ENVIRONMENTAL PROFILE REPORT

Life-Cycle inventory data for aluminium production and transformation processes in Europe

February 2018

EUROPEAN ALUMINIUM

Table of Contents

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 in supplying information and data, making its best to provide information in line with the study goal and scope.
As example, European Aluminium has been strongly involved in the Product Environmental Footprint (PEF) initiative launched in 2013 as part of the communication "Building the Single Market for Green Products Facilitating better information on the environmental performance of products and organisations" (COM/2013/0196). PEF aims at harmonizing the LCA methodology to assess the environmental performance of products in Europe. Since 2014, European Aluminium contributes actively to the PEF methodological developments, especially through its participation in the PEF pilot project on metal sheet.

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 around 90% for the automotive sector and for the building sector [16]. 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 70% in 2015, without considering informal recycling routes [17]. Since the current aluminium product range is extremely wide, the end-of-life recycling rates can vary significantly.

As supported by the whole metal industry [14], the European aluminium industry recommends considering the environmental benefits resulting from recycling through the end-of-life recycling approach [14] and not through the recycled metal content approach. Recycled metal content is considered as incomplete and has limited environmental significance for metal 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. The European aluminium industry recommends using the so-called substitution methodology to consider the benefits of aluminium recycling in LCA. This methodology is explained within the technical paper "aluminium recycling in LCA" which can be downloaded from European Aluminium website (www.european-aluminium.eu).

These allocation rules for recycling [22, 23] were heavily debated under the PEF initiative. In 2014, the initial proposal from the European Commission was to use the so-called 50/50 methodology, i.e. considering equally the recycled Content and End of Life Recycling for all materials (i.e. with a 50% credit for each regarding the recycling benefits). By highlighting the specificities of metal products and the market value of scrap, the commission has finally accepted that a material-specific rule would be more adequate. As a result, the commission agreed to a new compromise in 2016, i.e. the 20/80 allocation methodology which considers 20% of the recycled content and 80% of the EoL recycling rate. This new compromise is closer to the recommendations of the metal industry.

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 [8-9]. This document is based on environmental data related to the year 2015. It updates the previous datasets which have been published in April 2013 [1] with reference year 2010, May 2008 with reference year 2005 [2] and in September 2005 with reference year 2002 [3].

1. The aluminium product life cycle

The typical life cycle of an aluminium product system can be modelled using a system of different process steps in accordance with the flow chart reported in Figure 1-1. The specific system boundaries of European Aluminium datasets are explained in Figure 2-1 below.

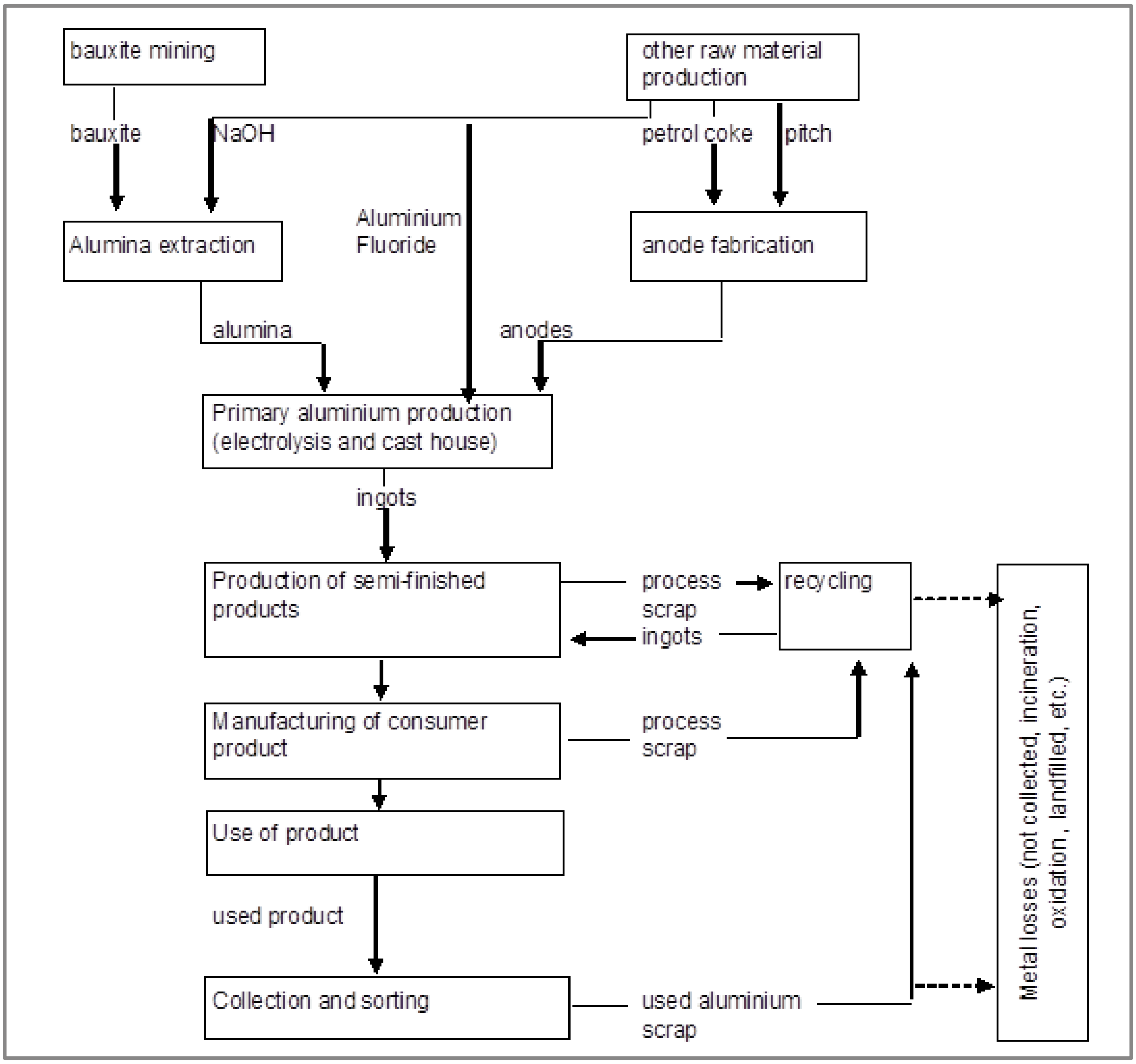

Figure 1-1 *Simplified life cycle material flow chart of an aluminium product*

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 together 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 formed during the various aluminium fabrication steps. This scrap is either recycled in a closed loop at the plant where it is generated, or recycled outside the plant by specialised remelters. Aluminium scrap from products after their service life is to a large extent recovered for recycling into new aluminium products.

