.000		1.000	1.000
Energy inputs					
Thermal energy (i.e. fuels)	MJ/t	1.630	1.153	2.783	3.098
Heavy Oil	MJ/t	0	0	0	26
Diesel and light fuel Oil	MJ/t	12	5	17	33
Natural Gas	MJ/t	1.608	1.148	2.756	3.039
Purchased electricity	KWh/t	532	41	574	531
Total energy (i.e. fuels + electricity)	MJ/t	3.545	1.302	4.847	5.011
Auxiliary products, inputs					
Fluxing salts	kg/t	0,0	0,1	0,1	7,5
Argon	kg/t	0,0	0,7	0,7	0,9
Nitrogen	kg/t	8,9	0,4	9,4	21,8
Chlorine	kg/t	0,0	0,0	0,0	0,1
Absorbant for exhaust gas treatment	kgCaO/t	0,0	0,2	0,2	0,1
Emulsion, hot rolling (oil content)	kg/t	1,1		1,1	1,0
Oil, cold rolling	kg/t	2,4		2,4	2,1
Filter earths for cold rolling oil	kg/t	1,4		1,4	0,7
Paper & cardboard for packaging	kg/t	2,5		2,5	2,0
Wood for packaging	kg/t	17,2		17,2	6,2
Steel for packaging	kg/t	0,8		0,8	0,3
Plastic for packaging	kg/t	1,5		1,5	0,6
Other ancillary material input	kg/t	4,7		4,7	0,0
Water inputs					
Process water	m³/t	1,5	0,2	1,8	0,3
Cooling water	m³/t	1,1	0,5	1,6	6,6
Total water supply	m³/t	2,6	0,7	3,4	6,8
Aluminium outputs					
Finished cold rolled strip	kg/t	1.000		1.000	1.000
Emissions to air					
Chlorine (as Cl ₂)	g/t	-	0,3	0,3	0,2
Other inorganic chlorinated compounds (expressed as HCl)	g/t	3,9E-03	2,9	2,9	3,7
Hydrogen Fluoride (as HF)	g/t	0,0	0,3	0,3	0,1
Dust/particulates, total	g/t	0,1	2,0	2,0	24,5
NO _x , as nitrogen dioxide	g/t	171,8*	67,3	239,1	276,0
SO _x	g/t	6,0*	17,1	23,1	24,1
Emissions to water					
Water output	m³/t	5,9	1,2	7,1	6,2
Waste (excluding dross, aluminium scrap & demolition waste)					
Hazardous waste for land-filling	kg/t	1,4	0,4	1,8	0,9
Hazardous waste for incineration	kg/t	1,2	0,1	1,4	0,9
Hazardous waste for recycling or further processing	kg/t	4,5	0,5	5,0	9,8
Total hazardous waste	kg/t	7,1	1,0	8,2	11,5
Non-haz. waste for land-filling	kg/t	0,3	0,5	0,8	1,5
Non-haz. waste for incineration	kg/t	0,1	-	0,1	1,0
Non-hazardous waste for recycling or further processing	kg/t	3,0	1,8	4,8	7,1
Total non-hazardous waste	kg/t	4,1	2,8	6,9	10,7
By-products					
Metal scrap for recycling, excluding aluminium	kg/t	0,8	0,5	1,3	1,1

The SO₂ and NO_x emissions for the rolling process were maintained at their 2015 levels due to insufficient data collected for 2021.

N.B.: Missing data are shown in the table as "-". Grey boxes correspond to "not applicable" for a specific process.

5.4 European LCI datasets and environmental indicators for sheet production

The European gate-to-gate dataset for aluminium sheet production was computed using the LCA for Experts software, following the flow diagram depicted in Figure 5-3. This comprehensive dataset is available on request at lc@european-aluminium.eu. The related environmental indicators and primary elementary flows are detailed in Figure 5-4 and Table 5-3.

5.4.1 Environmental indicators

From Figure 5-4, it appears that most of the environmental impacts are related to energy production, aluminium processes and auxiliaries' processes. For instance, the Global Warming Potential (GWP) and the total primary energy demand from non-renewable sources are predominantly influenced by energy processes (both thermal and electrical). Conversely, electricity contributes significantly to the Ozone Layer Depletion Potential, while direct and auxiliary processes are the main contributors to impacts related to Abiotic Depletion and Photochemical Ozone Creation Potential.

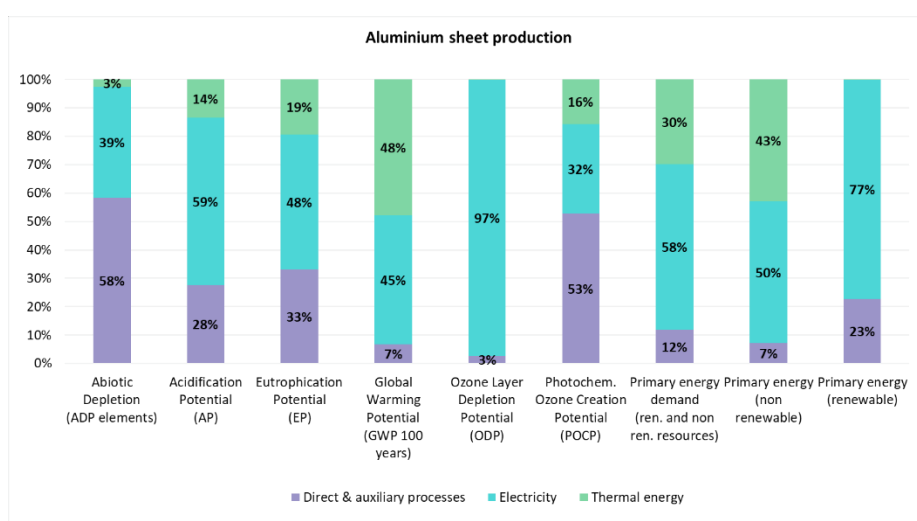


Figure 5-4 Relative contribution to environmental impact indicators values per key process type for the European production of aluminium sheet

In comparison to 2015, the environmental performance of the aluminium rolling mill process in Europe significantly improved (Table 5-2). For instance, the GWP decreased by 4% from 2021 to 2015. In addition, indicators like acidification (AP) and eutrophication potential (EP) decreased as well by 52% and 25%, respectively. This decline in all indicators is primarily driven by improvements in the environmental footprint of electricity production, as described in Section 2.2.5.2. Additionally, reductions in SO₂ and NO_x emissions for aluminium sheet production, shown in Table 5-1, also contribute to the decreases in AP, EP, and POCP. On the contrary, primary energy demand increased between the two years driven by an increase in renewable energy sources.

Table 5-2 Comparison of environmental indicators for the sheet production (2021 vs 2015)

Environmental indicators (per tonne of aluminium sheet) - gate to gate -	2021	2015	2021 vs 2015 (in %)
Abiotic Depletion (ADP elements) [kg Sb eq.]	1,1E-04	3,2E-04	-67%
Acidification Potential (AP) [kg SO ₂ eq.]	6,3E-01	8,6E-01	-26%
Eutrophication Potential (EP) [kg Phosphate eq.]	9,6E-02	1,2E-01	-18%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	4,1E+02	4,3E+02	-4%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	4,0E-09	8,2E-09	-52%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	8,8E-02	1,1E-01	-19%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	1,1E+04	9,0E+03	+22%
Primary energy from non renewable resources (net cal. value) [MJ]	7,6E+03	7,1E+03	+7%
Primary energy from renewable resources (net cal. value) [MJ]	3,4E+03	1,9E+03	+82%

5.4.2 Main elementary flows

For each indicator presented in Table 5-2, the main contributing elementary flows are detailed in Table 5-3. **These elementary flows account for more than 80% of the respective indicators.**

Table 5-3 Main elementary flows and main related processes: rolling

Main elementary flows and main related processes: rolling				
Abiotic Depletion	Elementary flows	Sodium chloride (rock salt) : 42%	Zinc: 11%	Lead: 8%
	(Sub) Process	Auxiliaries (96%)	Auxiliary (61%), Electricity (28%)	Electricity (51%), Process (45%)
Acidification Potential	Elementary flows	Nitrogen oxides: 44%	Sulphur dioxide: 40%	Hydrogen sulphide: 9%
	(Sub) Process	Electricity (39%), Process (29%), Fuels (24%)	Electricity (71%), Process (11%)	Electricity (97%)
Eutrophication Potential	Elementary flows	Nitrogen oxides: 75%	Nitrate: 5%	Chemical oxygen demand (COD): 4%
	(Sub) Process	Electricity (39%), Process (29%), Fuels (24%)	Electricity (86%), Fuels (12%)	Electricity (82%), Auxiliary (16%)
Global Warming Potential	Elementary flows	Carbon dioxide: 94%	Methane: 5%	
	(Sub) Process	Fuels (48%), Electricity (46%)	Fuels (45%), Electricity (34%), Process (13%)	
Ozone Layer Depletion Potential	Elementary flows	R 141b (dichloro-1-fluoroethane): 98%	R 142b (chlorodifluoroethane): 2%	
	(Sub) Process	Electricity (97%)	Electricity (97%)	
Photochem. Ozone Creation Potential	Elementary flows	NMVOG (unspecified): 43%	Nitrogen oxides: 18%	Sulphur dioxide (12%)
	(Sub) Process	Process (92%)	Electricity (39%), Process (29%), Fuels (24%)	Electricity (71%), Process (11%), Auxiliary (10%)
Primary energy demand: total	Elementary flows	Natural gas: 41%	Primary energy from solar energy: 18%	Uranium: 15%
	(Sub) Process	Fuels (72%), Electricity (25%)	Electricity (63%), Auxiliary (36%)	Electricity (98%)
Primary energy from non renewable resources	Elementary flows	Natural gas: 59%	Uranium: 22%	Hard coal: 7%
	(Sub) Process	Fuels (72%), Electricity (25%)	Electricity (98%)	Electricity (90%)
Primary energy from renewable resources	Elementary flows	Primary energy from solar energy: 60%	Primary energy from wind power: 25%	Primary energy from hydro power: 14%
	(Sub) Process	Electricity (63%), Auxiliary (36%)	Electricity (98%)	Electricity (98%)

For instance, 94% of the Global Warming Potential (GWP 100 years) of aluminium sheets is attributed to carbon dioxide emissions, while approximately 5% is due to methane emissions to air. The carbon dioxide emissions are primarily generated during fuel combustion (48%), followed by electricity production (46%) (Table 5-3).

6 Aluminium foil production

6.1 Localisation of aluminium foil rolling mills in Europe

25 aluminium foil production sites operate in Europe (Figure 6-1) including Turkey here. This number is relatively stable in comparison with the 2015 survey.



Figure 6-1 Mapping of foil production sites in Europe.

6.2 Process steps description

There are two major successive stages in the production of aluminium foil from ingot: first the production of foil stock, then the cold rolling operations to achieve the desired aluminium foil features.

The production of foil stock can be achieved in two different ways. The hot rolling route is similar to the production of sheets. It uses an aluminium rolling ingot (slab) as the starting material, which is first hot-rolled and then cold-rolled into foil stock in the form of reels.

The other route – continuous casting – consists of casting the molten aluminium directly into a strip which is then cold rolled into foil stock.

Today, in Europe the hot rolling route accounts for about two-thirds of the production of foil. The foil stock, with a thickness generally below 1mm, is then cold rolled in successive passes to obtain the aluminium foil with the required thickness ranging from about 0.005 mm (5 μm) to the upper ISO-defined limit of 0.2 mm (200 μm). For thin foil (typically below 60 μm) the final rolling steps are carried out by “double-rolling”, i.e. rolling together two foil layers at the same time. The two layers of foil are then separated.

Other possible operations occurring during foil production include annealing (in the intermediate and/or final stage), surface treatment, finishing and slitting to the width needed for the particular application.

The production of aluminium foil generates scraps that are recycled through remelting. In the case of foil rolling plants with continuous casting equipment, the remelting of these scraps is generally performed on-site.

6.3 Data collection, averaging and modelling

The LCI dataset related to the production of foil was developed by EAFA (European Aluminium Foil Association) and covers the following processes:

- the production of foil stock (both hot rolling and continuous casting routes)
- the foil rolling process up to the final gauge
- the recycling of process scraps generated along the foil stock and final foil production

The input data for the foil rolling operations and the production of foil stock through the continuous casting route (covering also the in-house remelting of process scraps) were collected from European foil rollers for the year 2022. They cover more than 80% of the production of foil in Europe (including Turkey). In terms of production routes, the data collected accounts for about 70% of hot rolling and 30% of continuous casting.

The European Aluminium dataset for the production of aluminium sheet (2021 figures) has been used as a proxy for the production of foil stock through the hot rolling (see Section 5). The use of updated European Aluminium data (2021 figures) also applies to the remelting of process scraps when this operation is done externally (see section 8.8).

The inputs and outputs data for the year 2022 presented in

Table 6-1 below cover the whole foil production process i.e. from the production of foilstock (via *continuous casting and hot rolling production routes*) to the foil rolling mill. In the previous report based on 2015 data, the inputs and outputs data shown were focusing on the foil rolling process (i.e. *without the complete foilstock production*). Therefore, no direct comparison between the 2022 and 2015 inputs / outputs datasets has been made in this report.

The flow diagram for foil production is illustrated in *Figure 6-2* referred to 1 tonne of finished foil.



Figure 6-2 Flow diagram for aluminium foil production

Table 6-1 Direct inputs and outputs for the foil production and related scrap remelting (from the foilstock to the foil rolling mill production)– Figures scaled to 1 tonne of finished aluminium foil

Foil production - from the foilstock to the foil rolling mill production <i>(relative figures per tonne of aluminium foil)</i>	Unit	Foil production	Scrap remelting	Total
		2022 data		
Inputs				
Metal				
Ingots	kg/t	997		997
Clean scrap	kg/t	693	692	1.385
Energy				
Thermal energy	MJ/t	5.703	2.153	7.856
Heavy oil	MJ/t	2	0	2
Diesel and light fuel oil	MJ/t	34	9	43
Natural gas	MJ/t	5.667	2.144	7.811
Other energy resources	MJ/t	-	-	-
Purchased electricity	MJ/t	5.484	281	5.765
Total energy (fuel + electricity)	MJ/t	11.187	2.434	13.621
Auxiliary products, inputs				
Fluxing salts	kg/t	1,4	0,4	1,8
Argon	kg/t	-	1,2	1,2
Nitrogen	kg/t	17,1	0,8	17,9
Chlorine	kg/t	-	0,1	0,1
Absorbant for exhaust gas treatment	kg/t	-	0,6	0,6
Rolling and lubricant oil	kg/t	7,4		7,4
Filter material	kg/t	2,0		2,0
Paper & cardboard packaging	kg/t	4,8		4,8
Wood for packaging	kg/t	56,7		56,7
Steel for packaging	kg/t	11,1		11,1
Plastic for packaging	kg/t	2,8		2,8
Water inputs				
Total water supply	m³/t	7,1	1,3	8,4
Outputs				
Aluminium outputs				
Finished cold rolled strip	kg/t	1.000		1.000
Emissions to air				
Carbon monoxide	g/t	1.171	0	1.171
Chlorine	g/t	0,0	8,3	8,3
Other inorganic chlorinated compounds	g/t	0,0	4,8	4,8
Hydrogen fluoride	g/t	0,0	4,8	4,8
Dust/particulates total	g/t	96,5	3,3	99,8
NOX as nitrogen dioxide	g/t	24,4	26,5	50,9
SO2	g/t	559,4	28,7	588,2
VOC	g/t	1.171	12	1.183
Emissions to water				
Water outputs	m³/t	8,8	0,0	8,8
Waste (excluding dross, aluminium scraps)				
Hazardous waste for landfilling	kg/t	1,4	0,7	2,1
Hazardous waste for incineration	kg/t	6,0	-	6,0
Hazardous waste for recycling or further processing	kg/t	18,6	1,0	19,6
Total hazardous waste	kg/t	26,0	1,7	27,7
Non hazardous waste for landfilling	kg/t	0,5	0,0	0,5
Non hazardous waste for incineration	kg/t	0,6	0,0	0,6
Non hazardous waste for recycling or further processing	kg/t	31,8	3,3	35,1
Total non hazardous waste	kg/t	32,8	3,3	36,2
By products				
Metal scrap for recycling	kg/t	39,5	1,0	40,5

6.4 European LCI datasets and environmental indicators for foil production

6.4.1 Environmental indicators

The LCA for Experts software was used to calculate the European gate-to-gate dataset for foil production (including all the process stages from the production of foil stock from input until the packaging of finished foil) in accordance with the flow diagram described in Figure 6-2. This dataset is available on request at LCI@european-aluminium.eu and associated environmental indicators are presented in Table 6-2.

