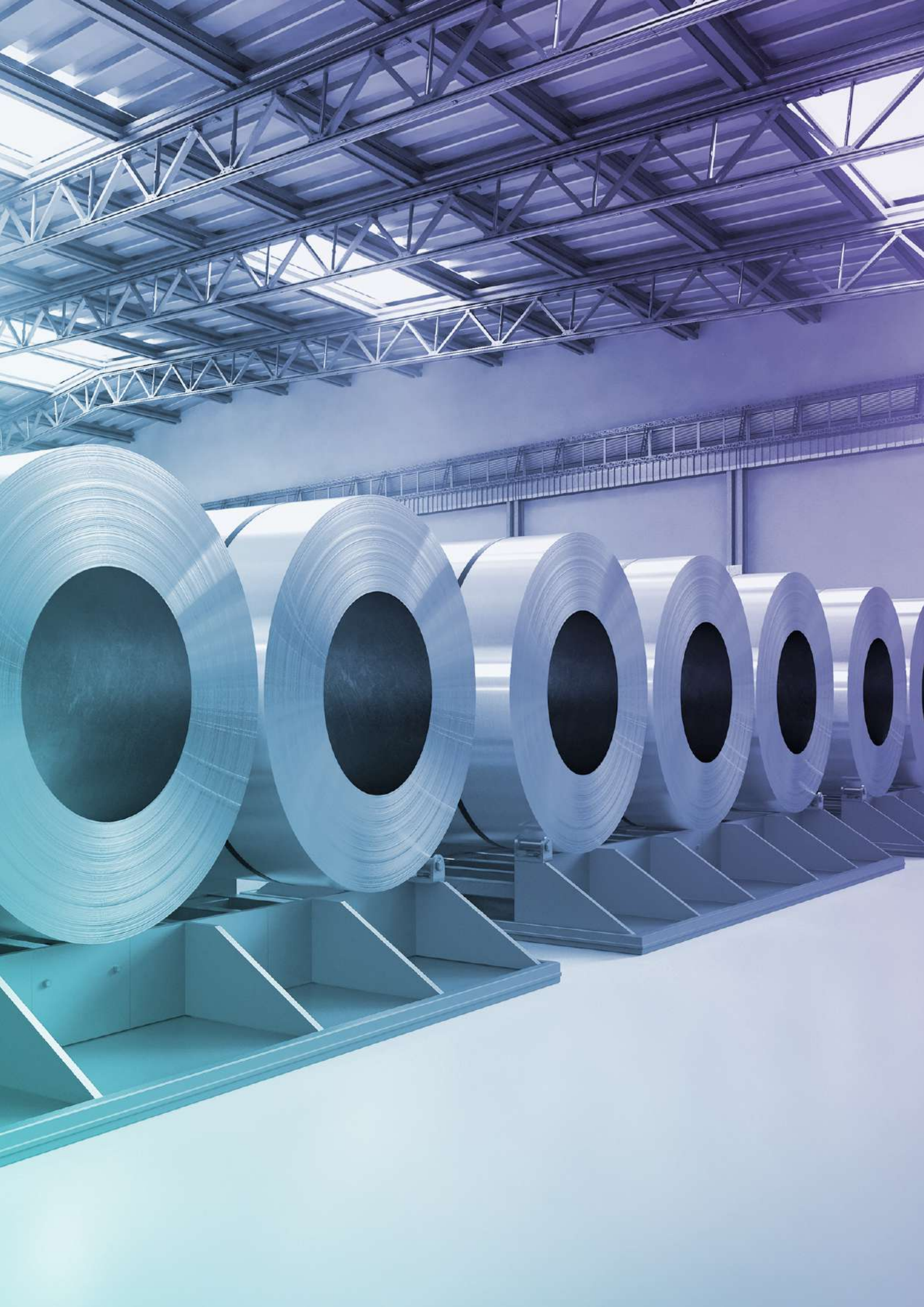
ENVIRONMENTAL PROFILE REPORT 2024 V.2.0

Executive Summary

May 2025

European Aluminium

ANYTHING BUT BASIC



1. Introduction

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For over 30 years, **European Aluminium** has been at the forefront of promoting life cycle thinking, encouraging stakeholders to evaluate the environmental footprint of aluminium products from production to end-of-life.