2. Goal and scope of the LCI project

2.1 Goal

These updated environmental data and associated LCI datasets, which are annexed to this report, should be used for:

- LCA studies related to aluminium products fabricated in Europe, i.e. product made of aluminium or containing aluminium.
- updating the various environmental and LCI databases related to aluminium processes in Europe

As such, these datasets **are intended for use as a reference material for life cycle assessment (LCA) studies of products made of, or containing aluminium**. To complete the product system under study, the user should collect the following additional data and information:

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

The data provided by the European Aluminium members for their own process steps are the most up-to-date average data available for these processes, and it is recommended that they be used for LCA purposes, whenever generic aluminium data for Europe are needed. Older literature data should be disregarded, as they may no longer be representative due to technological improvements, progress in operating performance, changes with regard to raw materials or waste treatment, etc.

In that context, this report is targeting mainly LCA practitioners (e.g. consultants, database providers), companies belonging to aluminium value chain (aluminium producers, customers or suppliers), research entities (university, environmental agencies) or any other stakeholders interested to have accurate environmental data related to aluminium industry performance in Europe.

The report is not a comparative LCI. However, the study / data may be used to support comparative assertions (related to products made of, or containing aluminium) to be disclosed to the public.

2.2 Scope

2.2.1 Products system and system boundaries

2.2.1.1 Products system

In total, 7 LCI datasets are reported in this report. The system boundaries of these various datasets are reported in Figure 2-1 below.

- 2 datasets on primary aluminium production (cradle to gate): one for primary aluminium "produced[1] in Europe" (A) and one for primary aluminium "used in Europe[2]" (B).

The "**produced in Europe**" **primary** LCI dataset (A) corresponds to the production of 1 tonne of ingot from primary aluminium, i.e. from bauxite mining up to the sawn aluminium ingot ready for delivery. This dataset includes all the environmental aspects of the various process steps and raw materials used to deliver 1 tonne of sawn primary ingot produced by the European smelters. Since the electricity consumption is the major contributor to the environmental aspects, a specific electricity model has been developed based on the electricity consumed by the European smelters (see section 4.4.2).

The "**used in Europe" primary** LCI dataset (B) is similar to the previous dataset but considers as well the primary aluminium which is imported into Europe and which represent 49% of the primary aluminium used in Europe in 2015 (see section 4). Global data from the International Aluminium institute [3] have been used for modelling the primary aluminium produced outside Europe and a specific electricity model for the electrolysis process has been developed (see section 4.4.4) based on the origins of the imports.

These 2 datasets are based on the year 2015.

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

The '**semi-production**' processes LCI datasets (**sheet, foil or profile**) correspond to the transformation of a sawn aluminium ingot into a semi-product, i.e. profile, sheet or foil ready for delivery to the user. These 'semi-production' datasets include the recycling of the scrap and chips generated during this semi-fabrication stage as well as the recycling of the dross. The datasets correspond respectively to the production of 1 tonne of profile, sheet and foil.

The datasets related to sheet and extrusion production are based on the year 2015. The foil datasets provided by the European Aluminium Foil Association (EAFA) cover the year 2014.

- 2 datasets on scrap (pre and post-consumer scrap) recycling (i.e. gate to gate)

The '**remelting'** process LCI dataset correspond to the transformation of the aluminium (pre or post-consumer) scrap into a wrought alloy ingot[3] ready for delivery to the user. It also includes the recycling of dross & skimmings. This dataset should be used for the recycling of process scrap as well as for the recycling of some specific end-of-life products using well controlled collection schemes like big aluminium pieces in building or aluminium beverage cans collected through specific collection networks. The remelting data are based on the year 2015.

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

[2] Including imports of primary ingots from outside Europe : 44% of primary aluminium used in Europe is imported (Source : Eurostat for EU27 and national customs data for EFTA countries)

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

The ‘**refining’** process LCI dataset correspond to the transformation of the aluminium (pre or post-consumer) scrap into a casting alloy ingot[4] ready for delivery to the user. This dataset includes the melting, purifying and casting operations. It also includes the salt slag processing. These ‘recycling’ datasets are based on the recycling of the European scrap mix according to the ESSUM model [10].

The refining data related to the year 2015 are still under preparation. The aluminium refining process efficiency and recycling routes highly depend on the scrap origin and quality. An ad hoc task force is working on this topic within European Aluminium and should develop specific datasets in the future. Hence, the datasets from 2010 have been reported.

In addition, for specific aluminium applications or products, it is highly recommended to analyse more closely the recycling scenario(s) and the recycling routes in order to develop more adapted models and associated LCI datasets. European Aluminium members should develop as well an ad hoc task forces on these topics. Please contact European Aluminium (lci@european-aluminium.eu) for more specific information.

2.2.1.2 System boundaries

The boundaries of the 7 LCI datasets presented in the report are highlighted in the figure below.

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[4] Aluminium alloys used for the production of castings where the final product shape is generated by pouring molten metal into a mould.