Looking at the contribution of the different processes in foil production (Figure 6-3), the impacts are mainly driven by the consumption of auxiliaries and direct emissions, except for primary energy indicators and ozone layer depletion for which the main impacts are related to electricity, and also for global warming potential with the main impacts linked to thermal energy.

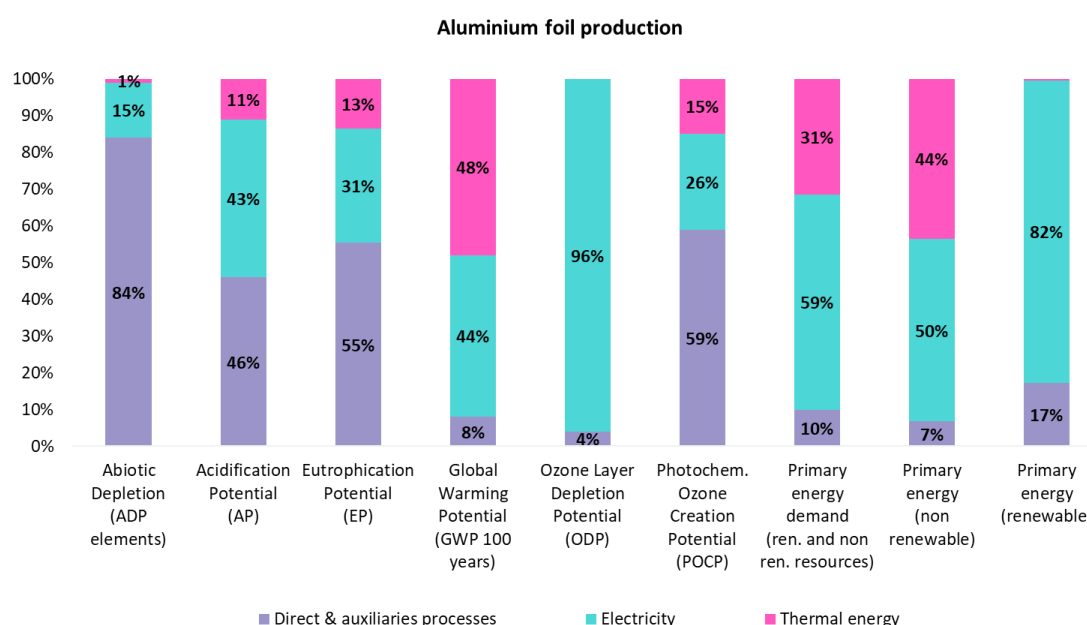


Figure 6-3 Relative contribution to environmental impact indicators values per key process type for the European production of aluminium foil production

Compared with previous 2015 datasets, a certain decrease in impact for all indicators covered can be observed (Table 6-2). This decline is explained to some extent by a change in the foil product mix with a shift towards thicker foil gauges (i.e. requiring fewer steps in the production process). By way of illustration, the share of thin foil with gauges below 30 microns has decreased from 51% to 46%. Additionally, improvement in the production of electricity (see section 2.2.5.2), and reduction of emissions to produce aluminium sheet (see Section 5) contribute to the decrease of some indicators like abiotic depletion (ADP), acidification (AP) or POCP. On the contrary, primary energy demand from renewable energy sources increased.

Table 6-2 Comparison of environmental indicators for the foil production (2022 vs 2015)

Environmental indicators (per tonne of aluminium foil) - gate to gate -	2022	2015	2022 vs 2015 (in %)
Abiotic Depletion (ADP elements) [kg Sb eq.]	7,5E-04	2,48E-03	-70%
Acidification Potential (AP) [kg SO ₂ eq.]	2,1E+00	2,67E+00	-22%
Eutrophication Potential (EP) [kg Phosphate eq.]	3,8E-01	3,79E-01	-0%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	1,1E+03	1,34E+03	-18%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	1,0E-08	2,27E-08	-55%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	2,5E-01	3,15E-01	-20%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	2,8E+04	2,90E+04	-4%
Primary energy from non renewable resources (net cal. value) [MJ]	2,0E+04	2,27E+04	-11%
Primary energy from renewable resources (net cal. value) [MJ]	7,6E+03	6,30E+03	+21%

6.4.2 Main elementary flows

For each indicator presented in Table 6-2Table 6-3, the main contributing elementary flows are detailed in Table 6-3Table 5-3. **These elementary flows account for more than 80% of the respective indicators.**

Table 6-3 Main elementary flows and main related processes: foil production

Main elementary flows and main related processes: foil production (gate to gate)				
Abiotic Depletion	Elementary flows	Zinc: 31%	Lead: 18%	Sodium chloride (rock salt): 17%
	(Sub) Process	Auxiliary (94%), Electricity (5%)	Auxiliary (91%), Electricity (8%)	Auxiliary (97%), Electricity (3%)
Acidification Potential	Elementary flows	Nitrogen oxides: 56%	Sulphur dioxide: 32%	Hydrogen sulphide: 6%
	(Sub) Process	Process (55%), Electricity (23%), Fuels (15%)	Electricity (62%), Process (18%), Auxiliary (13%)	Electricity (96%), Auxiliary (3%)
Eutrophication Potential	Elementary flows	Nitrogen oxides: 80%	Chemical oxygen deamnde (COD): 3%	
	(Sub) Process	Process (55%), Electricity (23%), Fuels (15%)	Electricity (86%), Auxiliary (12%)	
Global Warming Potential	Elementary flows	Carbon dioxide: 94%	Methane: 5%	
	(Sub) Process	Fuels (49%), Electricity (44%), Auxiliary (7%)	Fuels (46%), Electricity (32%), Process (17%), Auxiliary (6%)	
Ozone Layer Depletion Potential	Elementary flows	R 141b (dichloro-1-fluoroethane): 98%	R 142b (chlorodifluoroethane):2%	
	(Sub) Process	Electricity (96%), Auxiliary (4%)	Electricity (96%), Auxiliary (4%)	
Photochem. Ozone Creation Potential	Elementary flows	NMVOC: 33%	Nitrogen oxides: 26%	Carbon monoxide: 13%
	(Sub) Process	Process (91%), Electricity (3%), Auxiliary (3%)	Process (55%), Electricity (23%), Fuels (15%)	Electricity (34%), Process (31%), Auxiliary (20%), Fuels (15%)
Primary energy demand: total	Elementary flows	Natural gas: 42%	Uranium: 16%	Solar energy: 16%
	(Sub) Process	Fuels (74%), Electricity (24%), Auxiliary (3%)	Electricity (98%), Auxiliary (2%)	Electricity (72%), Auxiliary (27%)
Primary energy from non renewable resources	Elementary flows	Natural gas: 59%	Uranium : 26%	Hard coal: 7%
	(Sub) Process	Fuels (74%), Electricity (24%), Auxiliary (3%)	Electricity (98%), Auxiliary (2%)	Electricity (81%), Auxiliary (18%), Fuels (1%)
Primary energy from renewable resources	Elementary flows	Solar energy: 59%	Wind power: 27%	Hydropower: 12%
	(Sub) Process	Electricity (72%), Auxiliary (28%)	Electricity (97%), Auxiliary (3%)	Electricity (97%), Auxiliary (3%)

*additional flows that contribute to more than 80% of ADP are: Antimony (10%) and silver (7%), cadmium (4%)

For instance, 94% of the Global Warming Potential (GWP 100 years) of aluminium foil production is attributed to carbon dioxide emissions, while approximately 5% is due to methane emissions to air. The carbon dioxide emissions are primarily generated during fuel combustion (49%), followed by electricity production (44%) and auxiliary (7%) (Table 5-3).

7 Aluminium extrusion

7.1 Extrusion plants localisation

More than 300 extrusion plants are operating in Europe. Most of them are small or/and medium size plants with an installed capacity between 10 and 20 ktonnes. These plants are located almost everywhere in Europe (Figure 7-1).

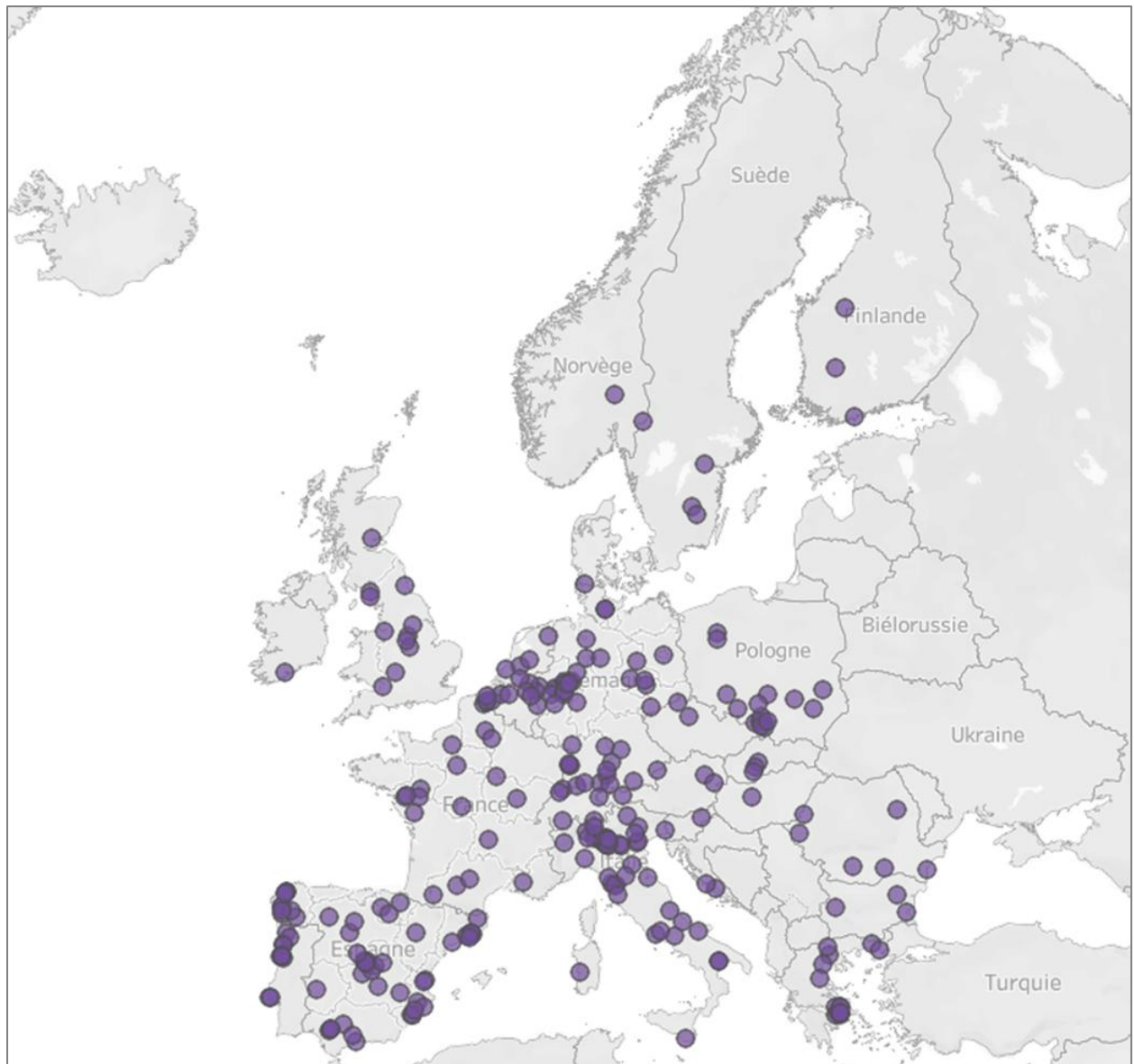


Figure 7-1 Mapping of extrusion plants in Europe.

7.2 Process steps description

The extrusion process is used to manufacture aluminium profiles, whereby a heated cylindrical billet of aluminium is pushed through a shaped die (Figure 7-2). The term “extrusion” is commonly used to refer to both the process itself and the resulting product.

The input material for aluminium extrusion is an extrusion ingot, also known as billet or log, which is a cylinder of several meters in length and typically ranging in diameter between 20 to 50 cm. These billets are generally created using DC casting technology, with the tops and tails being sawed off at the cast house for immediate remelting. Depending on the specific extrusion presses being used, the ingot may be cut into smaller cylindrical pieces before the extrusion process begins.

Before the extrusion, the billet is commonly pre-heated to a temperature of around 450 to 500°C. This pre-heating process is crucial as it reduces the flow stress of the aluminium alloys, making it easier to apply pressure to the metal and initiate the flow of the material through the steel die. This flow is initiated by a ram being applied to one end of the ingot, which forces the metal through the die located at the opposite end of the container. The resulting profile, or cross-sectional shape of which is defined by the shape of the die, can then be either used in long lengths or cut into shorter sections for application in vehicles, structures, or components.

The whole process, from the cast billet up to the finished profile, generates around 320 kg of scrap per tonne of extrusion. These scraps are recycled into new ingots through remelting, a process that can be either conducted on-site in integrated cast houses or externally. The recycling of process scrap is included in the dataset for the extrusion gate-to-gate production.