The Environmental Profile Report provides accurate and reliable data on the environmental impact of the entire aluminium value chain in Europe (defined here as EU, EFTA + UK unless noted otherwise), from metal supply (primary and recycling) to semi-fabrication (rolling, foil production and extrusion).

The latest data show encouraging progress. Since the last assessment in 2015, the carbon footprint of primary aluminium produced in Europe has declined and most of the European primary production is currently powered by low-carbon electricity. In fact, the electricity consumed during the primary smelting process accounts for about 70% of the primary aluminium carbon footprint, which makes the carbon footprint of primary aluminium highly dependent on the continued and increased availability of low-carbon electricity. Beyond primary production, the European aluminium industry has also made notable progress in semi-fabrication and recycling processes. These collective improvements represent a positive step toward achieving the European aluminium industry's net zero by 2050 target.

However, this progress is being undermined by structural challenges. While the industry is expected to face a potential 30% increase in demand by 2040, several primary aluminium producing plants in Europe have been forced to shut down or curtail capacity because of too high electricity prices in Europe compared to other regions in the world and a lack of supportive EU policies to ensure access to affordable and decarbonised electricity. This reached dramatic levels during the 2021 energy crisis in Europe when nearly half of the production capacity in the EU27 was either curtailed or shut down entirely.

With demand remaining high, the gap in domestic production has been increasingly filled by imports, which, in 2023, accounted for more than half of the European consumption of primary aluminium. The increased dependence on imports, combined with geopolitical developments, has come with significant environmental consequences. In 2023, imported primary aluminium had a carbon footprint twice as high as that of European production, with import flows shifting towards regions where primary aluminium production is largely powered by carbon-intensive energy sources.

These trends highlight the urgent need to reinforce European aluminium production and recycling capacity through robust policy support. Securing access to clean and affordable energy is critical not only to reduce reliance on carbon-intensive imports but also to meet the EU climate ambitions and maintain industrial resilience. In parallel, greater support for scrap recovery, sorting and high-quality aluminium recycling is essential, as secondary aluminium production requires far less energy and will be key in meeting future demand for sustainable aluminium.

Beyond environmental and economic considerations, strengthening the European aluminium industry serves a broader strategic objective. Aluminium has been recognised as a critical and strategic raw material under the EU Critical Raw Material Act, and reducing import dependence aligns with the EU's Clean Industrial Deal, Net-Zero Industry Act, and the EU Steel & Metals Action Plan, which all emphasise the need to secure supply chains for Europe's green and digital transitions.

Focus on Global Warming Potential (GWP) results

As an example of the environmental indicators in this report, the Global Warming Potential (GWP), best known as the carbon footprint, which measures greenhouse gas emissions in terms of CO_2 equivalents (CO_{2eq}), is detailed here for the various datasets covered by the report.

Most representative European aluminium datasets (Reference year)	**Value** (in kg CO_{2eq} per kg)
Primary aluminium produced in Europe (cradle-to-gate) (2023)	6.6
Primary aluminium used in Europe (cradle-to-gate) (2023)	10.1
Sheet production (gate-to-gate) (2021)	0.41
Foil production (gate-to-gate) (2022)	1.10
Extrusion production (gate-to-gate) (2021)	0.38
Remelting production (gate-to-gate) (2021)	0.26
Refining production (gate-to-gate) (2021) (without credit*)	0.41
Refining production (gate-to-gate) (2021) (with credit*)	0.37

* With or without aluminium oxide valorisation

2. Context

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The increasing societal focus on sustainability has driven a growing demand for transparency regarding the environmental impact of products. In response, companies are increasingly using Life Cycle Assessments[1] (LCA) as a communication tool. LCA methodologies are also used in certain European environmental legislations, such as the Eco-design of Sustainable Products Regulation (ESPR) and environmental products policies, where MEErP[2] and PEF[3] are used as background methodology.

As the EU intensifies its energy and climate transition efforts, there is an increasing demand from various stakeholders for reliable data on the environmental performance of raw materials.

As a result, there is also a growing need for various stakeholders to access reliable data on the environmental performance of aluminium, particularly its carbon footprint. This information is essential for shaping effective decarbonisation policies in the context of increasing societal focus on sustainability, which has driven a growing demand for transparency, and for providing intelligence to inform international trade agreements.