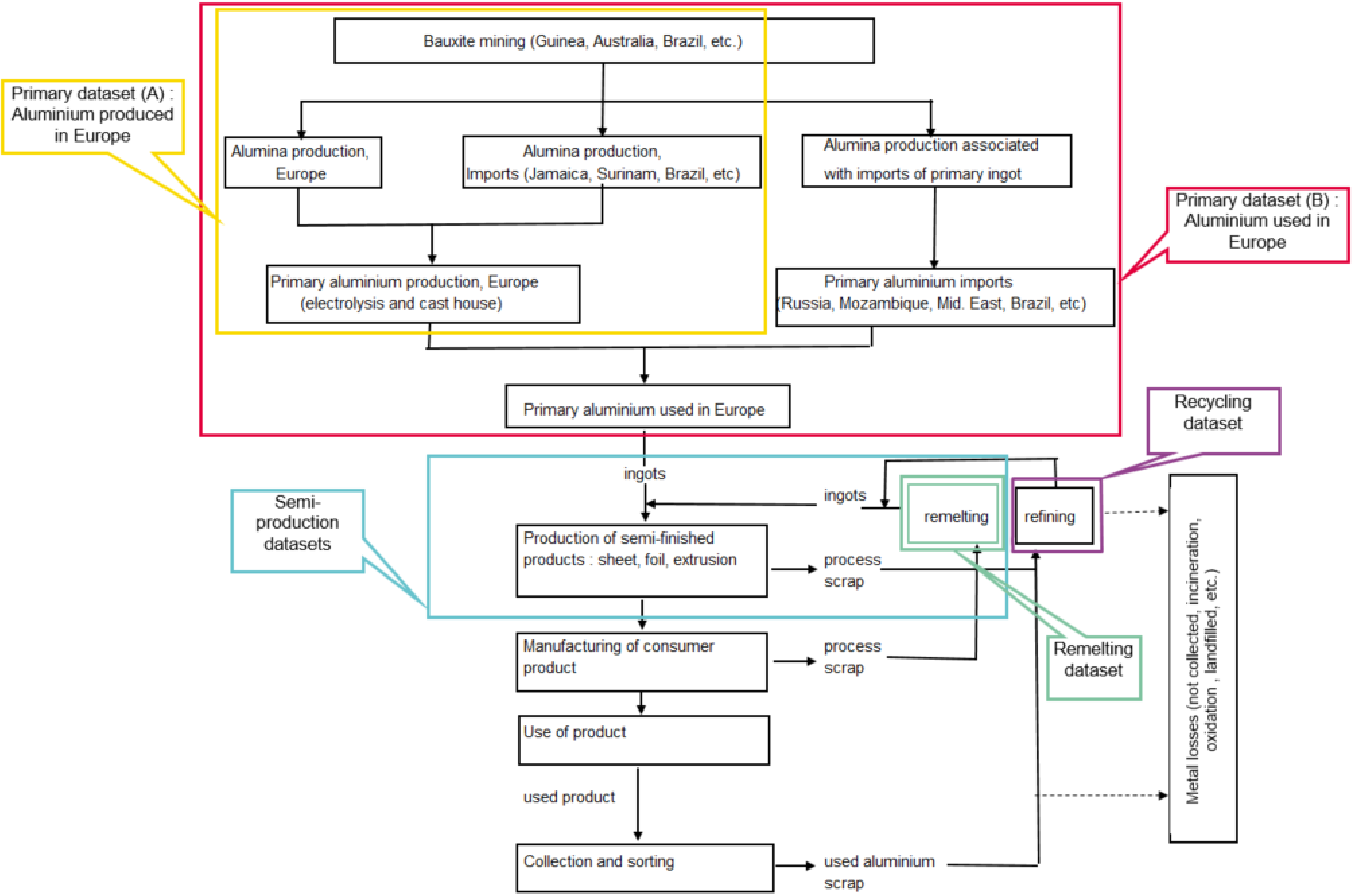

Figure 2-1: *System boundaries of the various LCI datasets*

2.2.1.3 Cut-off rules

Inputs and outputs data have been collected through detailed questionnaires which have been developed and refined from the first surveys organised in 1994 - 1996. In practice, this means that, at least, all material flows going into the aluminium processes (inputs) higher than 1% of the total mass flow (t) or higher than 1% of the total primary energy input (MJ) are part of the system and modelled in order to calculate elementary flows.

All material flows leaving the product system (outputs) accounting for more than 1% of the total mass flow are part of the system. All available inputs and outputs, even below the 1% threshold, have been considered for the LCI calculation.

2.2.2 Functional unit

For each of the 7 aluminium datasets, the functional unit is defined 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.
For instance, the functional unit of the primary aluminium produced in Europe dataset is "production in Europe of 1 tonne of primary aluminium ingot ready for delivery to the user". Later on in the report, the functional unit of each environmental dataset presented below will be mentioned again.

2.2.3 Allocation procedure

As much as possible, allocation has been avoided for the foreground data by expanding the system boundaries (see section 2.2.5). Each LCI dataset includes the aluminium scrap and dross recycling so that the only valuable material exiting the system is the aluminium ingot or semi-product (sheet, foil, extrusion).
The incineration of solid waste considers energy recovery (thermal and electricity). To avoid any allocation, such energy is directly re-introduced in the LCI model and the energy input is reduced accordingly. This procedure corresponds to energetic closed-loop recycling. In any case, such energy input from incineration is very limited (less than 1%).

Regarding recycling, the European aluminium industry recommends crediting the environmental benefits resulting from recycling through the so-called '**substitution' methodology**. This methodology is explained within the technical paper "aluminium recycling in LCA" downloadable from the European Aluminium website. In addition, more details to end of life approach recommended by European Aluminium is given in the metal industry declaration [14] as explained above.

As far the background datasets, the allocation rules used in Gabi 7 database [12] are conserved.