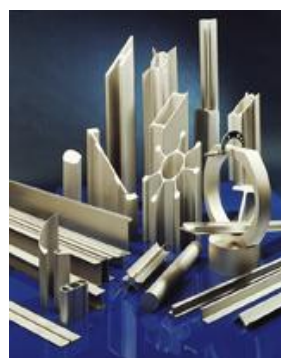
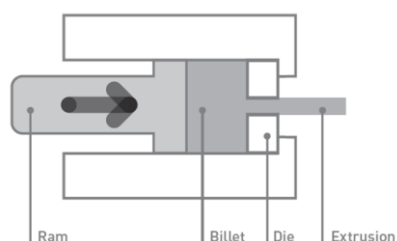


Figure 7-2 Extrusion process principle and some aluminium extruded products.

7.3 Data consolidation, averaging and modelling

The flow diagram related to the extrusion process is depicted in Figure 7-3. The specific inputs and outputs scaled to the production of 1 tonne of extrusion, respectively for the extrusion production and for the process of scrap remelting, are reported in Table 7-1.

In terms of thermal energy, there was an overall decrease of 29% driven by natural gas consumption (i.e. main thermal energy source). The releases of nitrogen oxides (NO_x) and sulphur dioxides (SO_2) during the extrusion process have declined by 9% and 23%, respectively.

In terms of waste, the total quantity of hazardous waste has increased by 51%, primarily due to a rise in the proportion that is landfilled (i.e., +46%) and the hazardous waste that is recycled or further processed (i.e., +114%). On the other hand, the quantity of incinerated hazardous waste declined by 94%. As for non-hazardous waste, there seems to be an overall decrease in 2021 (i.e., -31%). This pattern is consistent across all categories of non-hazardous waste.

European Aluminium: aluminium extrusion process in Europe

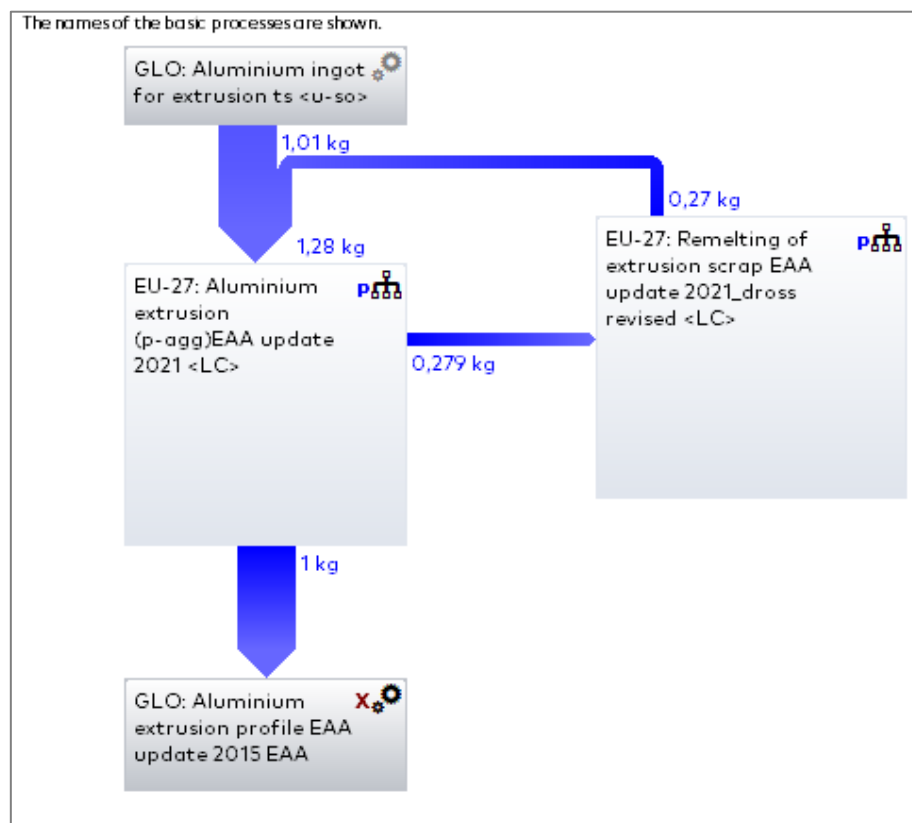


Figure 7-3 Flow diagram for extrusion production-

Table 7-1 Direct inputs and outputs data for extrusion and the corresponding scrap recycling - Figures scaled to 1 tonne of finished extruded product

Extrusion production and scrap remelting – relative figures per tonne of extrusion	Unit	Extrusion 2021 data	Remelting 2021 data	Total 2021	Total 2015
Inputs					
Metal					
Extrusion ingots	kg/t	1.000		1.000	1.003
Remelt: Clean Scrap	kg/t		287	287	291
Energy					
Total thermal energy (i.e. fuels)	MJ/t	1.502	1.017	2.519	3.538
Heavy Oil	MJ/t	0,2	0,0	0,2	2
Diesel and light fuel Oil	MJ/t	31	40	71	111
Natural Gas	MJ/t	1.413	972	2.385	3.379
Other thermal energy source (steam)	MJ/t	57	5	62	46
Purchased electricity	KWh/t	522	62	585	784
Total energy consumption (i.e. fuels +electricity)	MJ/t	3.382	1.242	4.625	6.362
Ancillaries					
Remelt: Fluxing salts	kg/t		0,4	0,4	0,3
Remelt: Argon	kg/t		0,5	0,5	0,3
Remelt: Nitrogen	kg/t		0,7	0,7	-
Remelt: Chlorine	kg/t		0,0	0,0	0,02
Remelt: Absorbant for exhaust gas treatment	kg/t		0,1	0,1	0,2
H2SO4, calculated as 100% H2SO4	kg/t	0,0		0,0	7,7
Alkalis, calculated as 100% NaOH	kg/t	7,5		7,5	16,9
Paper & cardboard for packaging	kg/t	9,7		9,7	15,1
Wood for packaging	kg/t	37,1		37,1	34,6
Steel for packaging	kg/t	0,6		0,6	0,1
Plastic for packaging	kg/t	0,4		0,4	6,6
Other ancillary product input	kg/t	0,0		0,0	2,1
Water					
Process water	m3/t	0,42	0,01	0,4	0,2
Cooling water	m3/t	2,9	1,2	4,1	5,8
Total water supply	m3/t	3,4	1,2	4,6	7,8
Outputs					
Aluminium output					
Finished profile	kg/t	1.000		1.000	1.000
Emissions to air					
Chlorine (as Cl2)	g/t	0,0	1,2	1,2	0,2
Other inorganic chlorinated compounds (expressed as HCl)	g/t	0,0	1,9	1,9	5,3
NOX, as nitrogen dioxide	g/t	42,5	54,9	97,4	106,9
SO2	g/t	6,6	8,1	14,7	19,2
Dust/particulates, total	g/t	0,0	10,6	10,6	11,1
Water					
Water output	m3/t	1,3	0,2	1,5	4,9
Hazardous waste					
Spent caustic bath/sludge for land-filling	kg/t	0,8	-	0,8	0,7
Other hazardous waste for land-filling	kg/t	2,1	0,3	2,5	1,7
Hazardous waste for incineration	kg/t	0,2	0,0	0,2	4,3
Hazardous waste for recycling or further processing	kg/t	18,3	6,9	25,2	11,8
Total hazardous waste	kg/t	20,7	7,2	27,9	18,4
Non-hazardous waste					
Non-haz. waste for land-filling	kg/t	2,0	0,3	2,3	4,8
Non-haz. waste for incineration	kg/t	0,5	0,1	0,6	2,0
Non-hazardous waste for recycling or further processing	kg/t	3,6	1,7	5,3	6,4
Total non-hazardous waste	kg/t	7,0	2,2	9,1	13,2
Other outputs / by products					
Metal scrap for recycling, excluding aluminium	kg/t	0,9	0,1	1,0	6,3
Spent caustic bath/sludge for further processing	kg/t	12,9	-	12,9	39,7

N.B.: Missing data are shown in the table as "-". Grey boxes correspond to "not applicable" for a specific process.

7.4 European LCI datasets and environmental indicators for extrusion production

The European gate-to-gate dataset for extrusion profile production was computed using the LCA for Experts software, following the flow diagram depicted in Figure 7-3. This comprehensive dataset is available on request at lc@european-aluminium.eu. The related environmental indicators and primary elementary flows are detailed in Figure 7-4 and Table 7-3.

7.4.1 Environmental indicators

From Figure 7-4, it can be observed that most of the environmental impacts associated with the aluminium extrusion process are linked to energy production, except for the Abiotic Depletion indicator, which is mainly driven by aluminium and auxiliary processes. Certain indicators, namely Acidification Potential, Ozone Layer Depletion Potential, and primary energy from renewable resources are predominantly influenced by electricity production. In contrast, the impacts of the extrusion process in terms of Global Warming Potential, Photochemical Ozone Creation Potential, and primary energy demand from non-renewable resources, are relatively balanced between electricity generation and thermal energy production.

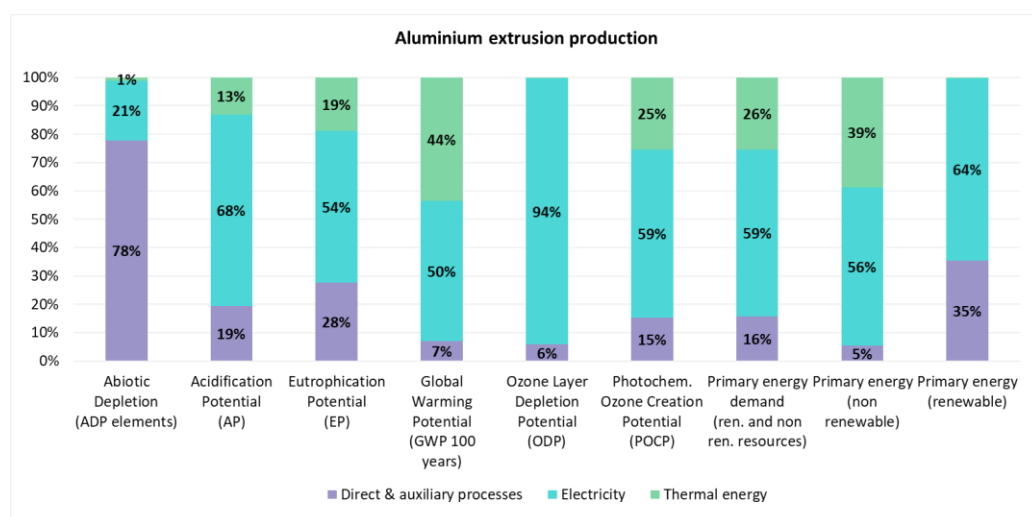


Figure 7-4 Relative contribution to environmental impact indicators values per key process type for the European production of extrusion profile

Compared to the environmental footprint of the extrusion process in 2015, there was a significant improvement across all environmental indicators in 2021 (Table 7-2). This decline in all indicators is primarily driven by improvements in the environmental footprint of electricity production, as described in Section 2.2.5.2. Additionally, there was a decline in primary energy demand from both renewable and non-renewable resources for the extrusion process. This can be attributed to a strong reduction in the consumption of energy to produce 1 tonne of extruded product in Europe between the two years. For instance, the electricity consumption decreased by 25% between 2021 and 2015.

The strong reduction in energy consumption for producing aluminium extruded products between 2015 and 2021 can be attributed to three key factors. First, prior to 2021, the extrusions industry in Europe faced unfair competition from third countries (i.e. China) which led to losses of production and an industry restructuring (e.g. plant closures). These facts have been confirmed by the EU Commission when applying [EU anti-dumping duty on extrusions coming from China](#) in 2021. Secondly, following the application of the EU anti-dumping measures, European production of extrusions started

to improve. On top, the extrusions market grew significantly in 2021 as a recovery from the 2020 COVID-19 crisis. For instance, between 2015 and 2021, European production of extrusions increased by 19%. Therefore, the capacity utilisation of the plants increased significantly leading also to energy efficiency per tonne of production (i.e. in MJ/tonne). Finally, continuous progress in process efficiency contributed to the overall improvement in energy usage during this period.

Table 7-2 Environmental Indicators comparison for the production of 1 tonne of aluminium extrusion profile (2021 vs 2015)

Environmental indicators (per tonne of aluminium profile) - gate to gate -	2021	2015	2021 vs 2015 (in %)
Abiotic Depletion (ADP elements) [kg Sb eq.]	1,9E-04	4,6E-04	-58%
Acidification Potential (AP) [kg SO ₂ eq.]	5,8E-01	1,6E+00	-62%
Eutrophication Potential (EP) [kg Phosphate eq.]	8,6E-02	1,7E-01	-49%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	3,8E+02	6,8E+02	-44%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	4,3E-09	1,9E-08	-77%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	4,7E-02	1,2E-01	-60%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	1,1E+04	1,6E+04	-32%
Primary energy from non renewable resources (net cal. value) [MJ]	7,1E+03	1,2E+04	-39%
Primary energy from renewable resources (net cal. value) [MJ]	3,7E+03	4,0E+03	-9%

7.4.2 Main elementary flows

For each indicator presented in Table 7-3, the main contributing elementary flows are detailed in Table 7-3. **These elementary flows account for more than 80% of the respective indicators.**

For instance, 96% of the Global Warming Potential (GWP 100 years) of the extrusion process is attributed to carbon dioxide emissions, while approximately 4% is due to methane emissions to air. Carbon dioxide emissions are primarily generated during electricity production (49%), followed by fuel combustion (44%) (Table 7-3).

Table 7-3 Main elementary flows and main related process: extrusion

Main elementary flows and main related processes: extrusion				
Abiotic Depletion	Elementary flows	Sodium chloride (rock salt) : 76%	Sulphur: 4%	Lead: 2%
	(Sub) Process	Auxiliary (96%)	Electricity (87%), Auxiliary (13%)	Electricity (81%), Auxiliary (12%)
Acidification Potential	Elementary flows	Sulphur dioxide: 45%	Nitrogen oxides: 38%	Hydrogen sulphide: 10%
	(Sub) Process	Electricity (78%), Auxiliary (9%), Process (7%)	Electricity (48%), Fuels (26%), Auxiliary (16%)	Electricity (95%)
Eutrophication Potential	Elementary flows	Nitrogen oxides: 68%	Chemical oxygen demand (COD): 7%	Nitrate: 6%
	(Sub) Process	Electricity (48%), Fuels (26%), Auxiliary (16%)	Electricity (62%), Auxiliary (27%), Process (9%)	Electricity (85%), Auxiliary (10%)
Global Warming Potential	Elementary flows	Carbon dioxide: 95%	Methane: 4%	
	(Sub) Process	Electricity (49%), Fuels (44%)	Fuels (49%), Electricity (45%)	
Ozone Layer Depletion Potential	Elementary flows	R 141b (dichloro-1-fluoroethane): 98%	R 142b (chlorodifluoroethane): 2%	
	(Sub) Process	Electricity (94%)	Electricity (94%)	
Photochem. Ozone Creation Potential	Elementary flows	Nitrogen oxides: 27%	Sulphur dioxide: 22%	Carbon monoxide: 17%
	(Sub) Process	Electricity (48%), Fuels (26%), Auxiliary (16%)	Electricity (78%), Auxiliary (9%)	Electricity (55%), Fuels (20%), Auxiliary (16%)
Primary energy demand: total	Elementary flows	Natural gas: 36%	Primary energy from solar energy: 23%	Uranium: 17%
	(Sub) Process	Fuels (69%), Electricity (28%)	Electricity (50%), Auxiliary (50%)	Electricity (97%)
Primary energy from non renewable	Elementary flows	Natural gas: 54%	Uranium: 26%	Lignite: 8%
	(Sub) Process	Fuels (69%), Electricity (28%)	Electricity (97%)	Electricity (92%)
Primary energy from renewable resources	Elementary flows	Primary energy from solar energy: 69%	Primary energy from wind power: 21%	Primary energy from hydro power: 9%
	(Sub) Process	Electricity (50%), Auxiliary (50%)	Electricity (95%)	Electricity (97%)

8 Aluminium recycling

Aluminium has been recycled since its first commercial use in the early 20th century. Over the years, numerous remelters and refiners flourished to transform both new and old aluminium scrap into new ingots, deoxidizers for the steel industry, or master alloys. It is worth noting that it is estimated that around 75% of all aluminium ever produced remains in use today (IAI, 2024).