Aluminium's inherent qualities, namely lightweight, strength, and recyclability, make it an ideal material for meeting the growing demand for sustainable products across key sectors such as transport, construction, and packaging. The availability of accurate environmental data ensures that these sectors can fully leverage aluminium's benefits while aligning with the EU's broader sustainability objectives.

This report aims to:

- **Update the environmental data** (e.g.energy consumption) on the various processes of aluminium production in Europe. The updated datasets, based on 2023 models, 2021 and 2022 production data, replace the 2015 versions.
- Provide accurate and reliable generic industry **Life Cycle Inventory (LCI) datasets** for the key process steps, which are essential for calculating the environmental impact of products using aluminium.
- Provide data on the **environmental footprint** of the European aluminium industry.

This report is primarily intended for LCA practitioners, researchers, and environmental managers working in the aluminium value chain. It is particularly relevant for experts who are part of aluminium companies, their customers in sectors such as transport, building, construction and packaging, consultancies (e.g. LCA databases suppliers), research entities (e.g. universities, R&D centres) or administrations (e.g. EU institutions).

The increasing societal focus on sustainability has driven a growing demand for transparency regarding the environmental impact of products.

[1] Life Cycle Assessment (LCA) is a technique to assess the environmental aspects and potential impacts associated with all the stages of product, process or services life.
[2] Methodology for the Eco-design of Energy related Products (MEErP) Available at: https://op.europa.eu/en/publication-detail/-/publication/03ac5f5a-eb3b-11ee-bf53-01aa75ed71a1
[3] Product Environmental Footprint (PEF) Available at: https://green-business.ec.europa.eu/environmental-footprint-methods_en

3. Highlights from the report

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The Environmental Profile Report and **the associated LCI data** have been developed in full alignment with the two relevant ISO standards, namely ISO **14040** and **14044**. The report was reviewed by **Prof Dr. Matthias Finkbeiner**, a renowned Life Cycle Assessment expert. It acknowledges the continuous efforts of the aluminium industry in Life Cycle Assessment (LCA), as emphasised in the following statement: "This update of LCA information for a key material represents another milestone in a continuous effort of European Aluminium since more than two decades. The foreground industry data coverage and the number of included production sites are outstanding".

3.1 Primary aluminium

European Aluminium provides two key environmental datasets for primary aluminium production: one for domestic primary production within Europe (representing the European production mix) and another for aluminium consumed in Europe, which includes net imports[1] of aluminium (representing the European primary consumption mix). These datasets are crucial for understanding the impact of various external factors on aluminium primary production and consumption in Europe.

One key factor is the European energy crisis, which peaked in 2022 and 2023, and had a significant impact on primary aluminium production, especially for EU-based smelters. This resulted in the full closures of seven smelters between 2015 and 2023.

Additionally, the geopolitical fallout from the war in Ukraine has significantly transformed the European supply chain for aluminium ingots. For instance, in 2023, "Rest of Europe" (mainly Russia) represented only 18 per cent of European imports of ingots versus 43 per cent in 2015. Conversely, Middle East & Central Asia represented 33 per cent of European imports in 2023 versus 21 per cent in 2015.

- **Primary aluminium production in Europe**

Due to the energy crisis, which mainly affected EU smelters, **the EU countries saw their share of European production decline from 50 per cent in 2015 to 27 per cent in 2023.**

Consequently, the share of renewable energy to produce electricity used by European smelters reached 78 per cent in 2023 versus 67 per cent in 2015. As a result, the carbon intensity of the grid mix of the European smelters declined from 132 g CO_{2eq} per kWh in 2015 to 105 g CO_{2eq} per kWh in 2023.

Despite a significant decrease in the carbon intensity of electricity, the carbon intensity of primary aluminium produced in Europe declined only slightly, from 6.7 kg CO_{2eq} per kg in 2015 to 6.6 kg CO_{2eq} per kg in 2023, mainly due to a higher contribution from ancillary materials such as calcined petroleum coke.