2.2.4 LCIA methodology and types of impacts

For each LCI dataset, environmental indicators have been calculated and reported for a pre-defined set of impact categories. **It is important to highlight that these environmental indicators are purely informative and should not be used for evaluating the environmental aspects of aluminium processes 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, is scientifically sound.**

The predefined set of environmental impact categories is reported in Table 2-1 while Table 2-2 gives a short explanation and definition of these impact categories. **These impact categories and related methodologies have been selected to allow an easy comparison with previous years.** Hence, they do not fully correspond to the latest developments / proposals which have been for example integrated into the latest PEF guidance document [21]. More details are also available in section 9.1.4.

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

Impact categories	Unit	Methodology
Depletion of Abiotic Resources elements (ADP)	[kg Sb-Equiv.]	CML2001 - Jan. 2016
Acidification Potential (AP)	[kg SO_2-Equiv.]	CML2001 - Jan. 2016
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	CML2001 - Jan. 2016
Greenhouse Gas emission (GWP 100 years)	[kg CO_2-Equiv.]	CML2001 - Jan. 2016
Ozone Layer Depletion Potential (ODP, steady state)	[kg R11-Equiv.]	CML2001 - Jan. 2016
Photo-oxidant Creation Potential (POCP)	[kg Ethene-Equiv.]	CML2001 - Jan. 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 description of the pre-selected environmental impact categories*

Indicators	Short description
Depletion of Abiotic Resources (ADP) elements	Resources are classified on the basis of their origin as biotic and abiotic. Biotic resources are derived from living organisms. 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)	This relates to the increase in quantity of acid substances in the low atmosphere, at the cause of "acid rain" and the decline of surface waters and forests. Acidification potential is caused by direct outlets of acids or by outlets of gases that form acid in contact with air humidity and are deposited to soil and water. Examples are: SO_2, NOx, ammonia. The main sources for emissions of acidifying substances are agriculture and fossil fuel combustion used for electricity production, heating and transport.
Eutrophication Potential (EP)	Aqueous eutrophication is characterized by the introduction of nutrients in the form of phosphatised and nitrogenous compounds for example, which leads to the proliferation of algae and the associated adverse biological effects. This phenomenon can lead to a reduction in the content of dissolved oxygen in the water which may result to the death of flora and fauna.
Greenhouse Gas emission (GWP 100 years, IPPC 2013)	The "greenhouse effect" is the increase in the average temperature of the atmosphere caused by the increase in the average atmospheric concentration of various substances of anthropogenic origin (CO_2, methane, CFC...). Greenhouse gases are components of the atmosphere that contribute to the greenhouse effect by reducing outgoing long wave heat radiation resulting from their absorption by these gases like CO_2, CH_4 and PFC.
Ozone Layer Depletion Potential (ODP, steady state)	Stratospheric ozone depletion (especially above poles) results mainly from a catalytic destruction of ozone by atomic chlorine and bromine. The main source of these halogen atoms in the stratosphere is photodissociation of chlorofluorocarbon (CFC) compounds, commonly called freons, and of bromofluorocarbon compounds known as halons. These compounds are transported into the stratosphere after being emitted at the surface. In the new Gabi 7 methodology, the halon 1301 has been replaced by CFC 11 as elementary flow in the petrochemical chain in line with the recent requirements in the

Indicators	Short description
	Montreal protocol which regulates and phased out the use of ozone depleting substances.
Photo-oxidant Creation Potential (POCP)	The majority of tropospheric ozone formation occurs when nitrogen oxides (NOx), carbon monoxide (CO) and volatile organic compounds (VOCs), such as xylene, react in the atmosphere in the presence of sunlight. NOx and VOCs are called ozone precursors. There is a great deal of evidence to show that high concentrations (ppm) of ozone, created by high concentrations of pollution and daylight UV rays at the earth's surface, can harm lung function and irritate the respiratory system
Total primary energy	Primary energy is energy that has not been subjected to any conversion or transformation process, e.g. Energy contained in crude oil.
Primary energy from renewable resources	Primary energy is energy that has not been subjected to any conversion or transformation process. Renewable energy refers to solar power, wind power, hydroelectricity, biomass and biofuels. For aluminium primary production, hydropower is the most significant renewable energy for electricity production.
Primary energy from non-renewable resources	Primary energy is energy that has not been subjected to any conversion or transformation process. Non-renewable energy is energy taken from finite resources like coal, crude oil, natural gas or uranium.

No normalization, grouping and weighting was applied due to their subjective nature. LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

For each LCI dataset, the various processes and materials involved in the system boundaries have been **classified in 5 categories, i.e. direct processes, auxiliary, transport, electricity and thermal energy.** Thus, the LCI data and the indicators can be distributed among such 5 categories as follows:

- **Direct process**: Direct material consumption/use or direct emissions associated with the aluminium processes. The following processes are considered as aluminium processes:
    - **Primary production**: bauxite mining, alumina production, anode/paste production, electrolysis, casting.
    - **Semi-production**: ingot homogenisation, ingot scalping, hot rolling, cold rolling, annealing, finishing & packaging, extrusion, foil rolling, scrap remelting, dross recycling.
    - **Recycling**: scrap remelting, scrap refining, dross recycling, salt slag treatment.
- **Electricity**: all the processes and materials needed to produce the electricity directly used by the aluminium processes. It includes fuel extraction and preparation.
- **Thermal energy**: all the processes and materials needed to produce the thermal energy directly used in the aluminium processes, excluding pitch and coke used for the anode production
- **Auxiliary**: all ancillary processes and materials used in the aluminium processes. It concerns mainly caustic soda, lime and aluminium fluoride.
- **Transport**: Sea, river, road and rail transport for bauxite and alumina and sea and river transport for imported ingots.

2.2.5 Types of sources of data

2.2.5.1 Foreground and background data

- Foreground data

The foreground data used in the report have been collected by European Aluminium members for each main production process. For instance, for the primary production, the foreground data have been collected for anode / cathode production, electrolysis and for the cast house process. In practice, these data are a mixture of measured, calculated and estimated data as required in the data collection surveys. For each aluminium segment, the various data collected are available in the report (e.g. see Table 4-7 for the electrolysis process).