Several commercial reasons have driven the recycling of aluminium to always take place, primarily due to the high intrinsic value of the metal. Secondly, aluminium and its alloys can be melted into new ingots without any loss of quality using modern technology. Thirdly, significantly less energy is required to remelt scrap aluminium into new ingots than to produce primary aluminium from ore. As a result, aluminium recycling conserves both energy and raw materials, while also alleviating the burden on landfill sites.

Recycling is a critical aspect of aluminium, playing a major role in ensuring its use. It represents a crucial attribute of the metal, with economic, ecological, and social implications. Based on [EA datasets](#), the production of over 50% of all aluminium in Europe currently relies on recycled materials, and this trend is expected to continue to rise (EA, n.d.). Given the increasing demand for aluminium and the lack of sufficient primary production domestically, Europe must maximize the collection of all available aluminium and develop the most resource-efficient scrap treatments and melting processes for a continuous supply of local aluminium.

8.1 Scrap terminology

New scrap, also known as process scrap or pre-consumer scrap, is excess materials generated throughout the production of aluminium products until they are sold to the end consumer. Hence, new scrap includes extrusion discards, sheet edge trim, turnings, milling and dross.

Conversely, old scrap, commonly named post-consumer scrap, is the residual aluminium material reclaimed from a product after its production, usage and subsequent collection for recycling. Examples of this category of scrap include used beverage cans, automobile cylinder heads, window frames, or electrical conductor cables.

8.2 Remelting and refining of aluminium scrap

Following the collection, sorting and treatment the recovered aluminium is recycled either through remelting or refining. Refining results in the production of casting alloys, whereas the remelting process generates wrought alloys for sheets, strips and extrusion. These two processes yield new aluminium materials that can be utilized in various applications. For instance, refined aluminium can be used in the production of cast engine blocks, while remelted aluminium finds applications in products such as car bodies or beverage cans (Figure 8-1).

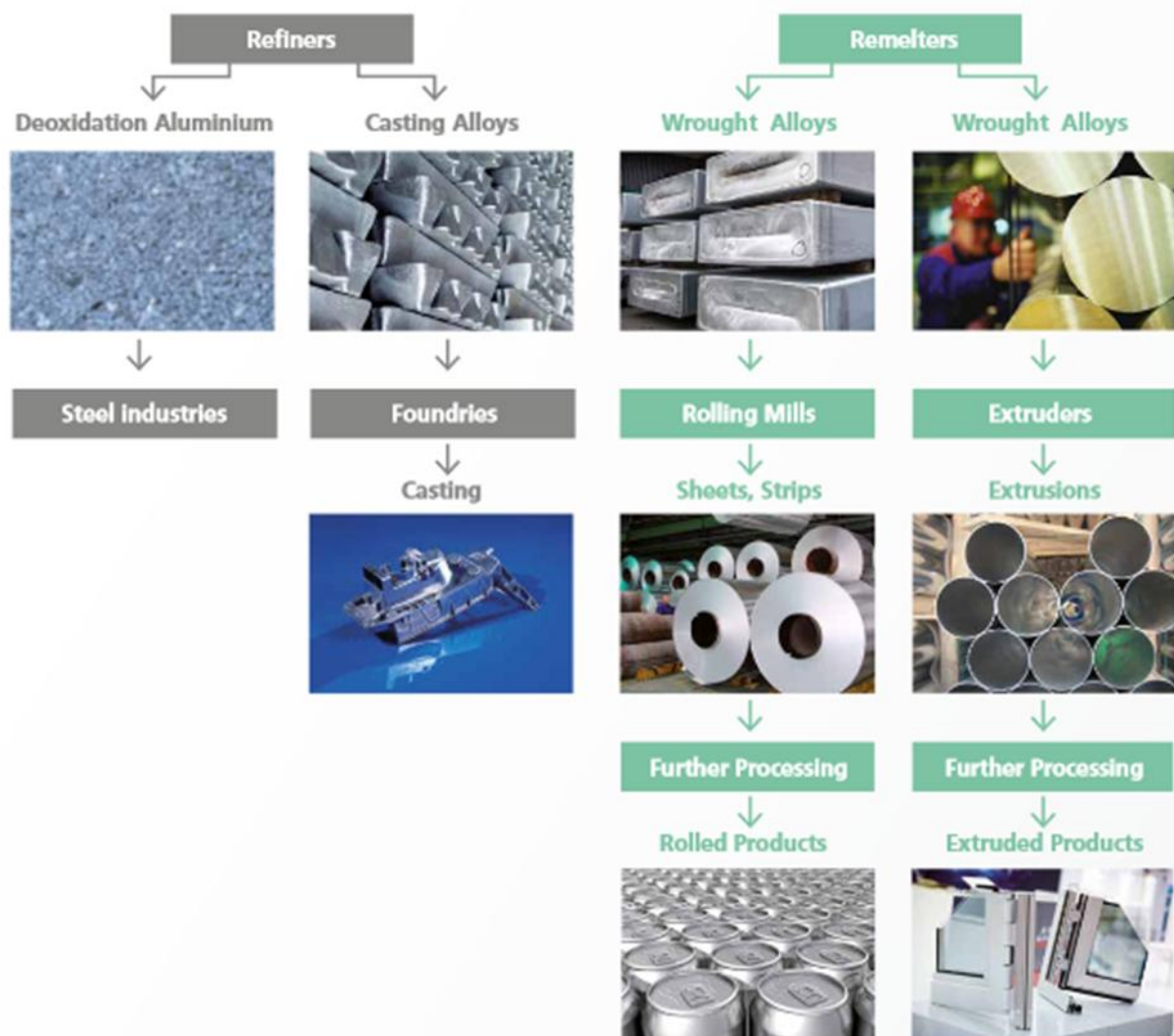


Figure 8-1 Aluminium refiners and remelters

8.3 Mapping of the recycling plants in Europe

The aluminium recycling (refiners and remelters) industry is composed of more than 220 plants (Figure 8-2). About 50% of the recycling plants are refiners. However, the refiners represent only about 30% of the installed capacity.

It should be noted that many of the recycling plants are small and medium-sized enterprises and family-owned businesses.



Figure 8-2 Mapping of the aluminium recycling industry in Europe

8.4 Scrap recycling route and corresponding models

Most aluminium scraps are directly sourced from the fabricators and are well-known in terms of their quality and alloy composition, arriving typically uncoated. These scraps require minimal preparation before being remelted, except for bailing in certain cases. Remelters commonly collect these scraps which are melted in reverberatory furnaces to produce new wrought alloy ingots (Figure 8-3). In contrast, new scraps generated during semi-finished processes may be coated with paint, ink or plastics. This scrap can undergo a de-coating process which involves the passage of the scrap through an oven or a mesh conveyor. During this process, hot gases circulate through the mesh, leading to the volatilisation or burning of the coating. De-coating is generally the primary and crucial step in preparing scrap for use as inputs in remelting furnaces.

This specific recycling route organised through the remelters is accounted for in the first model called “scrap remelting”. Scrap preparation occurring outside the remelting plants is not considered.

The efficient recovery of aluminium from sources such as old vehicles and household goods is guaranteed by a diversified network of metal merchants' waste management companies. The use of heavy machinery such as shredded combined with magnetic separators, that ensure the removal of iron, and sink-and-float installations facilitated the recovery of aluminium. Other advanced technologies, such as eddy current installations, further streamline the isolation of aluminium from other materials. Once collected, sorted and prepared, these old scraps become valuable inputs for refiners who remelt them to produce casting alloys, also known as foundry alloys. The refining process not only utilizes end-of-life aluminium scrap but also incorporates scrap from foundries, turnings, skimmings (i.e., dross) and aluminium metallics to produce casting alloys, also known as foundry alloys. **The second LCA model titled “scrap recycling” specifically focuses on this scrap route through the refiners.**



Figure 8-3 Overview of the aluminium recycling sector

8.5 Furnace technologies

Table 8-1 presents the most common melting technologies used within the industry. The decision to employ a certain melting process is influenced by various factors such as the composition of the scrap, the pre-existing plant processes, and economic and scheduling priorities. To ensure the production of good quality aluminium alloys, two main technologies have been developed: molten metal fluxing, a process that, among others, adjusts chemically the molten metal, maximizes yield and degases it, and filtrations technology, which removes any unwanted material before casting.

Considering that reverberatory furnaces are predominantly employed in remelting plants, only this furnace technology was considered for the modelling of the “scrap remelting” model. In contrast, a combination of rotary and reverberatory furnaces was applied for the “scrap recycling” model given that a large majority of the refiners favour these types of furnaces, and only a negligible percentage uses induction technology.

Table 8-1 Furnace types and their specificities for aluminium recycling.

Furnace type	Variations	Principal applications	Specificities/features	Comments
Reverberatory	Standard	Melting substantial volumes of clean scrap and primary feedstock	- Large metal capacity (≤ 100 t) - Few restrictions on feedstock sizes - No or little usage of salt flux - Main co-products: dross	- High yields thanks to the quality of the feedstock - Occasional use of molten metal pumps
	Side Well	As above, but also enabling the efficient recovery of finer feedstocks	- Large metal capacity - Wide range of feedstock possible - Main and only co-products: dross	- High yields possible according to the quality of the feedstock - Occasional use of molten metal pumps
	Sloping Hearth	Separating aluminium from metal contaminant with higher melting points (i.e., iron/steel)	- Highly efficient in removing contaminants with high melting points - Lower thermal efficiency - Main and only co-products: dross	- Yield depends on the level of contaminants - In certain cases, incorporated into other furnace types
Rotary	Fixed Axis	Recycling of a wide range of feedstocks	- No feedstocks restrictions - Large charge volume possible (< 50t) - Potential restrictions on feedstocks sizes - Relatively important usage of salt flux - Main co-product: salt slag	Resulting salt slags can be reprocessed
	Titling	As above	- As above, but lower use of salt flux - Potential restriction on feedstock sizes - Main co-product: salt slag	Tends to be used for lower scrap grades
Induction (not considered in our models)	Coreless	Melting of cleaner scrap or primary feedstock	- High yields obtained - No requisite of salt flux - Flexible use (batch and continuous processing possible) - Relatively small load (<10 t) - Restricted feedstock type - Potential restricted feedstock size	High cost (electricity)
	Channel	As above	- High yields obtained - No requisite of salt flux - No combustion gases - As above, but possible to have larger capacities ($\sim 20 - 25$t)	High cost (electricity)

To obtain the desired composition of the melt, the adjustment of its temperature and alloying conditions are critical during the recycling process. This involves the precise mixing of primary metals, recovered metals and master alloys.

Reverberatory furnaces generate dross, whereas rotary furnaces, using fluxing salts, yield salt slags as a main co-product. Both co-products typically undergo treatment to recover aluminium metal and regenerate salt. These treatments are accounted for in both recycling models.

8.6 Products from the recycling industry

The alloy type produced, regardless of whether billets or slabs are produced by primary smelters or remelters, is exclusively determined by the composition of the metal and the various inputs added in their cast house. Technologies such as filtration, degassing, casting and homogenizing enable uniform product quality.

Most of the materials within a refining cast house are transformed into foundry ingot, generally using aluminium-silicon alloy systems along with other metals being added such as copper and iron to meet national, international or aerospace standards. These ingots undergo various casting processes such as sand and permanent mould casting, high- and low-pressure casting and investment casting to produce casting alloys.

Multiple factors influence the specific mix of recycling techniques for a given product. For each specific LCA study concerning aluminium recycling, it is recommended to engage with aluminium industry representatives (more information at ici@european-aluminium.eu).

8.7 Dross recycling and salt slag treatment

When the melting of aluminium does not involve the utilization of fluxing salts, the main generated residues are skimming or dross, which primarily consists of aluminium oxides and entrapped aluminium metal. Generated quantities of dross fluctuate according to the quality and size of scrap that undergoes recycling, generally ranging from 20 to 100 kg per tonne of aluminium ingot produced, with metal content varying between 30 and 60%. The refining process includes the extraction of aluminium metal contained in dross or skimming. This step involves an initial mechanical removal of large pieces of metal from cool skimming. Subsequently, the skimming undergoes grinding within impact or ball mills in which the most friable aluminium oxide is reduced. Further screening operations may be employed to enable the retrieval of finer metal fractions. Various operations exist to retrieve aluminium metal from skimming. For instance, skimming can be fed into rotary furnaces and treated by fluxing salts.

Cleaning of the melt and the extraction of contaminants in rotary furnaces are facilitated using fluxing salts, ultimately leading to the production of salt slag. Salt slags comprise between 5 and 20% of aluminium metal, which is recovered in most cases. During this process, salt slags are initially crushed and ground to generate metal granulates containing around 80% aluminium metal. The resultant material is then melted again in rotary furnaces. Subsequently, the remaining metal is oxidized whereas the non-metallic residue is leached. A filtration step ensures the separation of the oxides and other insoluble compounds from the leaching solution. Eventually, fluxing salts are regenerated through a crystallisation process. Using the Best Available Technique (BAT), it is possible to fully valorise 100% of the salt slag.

The modelling of the salt slag treatment used in the report is based on the data collected in 2019 within our membership. These data were presented in the 2021 Environmental Profile Report of the refiners (EA, 2021).

8.8 Remelting model

8.8.1 Data consolidation, averaging and modelling

Input and output data for the “scrap remelting” model, focusing on integrated cast house associated with rolling plants, were gathered by European Aluminium, and are presented per tonne of ingot in Table 8-2. The data gathered covers 86% of the production output from these integrated cast houses. Typically, cast houses integrated with rolling plants utilize a diverse mix of aluminium materials, predominantly consisting of clean process scrap (~50%), ingots for remelting (~30%), liquid aluminium (~18%), and a minor proportion of alloying elements (~2%). To simplify the model, only scrap inputs were considered, substituting all other forms of aluminium inputs with aluminium scrap.

The energy required to melt scrap and produce wrought alloy ingot saw a roughly 6% decline in 2021 when compared to 2015. This decrease is primarily due to a reduction in the electricity consumption in the furnaces.