For other environmental indicators covered by the report, the results for primary aluminium produced in Europe showed mixed results. On one hand, the reliance on non-renewable energy fell while the share of renewable energy used in production strongly increased. However, other environmental indicators related to acidification, eutrophication and photochemical ozone creation increased between 2015 and 2023. These trends are partly driven by a change in the modelling of primary aluminium, using regionalised data to better reflect alumina import sources. This revealed a higher share of imports from regions relying more on heavy fuel oils, which emit significantly more acidifying gases, such as SO_2 and NOx, than natural gas or coal, thereby contributing to the rise in these impact categories.

- **Primary aluminium consumption in Europe**

This dataset encompasses European production of primary aluminium (as detailed above) and net imports[3]. Imports of aluminium ingots into Europe in 2023 slightly increased in percentage compared to 2015, accounting for 51 per cent of European primary consumption in 2023 versus 49 per cent in 2015.

However, due to the war in Ukraine, notable changes occurred in the sources of metal imports, as seen in Table 1. This shift in import sources explains the decline in the aluminium imports produced using hydroelectricity (35 per cent in 2023 vs 69 per cent in 2015) and the increase in imports produced with natural gas (34 per cent in 2023 vs 22 per cent in 2015) and coal (30 per cent in 2023 vs 8 per cent in 2015). Imports from "Rest of Europe" and "Africa" (e.g. Mozambique) are mainly based on hydropower, while other main regions' production predominantly sourced their electricity for primary aluminium production from natural gas (i.e. Middle East) and coal (e.g. India for Asia).

Table 1: Distribution of European imports of primary aluminium ingots by region

Regions	2015 Imports share	2023 Imports share
Middle East and Central Asia	21%	33%
Asia	3%	22%
Rest of Europe	43%	18%
Africa	23%	18%
North America	6%	4%
Oceania	1%	2%
Central and South America	3%	2%

[3] Net imports of ingots (i.e. HS 7601), assimilated to primary ingots by default.

Therefore, environmental indicators related to European imports of primary aluminium worsened. For instance, the carbon intensity of the electricity grid mix for imports increased from 267 g CO_{2eq} per kWh in 2015 to 492 g CO_{2eq} per kWh in 2023, i.e. +84 per cent versus the 2015 baseline.

As a result, in the 2023 model, the environmental impact in terms of the carbon footprint of the primary aluminium consumption in Europe reached 10.1 kg CO_{2eq} per kg primary aluminium, i.e. an increase of 14 per cent versus the 2015 baseline. It should be noted that the increase in the GWP due to the change in the electricity grid mix of imports is partly compensated for by an offsetting effect from improvements in the import modelling process (e.g. better regionalisation of the industry supply chain data).

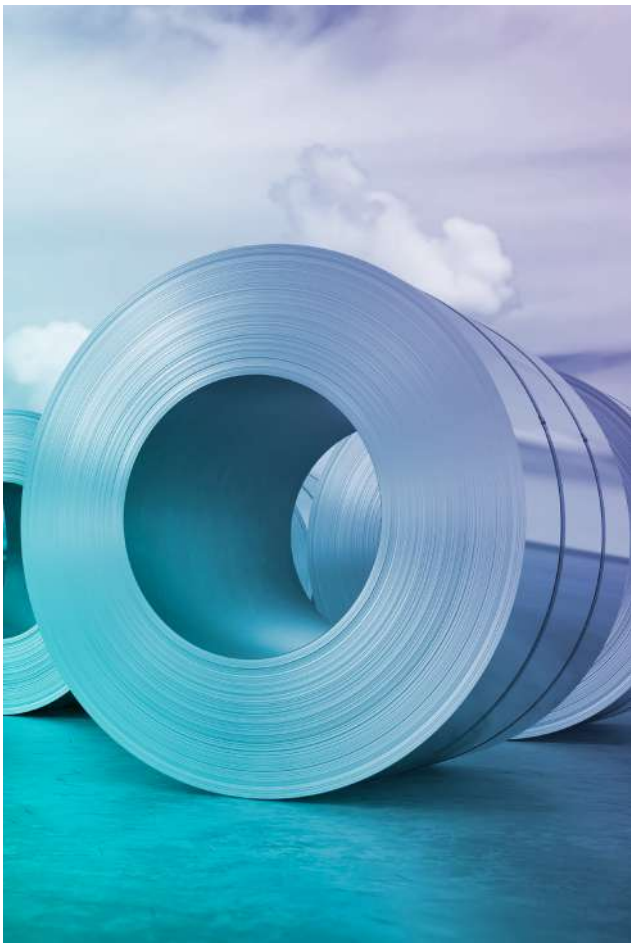
This trend underscores the need to strengthen the share of locally produced European primary aluminium, along with incentives for recycling. This will help reduce the carbon footprint of European consumption in view of achieving the EU's green transition and strengthen European strategic autonomy by reducing reliance on third countries. Notably, in the 2023 models, the carbon footprint of the domestic European primary aluminium production is half that of the imported ingots[4].