European Aluminium LCI surveys cover the various direct inputs (e.g. energy, ancillary materials, water, and transport) and outputs (e.g. air and water emissions, waste production) of the aluminium production processes. These surveys have been validated and constantly improved by experts based on the previous exercises since the first surveys more than 15 years ago. When relevant, additional data related to land use were collected as well (e.g. see Table 4-3 and Table 4-5).

Moreover, for the primary aluminium datasets (i.e. produced and consumed in Europe), in order to model aluminium processes (e.g. bauxite mining) taking place outside Europe (see Figure 2-1), global averages process data (i.e. from International Aluminium Institute) have been used [4, 5]. These processes are listed below as well as their respective contribution into the 2 LCI datasets.

Table 2-3 *Respective contribution*[5] *of the different processes used for the 2 primary aluminium LCI datasets*

Process step	**2015**		**2010**	
	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)
Alumina production	61% European Aluminium and 39% IAI data	35% European Aluminium and 65% IAI data	58% European Aluminium and 42% IAI data	32% European Aluminium and 68% IAI data
Electrolysis including anode production and casting	100% European Aluminium and 0% IAI data	51% European Aluminium and 49% IAI data	100% European Aluminium and 0% IAI data	56% European Aluminium and 44% IAI data

Since, Europe is an important importer of alumina and primary aluminium, the modelling of the primary aluminium “used in Europe” LCI dataset assumes that the whole alumina and primary aluminium produced in Europe is used in Europe. This assumption is confirmed by statistics (from Eurostat and national customs) since less than 10% of the alumina and 3% of aluminium produced in Europe is exported (i.e. outside EU28 + EFTA).

Regarding the semis production and recycling production processes, only European datasets have been used. As explained above, trade of these products is considered as limited (i.e. about 10%). In addition, no or few datasets are available for the other producing regions or at global level.

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[5] Based on Eurostat (EU28) and national customs data (EFTA countries)

- Background data

In addition to the environmental data related to the aluminium processes collected directly by European Aluminium and / or IAI, additional inventory datasets (background data) related to supplementary processes have been used. These datasets are included in the GaBi database version 7 [12]. The most important are (list not exhaustive):

  - Limestone production (DE, 2016)
  - Caustic soda production (DE, 2016)
  - Aluminium fluoride production (EU28, 2016)
  - Petroleum coke production (EU28, 2013)
  - Pitch production (DE, 2011)
  - Electricity supply systems (EU28, GLO, 2015)
  - Fuel supply systems and fuel combustion (EU28, 2015)
  - Transportation (GLO, 2015)

In current LCA methodology, solid wastes are not listed as elementary flows provided they are recycled, incinerated, composted or legally landfilled. This LCA methodology integrates such incineration, recycling or landfilling operations within the system boundaries and models the emissions associated with such operations.
In the various LCI datasets developed within this report, the treatment of the solid wastes have been modelled and integrated within the system boundaries. For most solid wastes which are landfilled, emissions have been calculated based on average LCI models since it was not possible to collect or model specific emission data in relation to their behaviour in landfilling sites.

2.2.5.2 Focus on specific datasets, processes and production steps

- *Focus on: thermal energy used in aluminium processes*

Many aluminium processes use fossil fuels (natural gas, propane, diesel, coal, etc.) as thermal energy sources. While input figures have been collected regarding the consumption of these fuels, only restricted data have been collected regarding the air emissions which are mainly associated with the combustion of these fuels. The collected data usually covers only particulates, SO_2 and NO_X.

In order to consider properly the various air emissions associated with the combustion of the fuels, the modelling also includes the use of LCI data for fuel supply systems and fuel combustion which are available in the GaBi software (reference year 2015 – EU28).

As schematised in Figure 2-2 for the air emissions associated with the alumina production process, the survey reported figures (i.e. particulates, SO_2 and NOx) are then complemented with all the other air emissions which are associated with the preparation and the combustion of these fossil fuels. Precautions were taken to avoid double counting of the reported emissions.

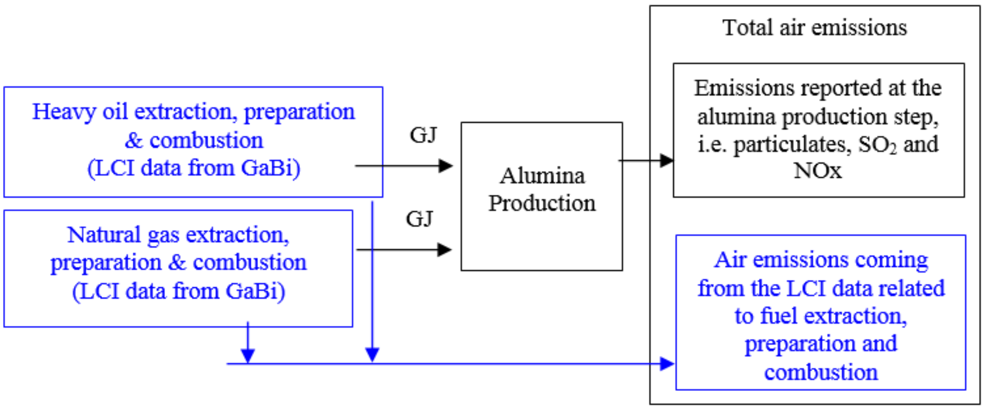

Figure 2-2: *Use of background LCI data related to fuel supply systems and combustion (Background GaBi LCI data in blue)*

The total air emissions from the alumina production is then a combination of reported figures for the main emissions completed with LCI data representative for fuel extraction, preparation and combustion. This approach has been systematically applied for any aluminium processes in which fuel combustion takes place.