Regarding scrap consumption, it decreased from 1 092 kg/t of ingot in 2015 to 1 087 kg/t in 2021. The amount of dross/skimming produced remained relatively stable (51 kg/t in 2021 vs 52 kg/t in 2015).

Table 8-2 Direct inputs and outputs for the production of 1 tonne of wrought alloy ingot from clean scrap (remelting process)

Scrap remelting production (within integrated cast house) – relative figures per tonne of ingot	Unit	Remelting & ingot casting	Remelting & ingot casting
Inputs		2021 data	2015 data
Aluminium scrap	kg/t	1.087	1.092
Energy inputs			
Thermal energy (i.e. fuels)	MJ/t	3.109	3.211
Heavy Oil	MJ/t	0	71
Diesel and light fuel Oil	MJ/t	13	47
Natural Gas	MJ/t	3.095	3.093
Purchased electricity	KWh/t	112	150
Total energy (i.e. fuels + electricity)	MJ/t	3.511	3.752
Auxiliary products, inputs			
Fluxing salts	kg/t	-	21,5
Argon	kg/t	1,8	1,9
Nitrogen	kg/t	1,1	0,8
Chlorine	kg/t	0,1	0,2
Absorbant for exhaust gas treatment	kg CaOeq/t	0,6	0,3
Water inputs			
Process water	m³/t	0,6	0,0
Cooling water	m³/t	1,3	8,2
Total water	m³/t	1,9	8,3
Aluminium outputs			
Unscalped rolling ingots	kg/t	1.000	1.000
Dross/skimmings	kg/t	52	51
Metal content of dross/skimmings	%	55%	44%
Emissions to air			
Chlorine (as Cl ₂)	g/t	0,7	0,7
Other inorganic chlorinated compounds (expressed as HCl)	g/t	7,8	10,6
Dust/particulates, total	g/t	-	31,3
NO _x , as nitrogen dioxide	g/t	181,6	300,0
SO _x	g/t	46,1	52,2
Total gaseous organic carbon (TOC)	g/t	19,1	65,1
Waste (excluding dross, aluminium scrap & demolition waste)			
Hazardous waste for land-filling	kg/t	1,0	1,3
Hazardous waste for incineration	kg/t	0,3	0,0
Hazardous waste for recycling or further processing	kg/t	1,4	2,4
Total hazardous waste	kg/t	2,8	3,8
Non-haz. waste for land-filling	kg/t	1,3	0,6
Non-haz. waste for incineration	kg/t	0,0	0,0
Non-hazardous waste for recycling or further processing	kg/t	4,8	2,1
Metal scrap for recycling, excluding aluminium	kg/t	1,5	0,2
Total non-hazardous waste	kg/t	7,6	2,7

N.B.: Missing data are shown in the table as "-".

8.8.2 Environmental indicators and main elementary flows for scrap remelting

The European gate-to-gate dataset for producing 1 tonne of sawn ingot from scrap was computed using the LCA for Experts software, following the data presented in Table 8-2. This comprehensive dataset is available on request at ICI@european-aluminium.eu.

The relative contributions of key processes related to scrap remelting to the set of impact categories considered are illustrated in Figure 8-4. Most environmental impacts are linked to energy production, both thermal and electrical, apart from Abiotic Depletion, which is mainly driven by aluminium and auxiliary processes. For instance, thermal energy production accounted for the majority of the Global Warming Potential (GWP) and the total primary energy demand. Additionally, electricity generation was the main contributor to the Ozone Layer Depletion Potential, while the Eutrophication Potential, was mainly influenced by direct and auxiliary processes.

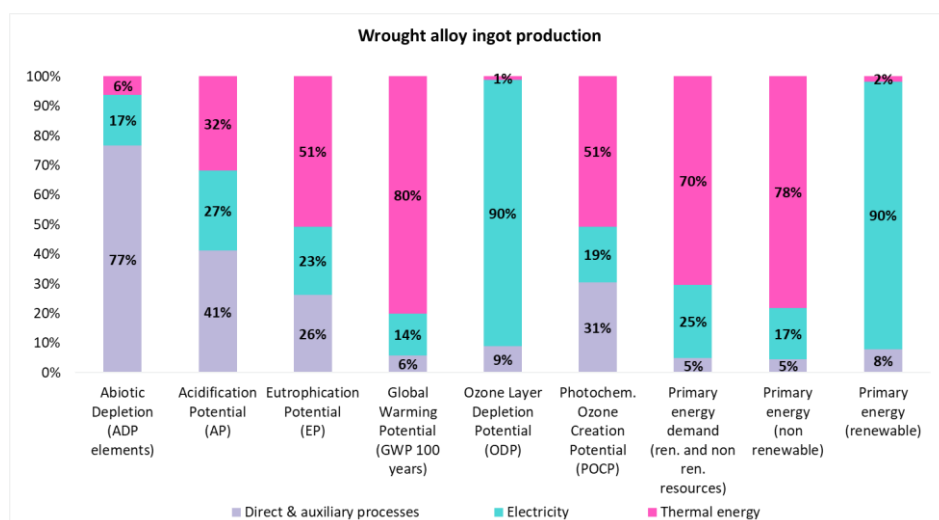


Figure 8-4 Relative contribution to environmental impact indicators values per key process type for the European production of wrought alloy ingot from scrap

Table 8-3 Comparison environmental indicators for the processes for 1 tonne of aluminium wrought alloy ingot from scrap (without scrap benefits/burdens) – 2021 vs 2015

Environmental indicators (per tonne of wrought ingot from scrap) - gate to gate -	2021	2015	2021 vs 2015 (in %)
Abiotic Depletion (ADP elements) [kg Sb eq.]	4,6E-05	1,2E-04	-62%
Acidification Potential (AP) [kg SO ₂ eq.]	2,8E-01	6,8E-01	-58%
Eutrophication Potential (EP) [kg Phosphate eq.]	3,9E-02	9,3E-02	-58%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	2,6E+02	3,3E+02	-22%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	8,8E-10	3,5E-09	-75%
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	2,9E-02	6,0E-02	-52%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	4,9E+03	5,9E+03	-16%
Primary energy from non renewable resources (net cal. value) [MJ]	4,4E+03	5,4E+03	-18%
Primary energy from renewable resources (net cal. value) [MJ]	5,1E+02	4,8E+02	+5%

The environmental performance of the remelting of scrap significantly improved in 2021 compared to 2015 (Table 8-3). This strong improvement is explained by a strong decrease of the direct emissions/consumption in the industry as reported in Table 8-2. Only the primary energy demand from renewable resources increased by 5%. This is in accordance with the increase in primary energy demand from renewable resources per kWh of electricity produced in Europe, as shown in Section 2.2.5.2

For each indicator presented in Table 8-3, the main contributing elementary flows are detailed in Table 8-4. **These elementary flows account for more than 80% of the respective indicators.**

For instance, 94% of the Global Warming Potential (GWP 100 years) of the remelting process is attributed to carbon dioxide emissions, while approximately 5% is due to methane emissions to air. The carbon dioxide emissions are primarily generated during fuel combustion (81%), followed by electricity production (14%) (Table 7-3).

Table 8-4 Main elementary flows and main related process: remelting of clean scrap

Main elementary flows and main related processes: remelting				
Abiotic Depletion	Elementary flows	Sodium chloride (rock salt): 73%	Sulphur: 6%	Zinc: 5%
	(Sub) Process	Auxiliary (99%)	Electricity (52%), Auxiliary (47%)	Fuels (65%), Electricity (30%), Auxiliary (5%)
Acidification Potential	Elementary flows	Sulphur dioxide: 43%	Nitrogen oxides: 41%	Hydrogen sulphide: 4%
	(Sub) Process	Process (45%), Electricity (32%), Fuels (16%)	Fuels (59%), Electricity (18%), Process (18%)	Electricity (91%)
Eutrophication Potential	Elementary flows	Nitrogen oxides: 79%	Nitrogen dioxide: 4%	
	(Sub) Process	Fuels (59%), Electricity (18%), Process (18%)	Auxiliary (100%)	
Global Warming Potential	Elementary flows	Carbon dioxide: 94%	Methane: 5%	
	(Sub) Process	Fuels (81%), Electricity (14%)	Fuels (75%), Process (11%)	
Ozone Layer Depletion Potential	Elementary flows	R 141b (dichloro-1-fluoroethane): 98%		
	(Sub) Process	Electricity (90%)		
Photochem. Ozone Creation Potential	Elementary flows	Nitrogen oxides: 23%	Sulphur dioxide: 17%	Carbon monoxide: 11%
	(Sub) Process	Fuels (59%), Process (18%), Electricity (18%)	Process (45%), Electricity (32%), Fuels (16%)	Process (66%), Electricity (28%)
Primary energy demand: total	Elementary flows	Natural gas: 76%	Uranium: 8%	Primary energy from solar energy: 5%
	(Sub) Process	Fuels (91%)	Electricity (93%)	Electricity (90%)
Primary energy from non renewable resources	Elementary flows	Natural gas: 85%	Uranium: 8%	
	(Sub) Process	Fuels (91%)	Electricity (93%)	
Primary energy from renewable resources	Elementary flows	Primary energy from solar energy: 54%	Wind power: 31%	Hydro power: 13%
	(Sub) Process	Electricity (90%)	Electricity (91%)	Electricity (89%)

*additional flows that contribute to more than 80% of POCP are: carbon monoxide (10%) and methane (9%), VOC (8%)

8.9 Refining model

8.9.1 Background

In the European Aluminium 2021 Environmental Profile Report for refiners(EA, 2021), two datasets have been developed, as depicted in Figure 8-5:

- 1 dataset on the production of aluminium cast alloy from (pre-and post-consumer) scrap [Scope A: gate to gate]

The “aluminium refining” process LCI dataset corresponds to the transformation of the aluminium (pre- or post-consumer) scrap into a cast alloy ingot¹⁷ ready for delivery to the user. This dataset includes the scrap preparation done on-site, melting, purifying, and casting operations. It also includes the salt slag recycling process.

- 1 dataset on the production of aluminium cast alloy from (pre-and post-consumer) scrap including the benefits related to the recovery of aluminium oxide from the salt slag recycling process [Scope B: gate to gate + system expansion]

In addition to the dataset presented above, this specific “aluminium refining + valorisation of aluminium oxide” process includes also the environmental benefits related to the recovery of aluminium oxide via the salt slag recycling unit. **The salt slag recycling process allows the recovery of three main value-added products** i.e., aluminium, aluminium oxide, and fluxing salt.

This dataset should be considered as one example of substitution but does not intend to reflect all possible substitution routes available on the market. This approach uses the system expansion methodology as defined by the ISO standards ISO 14040 and 14044.

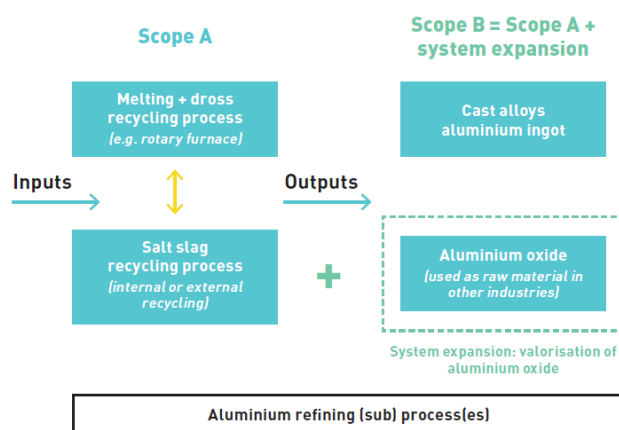


Figure 8-5 System boundaries of the 2 datasets for the refining process

¹⁷ Cast aluminium alloys are used to produce castings where the final product shape is generated by pouring molten metal into a mould.

8.9.2 Update of the LCA models

Background data to produce European gate-to-gate cast alloy ingot from scrap were updated to the LCA FE software version 10 (LCA for Experts, 2023), while foreground datasets from the previous report (EA, 2021), which covered 2017 and 2018, were kept unchanged. Based on expert's judgement, the industry data collected for 2017-2019 still accurately represent the refining process.

The LCA datasets detailed the process involved in producing 1 tonne of casting alloy aluminium ingot (i.e. casting ingots used by foundries), as shown in Figure 8-6.

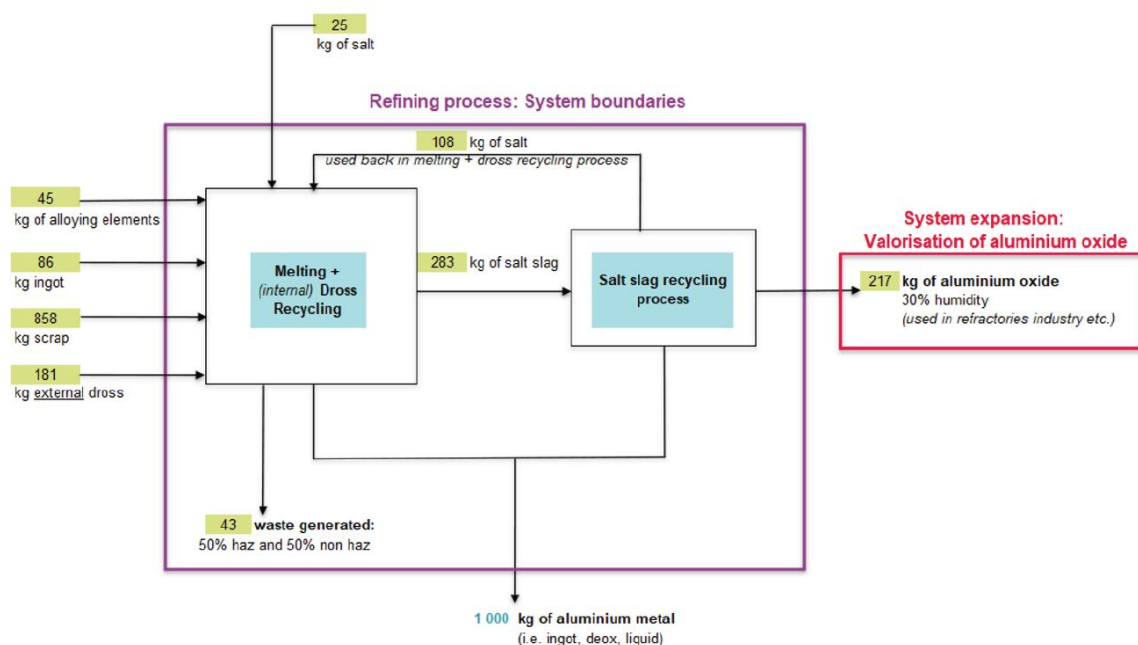


Figure 8-6 System boundaries of the LCA models of the aluminium refining with and without valorisation of aluminium oxide

8.9.3 Environmental indicators for aluminium cast alloys ingot production from scrap

Table 8-5 Environmental indicators comparison for the processing of 1 tonne of cast alloy aluminium ingot from scrap (without scrap benefits/burdens) (2023 vs 2018)

Environmental indicators (per tonne of cast alloys ingot from scrap) - gate to gate -	2023	2018	2023 vs 2018 (in %)
Abiotic Depletion (ADP elements) [kg Sb eq.]	4,4E-04	4,7E-04	-5%
Acidification Potential (AP) [kg SO ₂ eq.]	7,7E-01	8,3E-01	-8%
Eutrophication Potential (EP) [kg Phosphate eq.]	1,3E-01	1,3E-01	-3%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	4,1E+02	4,4E+02	-5%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	1,4E-09	2,4E-12	> 100%*
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	7,5E-02	8,2E-02	-9%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	7,2E+03	7,2E+03	+1%
Primary energy from non renewable resources (net cal. value) [MJ]	6,4E+03	6,6E+03	-2%
Primary energy from renewable resources (net cal. value) [MJ]	8,1E+02	6,3E+02	+29%

*Inconsistent ODP value in 2018, mainly due to the European electricity production datasets in Gabi 9 database.