For most environmental indicators covered by the report, the environmental performance of the primary aluminium consumed in Europe worsened as well.

3.2 Semi-fabrication

The report covers three environmental datasets for semi-fabrication: one for rolling, one for foil production and one for extrusion.

It should be noted that given the economic structure of these processes, the impact of the energy crisis on these industry segments was more limited compared to primary production (e.g. no direct plant closures). Therefore, European Aluminium considers the latest baselines below to be fully representative of the current situation of the industry.

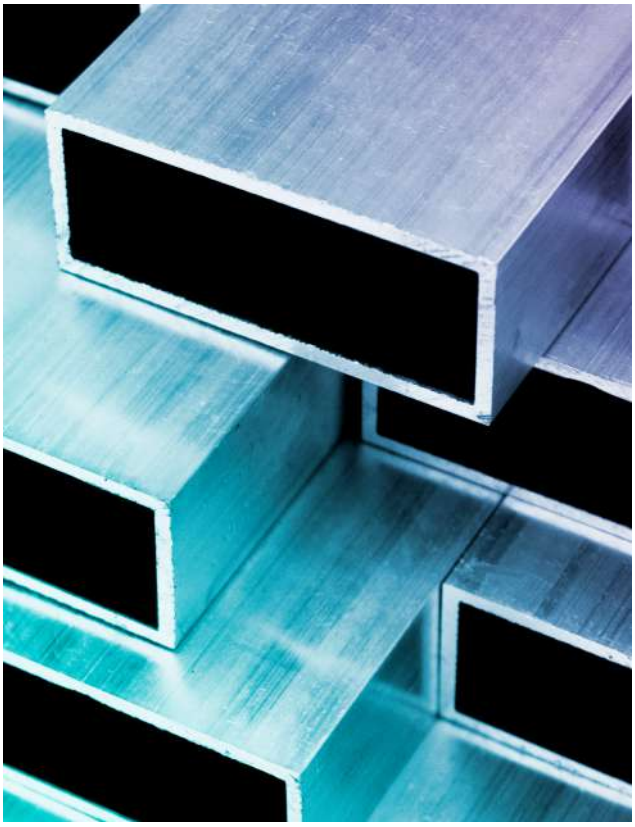


- **Rolling:**

  Compared to 2015, the environmental performance of the aluminium rolling mill process in Europe has improved for most indicators. For example, total energy consumption declined by 3 percent. Similarly, the consumption of input materials, such as ancillary products and packaging, also declined. Major air emissions (i.e. sulphur dioxide (SO_2) and nitrogen oxides (NOx) saw a decline during the overall process, and the amount of waste generated decreased as well.

  Consequently, the environmental impact of the aluminium rolling mill process has declined for most indicators. For instance, the GWP decreased by 4 percent, i.e., reaching 412 g of CO_{2eq} per kg of aluminium

[4] The GWP of imported ingots in Europe is equal to 13.2 kg CO_{2eq} per kg of aluminium versus 6.6 kg CO_{2eq} per kg for the domestic European production in 2023.



sheet. Other indicators, such as acidification (linked to SO_2 emissions) and eutrophication (linked to NOx emissions), have significantly decreased by 26 per cent and 18 per cent, respectively.

- **Foil:**
  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. Compared with previous 2015 datasets, a certain decrease in impact for all indicators can be observed. This 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).