- *Focus on: direct CO2 emissions in aluminium processes*

Direct CO_2 emissions have been calculated for the various aluminium processes based on their respective fuel consumption. The CO_2 conversion factors representative for EU-28 have been taken from GaBi 7 and are reported in the next Table 2-4.

Table 2-4 *CO_2 conversion factor for the various fuels*

Fuel type	CO_2 intensity (kg CO_2/MJ)
Heavy oil	$8,51.10^{-2}$
Natural gas	$6,32.10^{-2}$
Hard coal	$9,79.10^{-2}$
Diesel / light oil	$8,26.10^{-2}$
Steam	$7,02.10^{-2}$

- *Focus on: electricity production*

Electricity production has been included in the system boundaries. Electricity production is particularly critical for the electrolysis step, i.e. the smelter, since about 15 MWh/tonne of primary aluminium is used. Three specific models have been developed: two models for the electricity used by the European smelters, i.e. one for "pre-baked" smelters and one for "Soderberg" smelters, and one model for the electricity used by smelters exporting to the European market. These models are described in the section 4.4.

For the other processes, any electricity consumption is supposed to be reflected by the LCI data related to the EU28 electricity model (reference[6] year 2013) are used (see below).

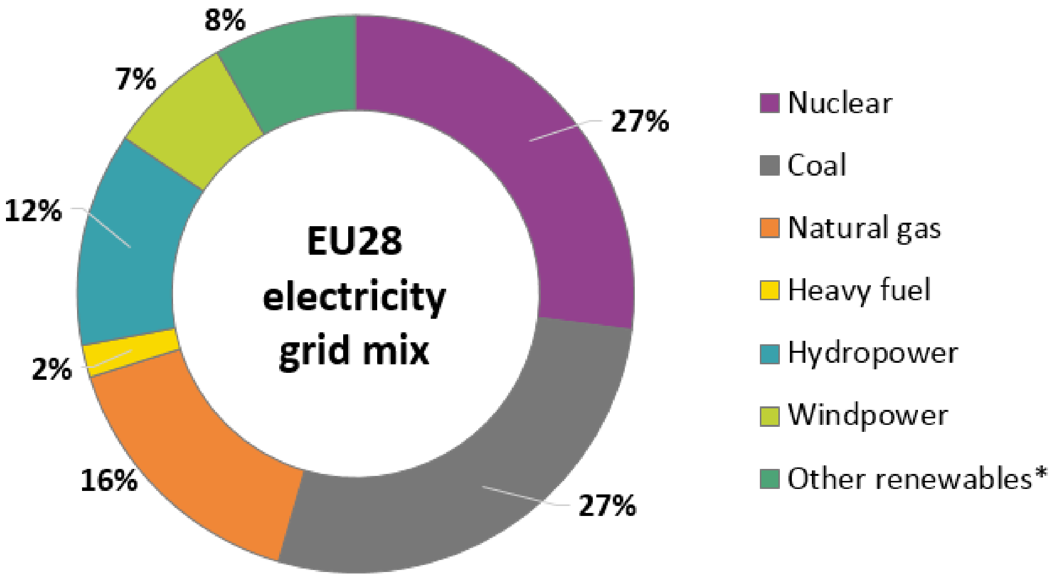

Figure 2-3 *Electricity Mix of EU28*

*other renewables: biomass, biogas, waste, photovoltaic, solar and geo thermal

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[6] 2013 data were used by default : 2015 data were not available in Gabi 7 software

In comparison with 2010 data EU28 electricity grid mix is containing more renewable energy (i.e. 27% in 2015 vs 18% in 2010) and less natural gas (i.e. 16% in 2015 vs 23% in 2010).

Table 2-5 *Main environmental indicators for the production of 1 kWh based on the EU-27 electricity grid mix*

Environmental indicators[7] per kWh electricity,	**2015**	**2010**	**2015 vs 2010 (in %)**
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	1,70E-07	4,01E-08	+324%
Acidification Potential (AP) [kg SO_2-Equiv.]	1,20E-03	2,08E-03	-42%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	1,09E-04	1,12E-04	-3%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	4,24E-01	4,89E-01	-13%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	1,84E-11	3,19E-08	-100%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	7,66E-05	1,27E-04	-40%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	9,93E+00	9,78E+00	+2%
Primary energy from renewable resources (net cal. value) [MJ]	2,53E+00	1,25E+00	+102%
Primary energy from non-renewable resources (net cal. value) [MJ]	7,40E+00	8,53E+00	-13%

In most of the case, the environmental indicators related to production of 1kWh of electricity in EU improved considerably from 2010 to 2015. These changes are mainly related to the electricity grid mix composition as explained above (i.e. more renewable energy and less fossil fuel).
On one hand, the Global Warming Potential (GWP) of the electricity production in EU decreased by 13%. On the other hand, the abiotic depletion increased by +324%. Basically, the use of silver and other rare or precious metals in the wind power mills or in photovoltaic cells explains the strong increase of ADP.

Regarding Ozone Layer Depletion Potential (ODP), the strong decrease (-100%) between 2015 and 2010 is related to an update of the Montreal Protocol which regulates and phased out the use of ozone depleting substances. Thus, in the new Gabi 7 methodology, the halon 1301 has been replaced by CFC 11 as elementary flow in the petrochemical chain in line with the recent requirements in the Montreal protocol.

These major changes in ADP and ODP related to the EU electricity grid mix will also have an influence on the evolution of these indicators for most aluminium datasets especially for the semi and recycling processes where only EU electricity grid mix is used.

- *Focus on: transport*

Bauxite, alumina and primary ingots imported into Europe are transported mainly by sea boat and to a lesser extent by river (barge), road and rail transport. Like in 2010, all these transport models were considered into the European Aluminium LCI dataset of primary aluminium.

Bauxite used in Europe is imported, mainly from South America (e.g. Brazil, Guyana) and Africa (e.g. Guinea). The average transport distance for imported bauxite is about 6.100 km by sea.