Table 8-6 Environmental indicators comparison for the processing of 1 tonne of cast alloy aluminium ingot from scrap (without scrap benefits/burdens) – including aluminium oxide valorisation (2023 vs 2018)

Environmental indicators (per tonne of cast alloys ingot from scrap) - gate to gate -	2023	2018	2023 vs 2018 (in %)
Abiotic Depletion (ADP elements) [kg Sb eq.]	3,6E-04	3,9E-04	-6%
Acidification Potential (AP) [kg SO ₂ eq.]	5,4E-01	6,0E-01	-10%
Eutrophication Potential (EP) [kg Phosphate eq.]	1,0E-01	1,1E-01	-3%
Global Warming Potential (GWP 100 years), excl biogenic carbon [kg CO ₂ eq.]	3,7E+02	3,9E+02	-6%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11 eq.]	1,4E-09	1,94E-12	> 100%*
Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]	6,0E-02	6,8E-02	-11%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	6,5E+03	6,5E+03	+1%
Primary energy from non renewable resources (net cal. value) [MJ]	5,8E+03	5,9E+03	-2%
Primary energy from renewable resources (net cal. value) [MJ]	7,1E+02	5,3E+02	+34%

*Inconsistent ODP value in 2018, mainly due to the European electricity production datasets in Gabi 9 database.

8.10 LCA & aluminium recycling

Preserving the aluminium metal during the whole product life cycle and recycling should be a main goal for aluminium products since recycled aluminium can be used for producing new wrought or cast aluminium alloys which are used for new products. As a result, any LCA study needs to consider and credit properly the ability of aluminium to be efficiently recycled without losing its properties.

When addressing the full life cycle assessment (“Cradle to Grave”), the aluminium industry recommends using the end-of-life recycling approach which is the methodology best describing the environmental aspects related to the recycling performances of the final products. The end-of-life recycling approach is based on a product life cycle and material stewardship perspective. It considers the fate of products after their use stage and the resultant material output flows. substitute primary aluminium so that only metal losses during the whole life cycle need to be balanced by primary aluminium when addressing the full life cycle assessment (“Cradle to Grave”) of a product. This allocation methodology can be illustrated through the example of an aluminium can “at its end of life”. The key parameter is the end-of-life recycling rate, which is the fraction of the product at the end of life which is effectively recycled into a new ingot. For instance, if the recycling rate for the modelled product is 80%, this means that the material acquisition in the product model will be based on 80% on recycling and 20% on primary production. This approach directly links the life cycle burdens of the aluminium cans to their end-of-life recycling rates, providing strong metal-to-metal conservation and the development of optimal collection and recycling schemes.

9 Interpretation

9.1 Identifying the limiting factors

9.1.1 Functional unit definition

For each dataset related to aluminium production or transformation, the functional unit and the system boundary have been defined in the various chapters above. The functional unit has been defined as “1 tonne of aluminium product ready for delivery to the user at the gate (i.e. out) of the system boundary”. This functional unit covers a mix of products (i.e. representing the European market) used in various applications such as transport (e.g. automotive), building & construction and packaging.

This functional unit is generic, i.e. not specific to one application or a customer requirement regarding the metal composition (e.g. alloys) or a defined thickness (e.g. aluminium sheet). Thus, in case of a specific requirement for a customer, a specific assessment should be performed when using European Aluminium datasets.

In addition, as mentioned above the LCI modelling is based on a mass flow of pure aluminium. Alloying elements have been neglected and replaced by pure aluminium. This simplification could be seen as a reasonable proxy for most of the wrought aluminium alloys which usually contain less than 5% of alloying elements.

For cast alloys, it is recommended that the user analyse more closely the contribution of alloying elements, mainly silicon and magnesium since such alloying elements usually constitute 5 to 15% of the mass of the casting alloys.

9.1.2 Inventory analysis and data quality

Foreground data has been assessed as robust and representative of the European aluminium industry. For instance, the completeness of the data survey stands at approximately 80% for primary production and aluminium sheet production. However, data completeness is more limited for extrusion production, around 40%. Nevertheless, based on expert assessments, the plants covered (over 55) are deemed representative of the various end-use markets for extrusion in Europe.

With a consistent emphasis on energy (such as electricity consumption for primary processes), air emissions, and land occupation and transformation associated with bauxite mining and alumina production (based on IAI datasets), the coverage of the various inputs and outputs was comprehensive. European Aluminium collected industry data on the other types (i.e. besides hydropower) of renewable energy sources (e.g. solar and wind power) used in the electricity grid mix of European smelters in view of improving the LCA modelling and calculating their related environmental impacts.

Moreover, as explained in Section 4.2, regionalized inputs/outputs data for the primary production have been implemented. Therefore, we can consider that the data quality has been significantly improved.

As explained in Section 3.5, European Aluminium integrated the latest data related to the processing of the salt slag and dross from the recycling process. In the previous 2015 update, old

data had been kept by default. This illustrates an additional improvement in the data quality versus the previous reports.

Concerning water use (e.g. seawater), the reliability of data depends significantly on local water scarcity, determined by each aluminium plant location. Consequently, the European average figure may not accurately reflect local conditions. Therefore, in this model update, an attempt was made to account for water consumption based on the geographical position of aluminium plants, as reported in Table 3-1.

9.1.3 Modelling and methodological choices

Energy production, both thermal and electrical, has the most significant influence on environmental impact categories for most datasets. This is particularly true for primary aluminium production which is an energy-intensive process.

Consequently, 90% of the European electricity model for the electrolysis process is based on direct reporting from companies, detailing the proportion of each energy carrier used to generate the electricity they consume. For the remaining 10%, where no direct data were available, the distribution of energy carriers was estimated based on the national grid mixes reported by the International Energy Agency (IEA, 2023) for the countries where the plants are located. This estimation is considered a conservative choice, as detailed in Section 4.4.2.

As reflected in Section 4.3, European Aluminium adjusted the modelling (energy and other inputs/outputs data) of the imports (e.g. direct and indirect imports of alumina, direct imports of ingots) to capture the reality of the industry supply chains. This work has been possible in this report due to the availability of regionalized datasets by the International Aluminium Institute.

Moreover, as explained in Section 9.2.2.1, an update of the modelling of coke used in the anode production has been performed. In practice, petroleum coke, also known as “green coke”, has been replaced by calcined petroleum coke (CPC). This update brings more accuracy to the modelling of the environmental impacts of the primary aluminium processes.

Regarding the other background datasets, in some cases, 2021 data was not yet available in the LCA for Experts version 10 database (LCA for Experts, 2023). Thus, the latest background dataset available was used (e.g. 2019 data for aluminium fluoride production used in primary aluminium datasets). However, the impacts on the results are expected to be limited and could be seen as well as a conservative approach as 2021 data could be expected to be better.

For most solid wastes which are stored (e.g. bauxite residue) or landfilled, emissions have been calculated based on average LCI models (e.g. landfill of inert material including leachate treatment) since it was not possible to collect or model specific emission data concerning their emissions in storage or landfilling sites. As done previously, this proxy has been considered based on discussions with experts.

Allocation has been avoided for the foreground data by expanding the system boundaries as explained in Section 2.2.3. In other words, the recycling of scrap and dross has been included in each LCI dataset, ensuring that only valuable aluminium products (like ingots or semi-products)

exit the system. This approach avoids allocation procedures by keeping process scrap within the system boundaries, effectively creating a closed-loop model. As for the background datasets, the allocation rules used in LCA for Experts (2023) are conserved.

9.1.4 Impact categories

The impact categories (and related methodologies) focus on robust and directly relevant impact categories. In the framework of the Product Environmental Footprint (PEF) project led by the European Commission, up-to-date impact categories and methodologies were proposed/presented in the latest PEF recommendations. These PEF recommendations are frequently revised/modified as part of the process.

Consequently, in the framework of the update of European Aluminium datasets and to ensure consistency and allow a direct comparison with previous datasets, it has been decided to use the same set of environmental impacts used in previous reports (EA 2005, 2008, 2013, 2018, 2021). The impact categories considered are also in line with recommended LCA methodologies for metals (Santero & Hendry, 2016). Impacts related to land use, human or ecotoxicity, and water use were not considered because these impacts carry a level III recommendation, indicating they are suggested for use, but only with caution due to significant uncertainties, gaps, or other limitations (European Commission, 2021).

Despite recent progress in method harmonization (Berger et al., 2020), the metal industry does not recommend including the impact of resource depletion in LCAs for metals (Santero & Hendry, 2016). Moreover, the decision to exclude the alloying elements and replace them with pure aluminium for this LCI modelling could underestimate that impact category as it does not account for the wide range of mineral and metal resources aluminium alloys require.

For the future European Aluminium Environmental Profile Reports, the European Aluminium selection of impact categories could be adjusted when relevant based on these new developments.

9.1.5 Significant contribution from life cycle stages, units or groups of processes, and related elementary flows.

Elementary flows contributing more than 80% to a specific impact category considered in this report are listed in a table for each process (e.g. refer to Table 4-22 for primary aluminium used in Europe). Additionally, the contributions of each unit or group of processes to these elementary flows are highlighted in these tables.

- Energy

As mentioned previously, energy significantly impacts the environmental footprint of aluminium production, which is why specific electricity and thermal models were developed for primary aluminium production. Only the upstream processes (e.g. smelting) are considered energy-intensive. Additionally, some European Aluminium have their electricity production process. **Therefore, it is essential to use industry-specific power mixes for primary aluminium production.** As explained in Section 4.3.2, in this 2024 report, European Aluminium implemented specific thermal energy data (e.g. alumina, primary cast house) in addition to the industry-specific electricity mixes used in the previous LCA modelling (e.g. smelting process).

On the other hand, for semi-finished products and recycling, the European electricity grid mix and the European datasets for thermal energy from the LCA for Experts database were used. These datasets can be considered consistent averages/proxies.

- Transport

Only the transportation of bauxite, alumina, and ingots (for the dataset on aluminium used in Europe) were considered for the two primary aluminium datasets (i.e. cradle-to-gate). These products are mainly sourced from regions/countries outside Europe, and their transportation modes are sea boat, barge and rail. The impacts related to the transportation of other materials were considered negligible since they are mostly sourced regionally and utilized in limited quantities (e.g. producing 1 tonne of liquid aluminium via the electrolysis process requires about 2 tonnes of alumina versus 16 kg of aluminium fluoride). Hence, the transportation of other materials was not included in the European datasets.

Regarding the transformation and recycling processes, the transportation of raw materials (including scrap or ingots) within the plant is not included in the system boundaries. As mentioned previously, the datasets are gate-to-gate processes, meaning the processing of the inputs arrived on the production site into 1 tonne of output at the gate of the factory. In any case, the impacts of these steps are expected to be limited since the raw materials inputs are sourced at the local (or regional) level.

- Scrap preparation

No additional scrap preparation was included in the LCA for Experts models, as mentioned in Section 8.4. All the scrap preparation phases which are occurring on the recycling production site are included in the datasets (e.g. electricity consumption for bailing or for de-coating, if necessary). The European Aluminium datasets represent an average of the scrap preparation phases/technologies occurring on the recycling site.

Thus, in case some scrap preparation stages are occurring exclusively outside the plant, these additional steps should be taken into consideration when assessing the environmental impacts of the recycling production.

9.2 Evaluation of completeness, sensitivity and consistency

9.2.1 Data Completeness

European Aluminium has been collecting and developing LCI datasets for more than 20 years, conducting this exercise on a 5-year basis (EA 2005, 2008, 2013, 2018, 2021). Hence, the dataset collected remains consistent over the year and has been refined based on the experience gained from the previous exercises (e.g. dross and salt slag processing modelling). However, when limited data was collected for a specific parameter (e.g. NO_x and SO_x for the rolling process) to represent accurately the European picture, previous data from the previous exercises was kept by default in the LCA modelling.

Like previous efforts, 2021 industry data have been collected, analysed and consolidated to generate European averages in collaboration with the LCA Committee of European Aluminium. Any major differences between the 2021 and 2015 datasets have been identified and explained in the report.

In addition, as mentioned above the LCI modelling is based on a mass flow of pure aluminium. Alloying elements have been neglected and replaced by pure aluminium.

In addition, European Aluminium has collaborated with external LCA experts acting as consultants: the LCA for Experts (fka GaBi) models/plans were developed, for this update, in collaboration with EcoInnovazione, and the Environmental Profile Report was reviewed by Prof. Dr. Matthias Finkbeiner. The recommendations of these experts involved throughout the project in the interactive process have been integrated into the final report. The data presented in the report meets the goal and scope of the LCI project, which aims to provide updated environmental and LCI data on aluminium processes in Europe.

9.2.2 Sensitivity check

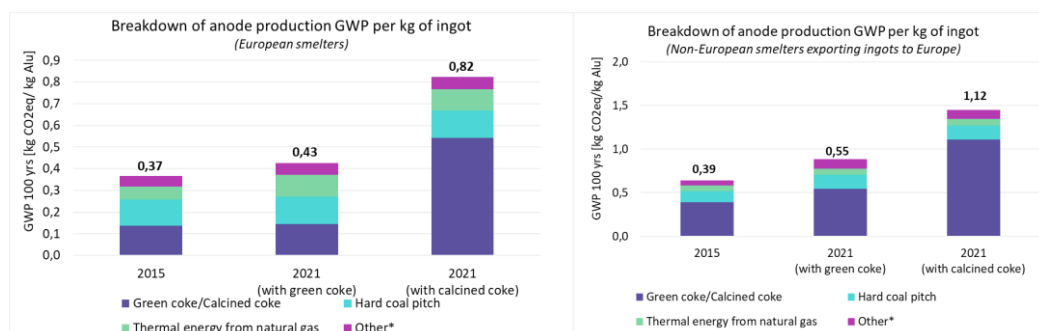
9.2.2.1 Impact of correction in anode modelling

One of the main corrections that were performed in the modelling of 2021 datasets for primary aluminium production compared to the last modelling (EA, 2018) was to switch the petroleum coke, also known as “green coke”, dataset in the model related to anode production to calcined petroleum coke (CPC), which is a primary raw material for producing anodes used in the aluminium electrolysis process. This change significantly increased the Global Warming Potential (GWP) related to the anode production and consequently its share of the overall carbon footprint. Specifically, the GWP of anodes used in European smelters increased by 93% (i.e. from 0.43 kg CO_{2eq}/kg ingot with green coke to 0.82 kg CO_{2eq}/kg ingot with CPC), and for foreign smelters exporting to Europe, the GWP of the anodes used increased by 104% (i.e. from 0.55 kg CO_{2eq}/kg ingot with green coke to 1.12 kg CO_{2eq}/kg ingot with CPC), due this correction. This correction was made in our LCA modelling based on expert judgments from our LCA Committee. For instance, a study that aimed at quantifying the carbon footprint of primary aluminium demonstrated that *"anode production and the related upstream production of calcined petroleum coke (CPC) contributed to 18% of the overall environmental impact of primary aluminium production, with CPC production having the largest share of this impact."* (Allacker et al., 2017).