- **Extrusion:**
  The environmental impact of extrusion processes improved significantly compared with 2015. For example, total energy consumption fell by 27 per cent. This decline may partly reflect changes in the product mix, with shifts in the types or proportions of products manufactured influencing overall energy demand alongside efficiency improvements. Consumption of ancillary materials has significantly declined in the same period, even if there seems to have been a slight increase in the consumption of materials for packaging (especially for wood packaging). Regarding the outputs from the process, there were significant reductions in the main air emissions (i.e. NOx and SO_2) of the overall process. While the total volume of waste generated has remained relatively stable, there has been an increase in the proportion of hazardous waste. Yet, most of this hazardous waste is directed towards recycling and not landfill or incineration.

Consequently, the overall environmental impact of the aluminium extrusion process decreased for all indicators. For example, the GWP fell by 44 per cent, reaching 382g CO_{2eq} per kg aluminium extrusion. In addition, indicators such as acidification (i.e. related to SO_2 emissions) and eutrophication (i.e. related to NOx emissions) have also decreased significantly, falling by 62 per cent and 49 per cent, respectively, largely due to the reduction in energy consumption during the process.

3.3 Recycling

European Aluminium provides two main environmental datasets for recycling in Europe: one for remelting production (i.e. for wrought alloy ingots) and one for refining production (i.e. for casting alloy ingots).

The refining production route also includes a scenario with system expansion to illustrate the substitution benefits from the recovery of aluminium oxide during the aluminium salt slag aluminium process. The aluminium oxide recovered during the aluminium salt slag recycling process can be used in other industries, such as refractories, ceramics, or cement, substituting other sources of aluminium oxides. **This is a prime example of circular economy practices and industry value chain symbiosis.**

- **Remelting:**
  The environmental performance of the remelting of scrap significantly improved in 2021 compared to 2015. For instance, total energy consumption for the process declined by 6 percent. Key air emissions, such as NOx and SO_2, of the overall process also declined in 2021 compared to 2015. However, the total amount of waste, mostly non-hazardous, increased. Nevertheless, most of this waste is directed for recycling rather than being sent to landfills.

  Consequently, the overall environmental impact of remelting has decreased for all indicators. The GWP declined by 22 per cent (i.e. reaching 260 g CO_{2eq} per kg of aluminium ingot), and total primary energy demand decreased by 16 per cent. Moreover, indicators such as acidification (linked to SO_2 emissions) and eutrophication (linked to NOx emissions) dropped by approximately 60 percent.

- **Refining:**
  The European model for aluminium refining was developed in 2021 based on data collection from 2017 to 2019. Given the comprehensive analysis in the previous report, only the background datasets, such as the EU electricity grid mix, provided by the Life Cycle Assessment (LCA) software were updated to the latest version. These updates ensure that the model reflects the most current energy sourcing and environmental factors. The foreground datasets, representing the actual industrial processes, were deemed still representative of the industry's current operations and thus retained without modification. **As a result, the overall environmental impact of the refining process has decreased across all indicators.** For example, GWP declined by 5 per cent to 415 g CO_{2eq} per kg of aluminium ingot. In addition, indicators such as acidification (linked to SO_2 emissions) and eutrophication (linked to NOx emissions) declined by 8 per cent and 3 per cent, respectively.

  The valorisation of aluminium oxide recovered from the salt slag recycling process has led to additional reductions in key environmental indicators. For instance, the GWP of the refining process decreased further, bringing it down to 367g CO_{2eq} per kg of aluminium ingot.

Consequently, the overall environmental impact of remelting has decreased for all indicators.

4. Scope of the report

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Life cycle transformation scope along the aluminium value chain

This report provides seven main environmental datasets covering the entire aluminium value chain production in Europe:

1. **Primary aluminium produced in Europe (cradle-to-gate[6]):** this dataset includes the environmental impact related to the production of primary aluminium ingot[7] in Europe, ready for delivery to the user, as well as the impact of sourcing the raw materials from the smelters (i.e. alumina and bauxite mining). The data reflects 2023 conditions and are based on 2021 industry figures from European plants still operating in 2023. To better represent 2023 conditions, production volumes and the average electricity grid mix used in smelting were updated, as smelting accounts for most of the environmental footprint.