Alumina imported in Europe is mainly sourced from Jamaica, Suriname and Brazil. The average transport distance for the imported alumina to Europe is around 4.700 km by sea. In addition, the present model assumes an average sea transport distance of 2.500 km for the primary ingots imported into Europe (main sources of imports Russia, Middle East and Mozambique).

Road and rail transport have also been modelled for the bauxite and alumina imports in Europe. Figure 2-4 summarises the average transport distances used in the model.

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[7] A brief presentation of the environmental impact categories is given in Table 2-2.

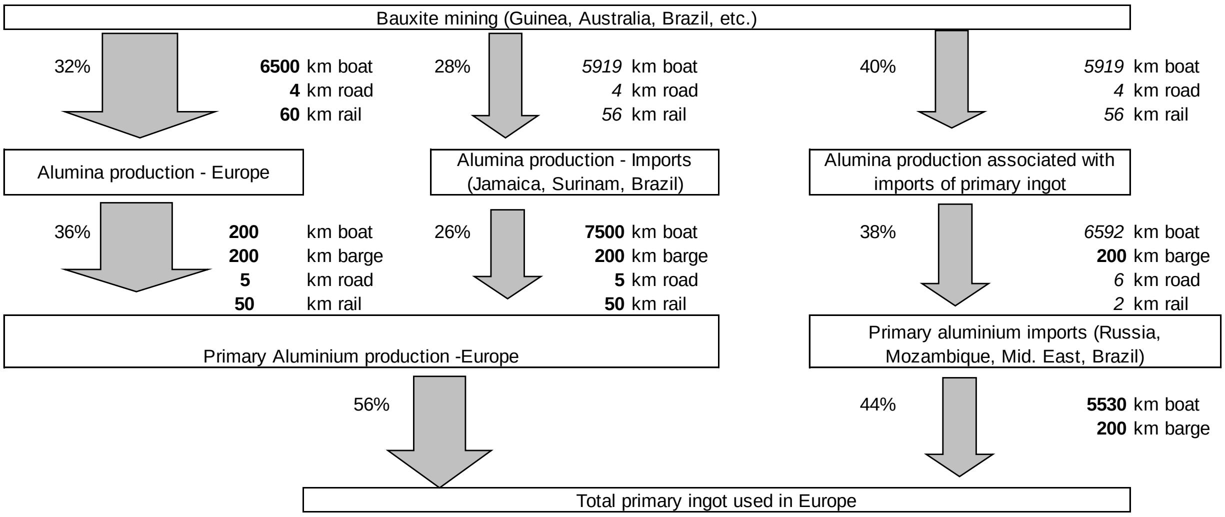

Figure 2-4 *Average transport distances of bauxite, alumina and imported aluminium*

Table 2-6 *Average transport distances*

Year	Type of transport	Unit	Bauxite	Alumina	Primary
2010 and 2015	Ocean/Cargo	km	6 104	4 516	2 433
	Barge	km	-	200	88
	Road	km	4	5	-
	Rail	km	57	32	-

A specific fuel consumption of 0.40 g of heavy oil per tonne transported and per km has been used (bulk carrier between 10.000 and 200.000 tonnes). As a result, the transport of 1 tonne of alumina or bauxite on 5.000 km gives then a consumption of 2.0 kg of heavy oil.

Regarding all the gate to gate process datasets (i.e. semis production and recycling processes), no specific transport data has been integrated into the models. The environmental impacts of the inputs materials are considered from their arrivals on the production site.

2.2.6 Data quality requirements

- Time-related coverage: all the datasets in the report are based on the annual average **corresponding to the year 2015**, unless otherwise stated (e.g. as mentioned the refiners data are based on the year 2010).
- Geographical coverage: European Aluminium datasets cover Europe which is composed of **the EU28 and the EFTA countries (Norway, Switzerland and Iceland)** unless otherwise stated (e.g. sheet production process data include as well Turkey).
- Technology coverage: the data presented in the report are **representative of the current technologies used in the aluminium industry for all the production steps** (e.g. European Aluminium data for electrolysis is a mix of 95% Prebake and 5% Soderberg technology).
- Precision: the values in the report represent the **production weighted average**[8] values for aluminium processes.

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[8] A production weighted average is a reflection of given reported process input or output data normalised per tonne of product for those the facilities that reported the relevant process input or output

- Completeness: **experts' judgement was used to identify outliers and to select data to be included in the consolidation**. As far as possible, before any decision of excluding data, reporting companies have been contacted and outliers have been possibly corrected according to the company feedback.
- Representativeness: an overview of the **representativeness is provided for each aluminium production step** in the various sections below (e.g. the representativeness of the electrolysis process is about 86% - see Table 4-1). When relevant, the representativeness of some specific flows has been highlighted (e.g. sea water inputs / outputs).
- Consistency: Data consolidation, averaging and modelling have been done by European Aluminium. The data collection procedures, the various questionnaires and the consolidated data are part of internal environmental reports **which have been found consistent and validated by experts' judgements** (i.e. European Aluminium Technical Working Group of the Sustainability 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 is updating its data on 5 years basis for more than 15 years. Regarding **the LCI models** (see section 3.4), they **have been developed in collaboration with ThinkStep** (i.e. acting as an external consultant).
- Sources of data: the **foreground data** in the report have been **reported by the aluminium industry** (i.e. via European Aluminium, International Aluminium Institute or European Aluminium Foil Association). The **background data are based on Gabi 7 software** [12].
- Uncertainty of the information (e.g. data, models, assumptions):
    - The LCI modelling is based on a pure aluminium mass flow. Alloying elements have been neglected and replaced by pure aluminium.
    - The LCI models use the substitution principle for scrap produced along the processing route, i.e. the recycling of all the aluminium from process scrap, chips, dross or salt slag which are produced along the production or transformation route are directly recycled into the lifecycle model. According to this modelling approach, the only valuable aluminium product exiting the LCI model is either the aluminium ingot or the aluminium semi-finished product. As a consequence, this approach supports the dataset modularity, i.e. the possibility to combine them directly.