Without this change, the GWP of anodes for European smelters and for smelters exporting to Europe would have been underestimated and would only have increased compared to 2015 by 4% and 6%, respectively, due solely to an increase in the process thermal energy consumption, as depicted in Table 4-5.

Hence, this modelling change contributed to a higher carbon footprint of primary aluminium ingots, irrespective of their production in Europe or outside Europe.

Table 9-1 Breakdown of the GWP of the production of anode for European smelters (left) and non-European smelters exporting to Europe (per kg of ingot)



9.2.2.2 Impact of imports regionalization

For the current update, European Aluminium had access and made use of more detailed information to model imports of primary aluminium. As previously mentioned, regional-level data from IAI were used to model aluminium processes (e.g., bauxite mining, and alumina production) occurring outside Europe whereas in the past, only global averages provided by IAI were made available. These inputs/output values at the global level included data from regions not necessarily relevant to European imports and not averaged proportionally to the contribution of the region to European imports.

Consequently, this higher degree of granularity allowed for a better understanding and assessment of the environmental impacts of European imports. For instance, as emphasized for all datasets, energy represents a critical part of the environmental footprint. Therefore, it is important to consider the regional specifics of where the energy is produced or sourced. To illustrate this, Table 9-2 compares the relative share of thermal energy sources in the IAI dataset averaged at the global level (IAI, 2022) and the European Aluminium dataset, which is based on regional-level values weighted according to each region's contribution to European imports. Using a weighted average, instead of a global average, highlights the greater proportion of heavy oil, to the expense of coal, to produce imported alumina in Europe.

Table 9-2 Comparison of thermal energy use for alumina production using globalized IAI data or regionalized European Aluminium data

Thermal energy for alumina production	Global IAI dataset	European Aluminium weighted average* dataset	Latin America (83% of European imports of alumina)	Oceania (9% of European imports of alumina)
Heavy oil	9%	45%	56%	0%
Diesel oil	0%	0%	0%	0%
Natural gas	25%	20%	8%	67%
Coal	66%	35%	36%	33%

*Based on the share of regions in European imports of alumina

9.2.2.3 Theoretical sensitivity analysis: using European smelters grid mix compared to alternative grids for primary aluminium production

Since electricity consumption is the primary contributor to the environmental impact of producing primary aluminium (e.g. Global Warming Potential), a specific electricity model was developed to reflect the electricity used by smelters. For primary aluminium production in Europe (i.e. EU27+UK+EFTA), the model utilizes the actual grid mix of European smelters rather than the EU-27 and/or other national electricity grid mix datasets (e.g. UK and EFTA) found in the LCA FE database. This approach ensures that the calculated environmental impact of producing liquid aluminium represents more accurately the electricity consumed by the smelters.

To illustrate the potential impact of various grid mixes on environmental indicators for primary aluminium produced in Europe, a theoretical sensitivity analysis was conducted. Table 9-3 outlines the differences in the energy sources composition used for electricity generation across several grid mixes: i) the grid mix of European smelters (in 2021 and in 2023), ii) the EU27 average grid mix, iii) the European national grid mix (EU27+UK+EFTA), iv) a weighted grid mix that accounts for the national grid mixes of countries where smelters are located (e.g. Norway, Greece, Romania, etc). This weighted mix is based on the primary production at each smelter's location. The latter two grid mixes are derived from publicly available data on national grid mixes for 2021, sourced from the International Energy Agency (IEA, 2023).

Table 9-3 Comparison between European smelters grid mix, EU27 grid mix, EU27+UK+EFTA grid mix and national grid mix of countries in which smelters are located.

Electricity grid mix	European smelters grid mix (2021)	European smelters grid mix (2023)	EU27 average grid mix (2021)	European national grid mix (EU27+UK+EFTA) (2021)	Weighted national grid mix for European smelters (2023)
Coal	6,4%	5,0%	16,1%	13,3%	2,5%
Natural gas	9,2%	7,1%	15,7%	17,0%	5,0%
Oil	2,7%	0,7%	1,3%	1,1%	0,9%
Nuclear	11,2%	10,7%	28,9%	25,8%	11,1%
Hydropower and other renewables	69,5%	75,8%	37,9%	42,4%	80,0%
Other non renewables (e.g. waste)	1,0%	0,7%	0,0%	0,4%	0,5%
Total low carbon energy (%)	80,7%	86,5%	66,9%	68,1%	91,1%

It can be observed that European smelters utilize a significantly higher proportion of low-carbon energy sources - over 81% compared to 67% in the EU27 grid mix and 68% in the EU27+UK+EFTA grid mix in 2021 (Table 9-3). Conversely, coal and natural gas are more prevalent in the EU27 grid mix. When weighing the European national grid mix for smelters production and location, the proportion of low-carbon energy sources rises to 91%.

In order to illustrate the theoretical changes in environmental impact due to variations in smelters grid mixes, the Global Warming Potential (GWP) was chosen considering it is highly sensitive to variations in grid mix and the proportion of low-carbon energy sources.

As seen in Table 9-4, the GWP calculated using the weighted national grid mix where smelters are located is 6,1 kg CO_{2eq}/kg of primary aluminium. In comparison, the GWP using the smelters'

actual grid mixes is 6,6 kg CO_{2eq} per kg of primary aluminium. If the EU27 average grid mix or the EU27+UK+EFTA grid mix were applied, the carbon footprint would be higher, at 9,3 kg CO_{2eq} and 9,0 kg CO_{2eq}/kg of primary aluminium, respectively.

Table 9-4 Global Warming Potential (GWP) of primary aluminium produced in Europe using different grid mixes.

Electricity grid mix for primary ingot production in Europe	GWP 100 year [kg CO _{2eq} /kg of primary ingot] -Cradle to gate-
European smelters grid mix (2021)	7,2E+00
European smelters grid mix (2023)	6,6E+00
EU27 average grid mix (2021)	9,3E+00
European national grid mix (EU27+UK+EFTA) (2021)	9,0E+00
Weighted national grid mix for European smelters (2023)	6,1E+00

9.2.3 Consistency check

The difference in data quality, the temporal differences and the allocation rules have been described and discussed in the chapter above. These inconsistencies were assessed as being acceptable for the study.

- Inventory data quality

Foreground data has been evaluated as robust and representative of the European aluminium industry. However, data completeness for extrusion production is lower than for the other process, around 40%. Nevertheless, based on experts' judgements the plants surveyed are representative of the extrusion market in Europe.

Additionally, coverage of foreground industry data slightly varied between 2015 and 2021 data collection for most of the processes (Figure 9-1). Although the differences in reporting rates were relatively small for most of the processes, these could influence some observed trends between the two inventories. Based on experts' judgment, these differences related to the change in reporting scope were considered limited for most of the cases, unless stated differently in the report (e.g. electricity mix of the smelters).

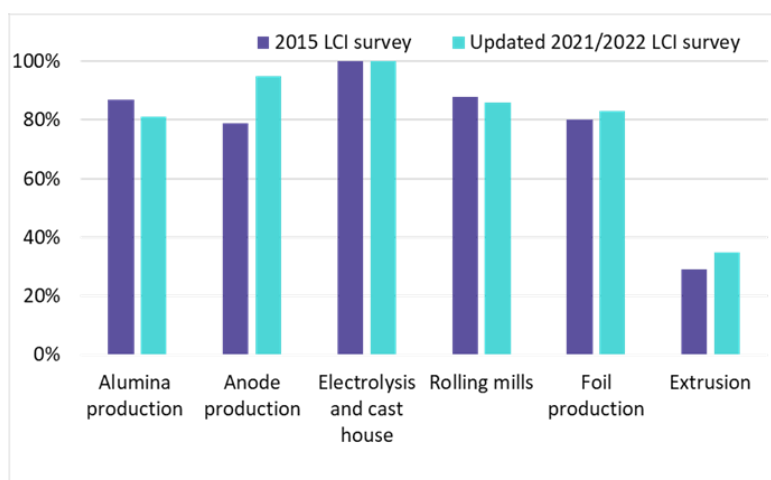


Figure 9-1: Primary industry data survey coverage (2021 vs 2015)

Finally, no foreground industry data collection was performed in the context of this report for the process of aluminium refining given that the last collection was relatively recent (i.e. 2017-2019) and was considered still representative of the refining process.

- Modelling and background data
 - Using LCA for Experts database

Considering the potential variability in data quality of background data provided by LCA FE, there are inherent accuracy limitations when modelling in the LCA FE database. For instance, some background processes (e.g. EU28 grid mix) were not available for 2021 in the LCA FE database. Consequently, the most recent reference year available was used, leading to a temporal mismatch between foreground and background data.

- Using proxy datasets

When region-specific background datasets were unavailable from the LCA FE database (e.g. thermal energy from natural gas from the Middle East), proxy data available with the LCA database was used. Each decision for a proxy dataset was made with caution, transparently explained, and prioritized the most representative option whenever possible.

- Creating models by only adjusting the import share and electricity grid mix

As explained above (see sections 4.7 and 4.8), EA developed post-21 energy crisis datasets to better reflect the current reality of the industry. For these datasets, only the electricity grid mix and the import flows of ingots were adjusted based on 2023 datasets. For the other foreground datasets, 2021 figures were used by default.

Yet, 2023 models addressing the post-2021 energy crisis provide a better assessment of the current situation than the 2021 datasets as i) electricity consumption and grid mixes significantly impact the environmental footprint of primary aluminium production, ii) the electricity grid mix of 2023 smelters is similar to the current one, iii) smelters that closed post-2021 are no longer operating, and iv) the 2023 ingot supply chain (i.e. imports of ingots) better reflects the current state of the aluminium industry in Europe.

10 Conclusion

10.1 Identification of limiting factors

The main findings of the interpretation stage regarding the identification of significant issues are:

- The functional units of European Aluminium datasets cover a mix of product uses in various applications in Europe. This functional unit is not specific to a specific application or a specific customer requirement regarding the metal composition (e.g. alloys) or to a specific thickness (e.g. aluminium sheet or foil processing). **Thus, for a specific product, European Aluminium should be used as a baseline, but it should also be assessed if further customization is needed.**
- **The various environmental data have been considered robust and representative of the European aluminium industry.** In addition, the data quality has been continuously improved in comparison with the previous report. As far (as fresh or seawater consumption, it should be taken into consideration within the local context.
- Impact categories: the impact categories presented in the report are given for information to allow a comparison between 2021 and 2015 data. In the framework of the PEF, some additional or new LCIA methods are under discussion. In the future Environmental Profile Reports, **European Aluminium's selection of impact categories could be adjusted when relevant.**
- Energy contributes significantly to the environmental impact of aluminium production. Thus, it is important to use industry-specific power mixes, especially for primary aluminium production.
- Transportation of other raw materials (except bauxite, alumina and ingots imported) is expected to have a limited impact on the cradle-to-gate datasets related to primary ingot production (used or consumed in Europe)
Regarding the recycling and transformation processes, which are gate-to-gate, the transport of raw materials is not included in the system boundaries. However, the impacts of transport are expected to be limited.
- The 2023 models addressing the post-2021 energy crisis, serve as a robust picture of the current state of play of the industry given that i) electricity plays a significant role in the environmental footprint of producing primary aluminium ingots, ii) the electricity grid mix of smelters operating in 2023 is similar to the one currently in operation, iii) the smelters idled post-2021 are not in operation iv) the 2023 supply chain of imports of ingots reflect better the current reality of the aluminium industry in Europe. **These 2023 datasets can be considered more representative of the current industry than the one based solely on 2021 datasets.**
- The European Aluminium datasets represent an average of the scrap preparation phases/technologies occurring on the site. Thus, in case some scrap preparation stages occur exclusively outside the plant, **these additional steps should be taken into consideration when assessing the environmental impacts of cast alloy ingot production.**

10.2 Evaluation of the methodology and completeness, sensitivity and consistency check

The main findings of the evaluation stage regarding the methodology, completeness, sensitivity and consistency check are:

- The sets of data reported in the report satisfy the goal and scope of the LCI project which is to provide updated environmental and LCI data related to aluminium processes in Europe.
- Uncertainties in the data (see 2.2.6) and allocation methods (2.2.3) highlighted above should be considered when interpreting the results
- The difference in data quality (see 2.2.6), the temporal differences (see 9.1.3) and the allocation rules (see 2.2.3) described above are assessed as being acceptable for the study.

10.3 Conclusions and recommendations

The Environmental Profile Report of European Aluminium aims to provide accurate and reliable data on the environmental performance of the aluminium industry in Europe from the metal supply (primary and recycling) to semi-fabrication (rolling, foil and extrusion).

The report includes updated Life Cycle Inventory (LCI) datasets and associated environmental indicators to be used for:

- Life Cycle Assessment (LCA) studies related to aluminium products fabricated in Europe, and products made of aluminium or containing aluminium.
- updating the various environmental and LCI databases related to aluminium processes in Europe

The data is collected from European Aluminium's members who provide data for each of their process steps. Therefore, our report provides the **most up-to-date industry data averages available for these processes, and it is recommended that they should be used for LCA purposes, whenever generic aluminium data for Europe is needed**. Older literature data should be disregarded, as they may no longer be representative due to technological improvements, progress in operating performance, changes regarding raw materials or waste treatment, etc.

It is also important to note that to assess the full environmental impacts of aluminium products, one must consider the full life cycle of the product as well (including the use and recycling phases). These steps are essential to fully reflect the intrinsic properties of aluminium products (e.g., lightweight, recyclability). **As highlighted in ISO 14040 and 14044, only the environmental aspects of a product system or a service in a life cycle perspective, i.e., from cradle to grave or from cradle to recycling, are scientifically sound.**

The data, methods and analysis included in this study have been subject to ongoing review and validation by various internal experts acting at different stages of the project (i.e. data collection/analysis, LCA modelling and reviewing of the LCI report). These experts come from the aluminium industry (i.e. via the European Aluminium LCA Working Group) and EcoInnovazione. In addition, the final report has been externally reviewed by Prof. Dr. Matthias Finkbeiner. His critical review confirmed the conformity of the study with ISO 14040 and ISO 14044.