2. **Primary aluminium used in Europe (cradle-to-gate[6]):** this dataset includes the environmental impact related to the use (i.e. domestic primary production and net imports[8]) of primary aluminium ingot in Europe ready for delivery to the user. It also captures the impact of sourcing the raw materials for the smelters (i.e. alumina and bauxite mining). The dataset combines 2021 industry data for European production, collected by European Aluminium, and 2019 industry data for imported aluminium, sourced from the International Aluminium Institute[9], and is adjusted to reflect the 2023 European consumption mix of aluminium. Additionally, electricity grid mixes of smelters from 2023 were used for both European smelters and smelters located in regions exporting primary aluminium into Europe.

3. **Aluminium sheet produced by rolling mill process in Europe (gate-to-gate):** this dataset includes the environmental impact of the aluminium rolling mill process, from ingot (i.e. slab) to aluminium sheet (i.e. flat rolled products) ready for delivery to the user. The data uses 2021 industry figures, which are still representative of the current situation.

4. **Aluminium foil produced in Europe (gate-to-gate):** this dataset includes the environmental impact of the aluminium foil production process in Europe i.e. from the production of the foil stock (hot rolling or strip-casting process) to the aluminium foil ready for delivery to the user. The data uses 2022 industry figures, which are still representative of the current situation. These datasets have been prepared by the European Aluminium Foil Association (EAFA).

5. **Aluminium profile produced by extrusion process in Europe (gate-to-gate):** this dataset includes the environmental impact of the aluminium extrusion process, from the ingot (i.e. billet) to the aluminium profile ready for delivery to the user. The data uses 2021 industry figures, which are still representative of the current situation.

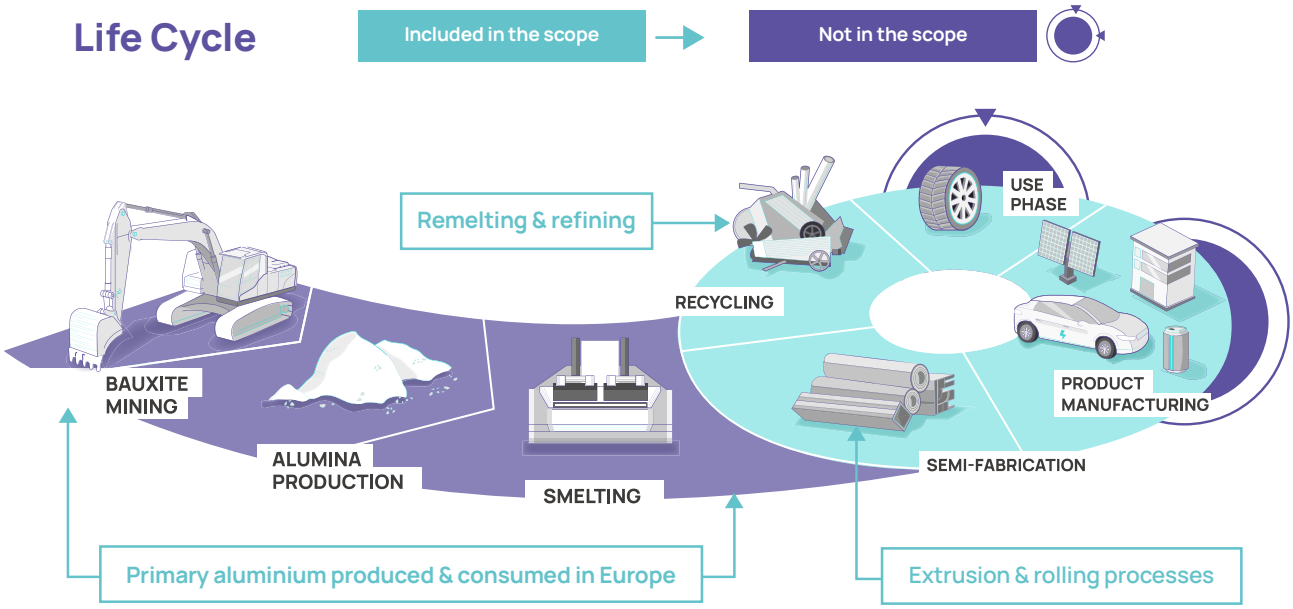
6. **Aluminium recycled ingot produced by remelting process in Europe (gate-to-gate):** this dataset includes the environmental impact of the aluminium remelting process, from pre-or post-consumer scrap to the wrought alloy ingot ready for delivery to the user. The data uses 2021 industry figures, which are still representative of the current situation.