Regarding the results, the updated data demonstrate a continuous improvement in the environmental performance of the aluminium industry in Europe. First, the environmental impacts of the primary aluminium production in Europe decreased when considering the 2023 model (*i.e. -10% for Global Warming Potential vs 2021 results and -2% vs 2015 baseline*). As explained previously, the increase between the 2015 and 2021 of the GWP baseline is mainly due to an adjustment of the LCA models (e.g. calcined petroleum coke) and a temporary higher carbon footprint of the electricity grid mix used by European smelters (e.g. less nuclear available). Other indicators, such as AP, EP, and POPC, which are primarily influenced by NO_x and SO₂ emissions, also increased in 2021 vs 2015. Finally, the increase in primary energy demand (from both renewable and non-renewable sources) for European primary aluminium production can be attributed to increased electrification of aluminium processes (e.g. alumina refining, casthouse) and the greater use of renewable energy sources such as solar and wind.

On the other hand, the environmental performance in terms of GWP of the primary aluminium consumed in Europe increased by 4% in 2021 versus 2015. The positive effects related to the improvements in the modelling of imports through their regionalization (e.g. alumina) were compensated by the adjustments in the LCA modelling related to the calcined petroleum coke and the increased carbon footprint of the electricity grid mix for imports. Other indicators, such as AP, POCP and EP increased in 2021 vs. 2015 due to higher emissions of NO_x and SO₂ emissions related to the production (*i.e. domestic production and imports*) of primary aluminium in Europe. Finally primary energy demand (renewable and non-renewable) increased from aluminium processes electrification.

The 2023 model for aluminium used in Europe indicated an 12% increase in the GWP compared to the 2021 baseline. This rise is attributed to higher import volumes into Europe of aluminium ingots produced in smelters that rely primarily on electricity generated from natural gas or coal (e.g. Middle East, India) rather than hydropower (e.g. Rest of Europe).

As explained above, these 2023 datasets can be considered more representative of the current industry than the one based solely on 2021 datasets.

Finally, updated data indicate a strong improvement in the environmental performance in the studied impact categories of semi-fabrication (rolling and extrusion) and the recycling industry processes in Europe. This improvement is attributed mainly to reductions in energy consumption, ancillary product usage, and key air emissions (*i.e. SO₂ and NO_x*) associated with all three processes.

The Environmental Profile Report demonstrates the European aluminium industry's ongoing commitment to understand better and to make available the Life Cycle Inventory (LCI) datasets associated with its processes and products, and to support wider Life Cycle Assessment (LCA) practices.

11 Appendix

11.1 Glossary & definitions

Term	Definition
Aluminium	Metal with a minimum content of 99,0% by mass of aluminium provided that the content by mass of any other element does not exceed the following limits: - iron + silicon content not greater than 1,0% - other element content not greater than 0,10% each, with the exception of copper which is permitted to a content of up to 0,20% provided that neither the chromium nor the manganese content exceeds 0,05% Note: aluminium in the liquid state or in the form of ingots for remelting is often called "unalloyed aluminium"
Ancillary material	Material input that is used by the unit process producing the product, but not directly used in the formation of the product
Casting (process)	Process in which molten metal is poured into a mould and solidified
Casting alloy	Alloy primarily intended for the production of castings
Elementary flow	Any flow of raw material entering the system being studied which has been drawn from the environment without previous human transformation; any flow of material leaving the system being studied which is discarded into the environment without subsequent human transformation
Extrusion	Process in which a billet in a container is forced under pressure through a die aperture
Extrusion ingot	Aluminium or aluminium alloy cast in a form suitable for extruding
Foil	Flat rolled product of rectangular cross-section with uniform thickness equal to or less than 0,20 mm Note: Sometimes the term "foil" covers two different products: -Foil: products with lesser thickness; - Thin strip: products with greater thickness. The dimensional limitations between these two products may vary from country to country
Forming	Process by which a product is transformed into a desired shape without changing its mass
Heat treatment	Heating, holding at elevated temperature and cooling of the solid metal in such a way as to obtain desired tempers or properties. Heating for the sole purpose of hot working is excluded from the meaning of this term
Homogenisation	Process in which metal is heated at high temperature during a specified time, generally in order to facilitate working and to confer certain desirable properties on the semi-fabricated product, in particular to eliminate or decrease micro segregation by diffusion
Hot working	Working of a metal within a temperature range and at a rate such that significant strain does not occur
Ingot for remelting	Metal cast in a form suitable for remelting which has been processed, as appropriate, to adjust the chemical composition and/or to remove certain metallic or non-metallic impurities
PAH	Polycyclic Aromatic Hydrocarbons
Primary aluminium	Aluminium produced by electrolytic reduction from alumina. Remelt metal is excluded from this term

Term	Definition
Primary ingot	Ingot produced from primary aluminium. It may incorporate suitably identified uncontaminated scrap from ingot production
Refined aluminium alloy	Aluminium alloy obtained after metallurgical treatment of molten metal obtained from aluminium scrap Note: this term is mainly used for casting alloys
Remelt metal	Wrought aluminium or aluminium alloy obtained by remelting
Rolling ingot	Aluminium or aluminium alloy cast in a form suitable for rolling
Section	Wrought product, usually extruded, of uniform cross-section along its whole length, usually supplied in straight lengths or sometimes in coiled form. Rods, bars, wire, tubes, sheet and strip are excluded from this term
Semi-finished product	Product which is supplied for further fabrication
Sheet/plate	Flat rolled product of rectangular cross-section with uniform thickness between 0,20 mm and 6 mm (sheet) or above 6 mm (plate), supplied in flat straight lengths usually with trimmed or sawn edges. The thickness does not exceed one-tenth of the width
Strip	Flat rolled product of rectangular cross-section with uniform thickness over 0,20 mm, supplied in coils usually with trimmed edges. The thickness does not exceed one-tenth of the width
Solution heat treatment	Process in which an alloy is heated to a suitable temperature and is held at temperature long enough to allow soluble constituents to enter into solid solution and then cooled rapidly enough to hold the constituents in solution
Working	Forming of a metal, generally with elongation but not necessarily in a preferred direction. Working may be carried out hot or cold by such processes as rolling, extruding, forging, etc
Wrought alloy	Alloy primarily intended for the production of wrought products by hot and/or cold working
Wrought product	General term for products obtained by hot and/or cold working processes such as extruding, forging, hot rolling, cold rolling or drawing, either exclusively or in combination. Examples of wrought products are rods/bars, wire, tubes, profiles, sheet, strip and forging

11.2 Definitions related to aluminium scrap for recycling taken from EN 12258-3

Term	Definition
(Aluminium) Scrap	raw material, destined for trade and industry, mainly consisting of aluminium and/or aluminium alloys, resulting from the collection and/or recovery of
	- metal that arises at various stages of fabrication or
	- products after use
	to be used for the production of wrought and cast alloys and for other production processes
Clean scrap	scrap which does not contain foreign material
Coated scrap	scrap consisting of pieces with any kind of coating, e.g. paint, varnish, printing ink, plastics, paper, metal
Dross	Skimmings with low metal content

Term	Definition
New scrap	scrap arising from the production and fabrication of aluminium products
Old scrap	scrap arising from products after use
Skimmings	material composed of intimately mixed aluminium and aluminium oxides which have been removed from the surface of the molten metal or from the bottom and walls of liquid metal containers, e. g. a furnace, transport ladles, or transfer channels
	NOTE: The same material with low metal content is often called "dross".
Metallics	material produced by the crushing or grinding of skimmings by means of ball mills, hammer mills, impactors, etc. and the selection of the coarser fraction where most of the metallic aluminium is concentrated, by screening
Fines	fine-grained portion obtained from the milling of skimmings holding a low metal content but a high content of aluminium oxides and other oxides.
Foreign material	any material other than aluminium or aluminium alloys which is physically identifiable as part of a scrap consignment. Foreign material can be attached to pieces of scrap or separate. Examples of foreign material are powder, water, oil or other fluids, grease, wood, plastic, glass, stones, paper, sand, non-aluminium metals, dry paints, inks, lacquers, rubber, dirt.
shredding	reduction of the size of pieces of scrap, end-of-life products or compacted scrap into small pieces, by operations such as crushing or tearing
Sorting	separation of different fractions of loose scrap, manually or by other methods
Sink and float	processes where materials with different densities are separated through air flotation or heavy media systems
casting alloys	Aluminium alloys used for the production of castings where the final product shape
	is generated by pouring molten metal into a mould. These aluminium alloys have an alloy concentration of up to 20%, mostly silicon, magnesium and copper. Typical castings are cylinder heads, engine blocks and gearboxes in cars, components used in the mechanical and electrical engineering industries, components for household equipment and many other applications.
Deoxidation aluminium	Aluminium consisting of alloys with a high concentration of metallic aluminium (usually exceeding 95%) used to remove free oxygen from liquid steel.
Foundry industry	Main customers of refiners. They produce a wide variety of castings which are mostly
	used in the transport sector.
Refiner	Producer of casting alloys and deoxidation aluminium from scrap of varying composition. Refiners are able to add alloying elements and remove certain unwanted elements after the melting process.
Remelter	Producer of wrought alloys in the form of extrusion billets and rolling slabs from mainly clean and sorted wrought alloy scrap.
Salt slag	By-product that arises when salt (mixture of sodium and potassium chloride) is used to cover the molten metal to prevent oxidation, increase yield and enhance thermal efficiency in the furnace.

Term	Definition
Wrought alloys	Aluminium alloys used for wrought products where the final product shape is generated by mechanically forming the solid metal. These aluminium alloys have an alloy concentration comprised between 1 and 10%, mostly manganese, magnesium, silicon, copper and zinc. Typical wrought alloy products are semi-fabricated items in the form of rolled sheets, foil or extruded profiles, which are processed into car body parts, heavy goods vehicle and commercial vehicle components, rail vehicles, building panels, doors, windows, packaging, and so on.
Recycled aluminium	Aluminium ingot obtained from scrap is now referred to as recycling aluminium.
Recycling	Aluminium collection and subsequent treatment and melting of scrap.
Recycling rates	Performance indicators of global recycling performance are as follows:
	<u>Recycling input rate</u> : Recycled aluminium produced from traded new scrap and old scrap as a percentage of total aluminium (primary and recycled sources) supplied to fabricators.
	<u>Overall recycling efficiency rate</u> : Recycled aluminium produced from traded new scrap and old scrap as a percentage of aluminium available from new and old scrap sources.
	<u>End-of-life recycling efficiency rate</u> : Recycled aluminium produced from old scrap as a percentage of aluminium available from old scrap sources.
	<u>The end-of-life collection rate</u> : Aluminium collected from old scrap as a percentage of aluminium available for collection from old scrap sources.
	<u>The end-of-life processing rate</u> : Recycled aluminium produced from old scrap as a percentage of aluminium collected from old scrap sources.

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12 Review statement

Critical Review

ENVIRONMENTAL PROFILE REPORT FOR THE EUROPEAN ALUMINIUM INDUSTRY

Commissioner: European Aluminium, Brussels, Belgium (EA)

Reviewer: Prof. Dr. Matthias Finkbeiner, Berlin, Germany

Reference ISO 14040 (2006): Environmental

Management -

Life Cycle Assessment - Principles and Framework ISO 14044 (2006): Environmental Management - Life Cycle Assessment – Requirements and Guidelines
ISO 14071 (2024): Environmental management - Life cycle assessment - Critical review processes and reviewer competencies

Scope of the Critical Review

The reviewer had the task to assess whether

- the methods used to carry out the LCA are consistent with the international standards ISO 14040 and ISO 14044
- the methods used to carry out the LCA are scientifically and technically valid,
- the data used are appropriate and reasonable in relation to the goal of the study,
- the technological coverage of the industry in the prevalent LCA study is representative of current practice,
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

The review was performed after completion of the study according to paragraph 6.2 of ISO 14044, because the study is not intended to be used for comparative assertions intended to be disclosed to the public. This review statement is only valid for this specific report version 2.0 dated May 2025.

The analysis of the LCI model and the verification of individual datasets are outside the scope of this review.

Review process

The review was coordinated between EA and the reviewer. As a first step in the review process, the first draft final report was submitted to the reviewer on 21.06.2024. This report was complete in terms of methodology. It contained all results except for foil production. The reviewer provided 90 comments of general, technical and editorial nature to the commissioner by 04.07.2024.

EA provided a revised report addressing the review comments on 22.08.2024. All technical issues and recommendations of the reviewer were addressed in a comprehensive and proper manner. The reviewer assessed the revised report and had just two remaining comments to be addressed. They were adopted in the finalisation of the study. On 07.10.2024 the revised report was delivered to the reviewer and at this stage also included the results on foil production provided by the European Aluminium Foil Association (EAFA). For the new result section, the reviewer had four technical and editorial comments, which were addressed in the final version of the report. The final version of the report was provided on 10.10.2024. The reviewer checked the implementation of the comments and agreed to conclude the critical review process.

In May 2025, EA provided an updated version of the report which included several amendments and corrections, which are transparently documented in the Change log section at the beginning of the report.

The reviewer acknowledges the unrestricted access to all requested information as well as the open and constructive dialogue during the critical review process.

General evaluation

The study report provides an update of the life cycle inventory data for aluminium production and transformation processes in Europe. This update is based on environmental data related to the years 2021 and 2023. It follows the previous reports and datasets provided by EA which were published in 2018, 2013, 2008 and 2005.

The study includes life cycle inventory datasets representing

- production (cradle-to-gate) for primary aluminium produced in Europe
- production (cradle-to-gate) for primary aluminium used in Europe
- production (gate-to-gate) of the semi-finished aluminium product sheet
- production (gate-to-gate) of the semi-finished

- aluminium product foil
- production (gate-to-gate) of the semi-finished aluminium product sheet
- production (gate-to-gate) of the semi-finished aluminium product extrusion profile
- remelting of scrap (pre- and post-consumer) and
- refining of scrap (pre- and post-consumer).

The study is performed in a professional manner using state-of-the-art methods. The amendments and corrections of the May 2025 2.0 edition of the report did not affect the overall conclusions of the report.

The outstanding feature of this study is the significant amount of foreground industry data collected. Over all products studied, data were collected at more than 160 reporting sites. This ensured a very good representation of a large share of the total European production of the different products (alumina production 81%, anode production 95%, electrolysis and cast house 100%, rolling mills 86%, foil production 83%, extrusion 35%, remelting 80%, refining 61%).

The defined and achieved scope for this study was found to be appropriate for the stated goals.

13 Conclusion

The study has been carried out in conformity with ISO 14040 and ISO 14044. The reviewer found the overall quality of the methodology and its execution to be adequate for the purposes of the study. The study is reported in a comprehensive manner including a transparent documentation of its scope and methodological choices.



Matthias Finkbeiner
14th May 2025



About European Aluminium

European Aluminium, founded in 1981 and based in Brussels, is the voice of the aluminium industry in Europe. We actively engage with decision makers and the wider stakeholder community to promote the outstanding properties of aluminium, secure growth and optimise the contribution our metal can make to meeting Europe's sustainability challenges. Our 100+ members include primary aluminium producers; downstream manufacturers of extruded, rolled and cast aluminium; producers of recycled aluminium and national aluminium associations, representing more than 600 plants in 30 European countries. Aluminium products are used in a wide range of markets, including automotive, transport, high-tech engineering, building, construction and packaging.



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