7. **Aluminium recycled ingot produced by refining process (gate-to-gate):** this dataset includes the environmental impact of the aluminium refining process from pre- or post-consumer scrap to casting alloy ingots ready for delivery to the user. The data uses industry figures from 2017 to 2019, which are still representative of the current situation.

[6] Mining to primary ingot casting
[7] Outputs of the aluminium casting process under all possible forms (e.g. slabs, billets, other shapes)
[8] Net imports of ingots (i.e. HS 7601), assimilated to primary ingots by default.
[9] IAI (2019), 2019 Life Cycle Inventory (LCI) Data and Environmental Metrics. Available at: https://archive.international-aluminium.org/resource/2019-life-cycle-inventory-lci-data-and-environmental-metrics/

Production, manufacturing of final products (e.g. motor vehicles, aluminium cans, etc.) and the use phase of the products are not included in this assessment, as these datasets are more specific to aluminium customers. However, these must be included when considering the full life cycle assessment of final products containing aluminium, as emphasised in the figure below.

- Geographical scope: **The geographical area covered by European Aluminium's dataset is representative of the 27 EU Member States, the UK, and the EFTA countries (Norway, Switzerland and Iceland) unless otherwise stated** (e.g. Türkiye for rolling and foil).



5. Methodology

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This report and the associated LCI data were developed in **strict accordance with ISO standards 14040[10] and 14044[11], ensuring compliance with relevant guidelines and best practices.** The environmental data were collected and compiled by European Aluminium based on inputs from its members. **The data completeness is considered excellent for most segments and representative of the aluminium industry.** For example, in the electrolysis step, which significantly impacts the environmental footprint of the value chain, the collected industry data covers more than 85 per cent of European production. The same reasoning was applied by EAFA with its members.

Once consolidated, the European data collected for the entire aluminium value chain were integrated into LCA software (i.e. LCA for Experts, formerly known as GaBi) to produce the environmental impact assessment of the different aluminium processes. For this step, both European Aluminium and EAFA worked with Ecoinnovazione, which acted as a consultant. Considering that primary aluminium production is an electricity-intensive process, **a specific model** (i.e. instead of the default regional or/and national electricity grid mixes) **was developed to accurately reflect energy sourcing for primary aluminium produced and used in Europe.**

As a final step, **the report was reviewed** by renowned LCA expert **Prof. Dr. Matthias Finkbeiner** (Technische Universität Berlin, Managing Director of the Department of Environmental Technology, Chair of Sustainable Engineering). Prof. Dr. Matthias Finkbeiner acted as an independent expert and not as a representative of his organisation.

The data completeness is considered excellent for most segments and representative of the aluminium industry.

[10] ISO 14040:2006/Amd 1:2020. (2020). Environmental management — Life cycle assessment — Principles and framework.
[11] ISO 14044:2006/Amd 2. (2020). Environmental Management – Life Cycle Assessment – Requirements and guidelines.

6. How to use these aluminium LCI datasets

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The aluminium industry develops environmental datasets for various stages of the production process, including primary production, recycling, rolling, foil production and extrusion. To accurately determine the life cycle profile of the respective products, these datasets need to be combined in a modular way. For example, to assess the life cycle impact of an aluminium sheet made from primary aluminium, one needs to combine the cradle-to-gate LCI dataset for the primary production or consumption phase with the gate-to-gate LCI dataset for the rolling process (which covers the transformation of ingots into aluminium sheet).

To fully assess the environmental impacts of aluminium products, **it is essential to consider the entire life cycle of the product, including the benefits or burdens the product presents during its use phase and at its end of life (e.g. recycling).** Additionally, the European aluminium industry strongly recommends addressing recycling aspects in LCA through the end-of-life recycling approach. These steps are essential to fully reflect the intrinsic properties of aluminium products (e.g., lightweight, recyclability) when assessing their environmental impact. **As highlighted in ISO 14040 and 14044, the environmental aspects of a product system or service must be assessed from a life cycle perspective—from cradle to grave or cradle to recycling—in order to be deemed scientifically sound.**

> **... it is essential to consider the entire life cycle of the product, including the benefits or burdens the product presents during its use phase and at its end of life.**

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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