      For the datasets addressing semi-production, remelting and refining, this approach allows evaluating the true environmental aspects of these aluminium processes, since it also considers the possible metal losses.
    - The modelling also considers ancillary processes like fuel preparation, electricity production or ancillary material production in order to develop LCI datasets mainly composed of elementary flows (i.e. material or energy directly drawn from the environment without previous human transformation or material or energy released into the environment without subsequent human transformation).

2.2.7 Critical review by independent experts

European Aluminium worked with Dr. Walter Klöpffer (Editor-in-chief, International Journal of Life Cycle Assessment, Am Dachsberg 56E, D-60435 Frankfurt) for the review of the 2 previous editions of the report (i.e. in 2008 and in 2013). For this new update of the report based on data of the year 2015, European Aluminium decided to include as well Dr. Matthias Finkbeiner (Technische Universität Berlin, Chair of Sustainable Engineering, Managing Director of the Department of Environmental Technology) as additional reviewer.

Taking into account the previous in-depth reviewing exercise [15-16], 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) [20] and in agreement with the ISO 14040 and 14044 rules [8, 9].

The review is performed as a critical review by external experts according to paragraph 6.2 of ISO 14044 (2006a), 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 excluded an assessment of the life cycle inventory (LCI) model, as well as an assessment of individual datasets. Individual reviewers were contracted as independent expert reviewers, not as representatives of their affiliated organizations. The reviewing report of the reviewers is annexed at the end of this document (see section 11).

2.2.8 Type and format of the report required for the study

In accordance with the ISO requirements (ISO, 2006), this document aims to report the results and conclusions of the LCI completely, accurately and without bias to the intended audience. 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. LCI inventory phase

3.1 Data collection and calculation

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

In order to update its various LCI datasets related to aluminium processes, the European Aluminium decided to organise in 2016 a new extensive environmental survey covering the year 2015, in which the European aluminium producers provided inputs and outputs data of environmental relevance for their respective production facilities.

The various European plants participating in the survey delivered absolute figures of process inputs/outputs for the whole year 2015 (e.g. in tonnes, GJ, m^3, etc.).
These data have been **aggregated at European level** by using a horizontal aggregation, i.e. averaging for each fabrication step. This horizontal aggregation supports the modular approach which allows an easy combination between the (sub) processes and which gives details on the contribution of the various process steps.
As highlighted above, the data collection, data consolidation procedures **have been validated by experts' judgements** (i.e. European Aluminium Technical Working Group of the Sustainability Committee and / or external consultants).

For each aluminium production step described in the sections below, a specific chapter focusing on "data collection and averaging" is available. For instance, for the primary aluminium production, this information is available in the chapter 4.2. The various datasets have been collected at unit process (e.g. electrolysis for primary production, hot and cold rolling for sheet production) within the system boundaries. When relevant, the data representativeness as European averages (e.g. sea water) have been discussed and the main trends in comparison with the 2010 figures highlighted.

In addition, for the main aluminium production process, the report contains:

- A process description (e.g. see section 7.2 for the extrusion process)
- A mapping of the 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 8-2 for the remelting process)
- Table(s) with the list of elementary flows contributing the most 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).

Moreover, for the primary aluminium production process, specific electricity models have been developed in section 4.4.
Finally, these European averages were then integrated within specific LCI models (with the support of ThinkStep acting as an external consultant) in order to generate the corresponding LCI datasets (i.e. lists of quantified elementary flows, associated with the main aluminium production or transformation processes).

3.2 Allocation

As explained above in section 2.2.3, as much as possible, allocation has been avoided for the foreground data by expanding the system boundaries (see section 2.2.5). Regarding the background datasets used in the modelling phase, the allocation rules used in Gabi 7 database [12] are conserved.

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 should 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 GaBi software version 7 [12] has been used to model and develop the various LCI datasets related to the year 2015. The previous European Aluminium LCI datasets were produced with the GaBi software version 5.

3.5 Main differences between current and approach used in 2010

The same modelling methods (e.g. electricity and transport models) have been applied in comparison with 2010 report for primary production / consumption as well as semi fabrication in Europe.

Regarding the refining (i.e. casting alloys) production, as this section was not fully cover in the previous report, a simple update was not fully possible. Thus, European Aluminium started to collect more accurate information to develop an ad hoc model with the support of its members. Due to the complexity to cover all aspects of the refining process (e.g. variety of scrap types, scrap melting, salt slag and dross processing) an ad hoc report will be developed separately at a later stage as explained in chapter 8.7.

Thus, the main changes compared to the previous modelling approach are reported in Table 3-1 . These changes are mainly linked to the update of the background datasets.

Table 3-1 Differences between current and past modelling

Generic differences	**2010**	**2015**
LCIA Methodology	CML 2001 – Nov 2010	CML 2001 – Jan 2016
Modeling tool	GaBi 5 software	GaBi 7 software
Main data sources for ancillary processes	GaBi & ELCD data (ref years between 2008 and 2010)	GaBi & ELCD data (ref years between 2013 and 2016)
Electricity production (excluding electrolysis step)	EU27 grid mix in GaBi (ref year 2008)	EU28 grid mix in GaBi (ref year 2015)
Specific differences	**2010**	**2015**
Alumina	No specific datasets	Data on mining and rehabilitation
Foil	Hot rolling process which generates the foil stock was not included as part of the scope	Hot rolling process which generates the foil stock is directly included as part of the scope
Electricity model for imports of primary aluminium ingots	Russia datasets were used to model the electricity from natural gas (coming from Middle East) as no other specific datasets were available	S. Arabian datasets were used as a better proxy to model the electricity generation from natural gas in the Middle East.

4. Primary production

4.1 Process steps description

4.1.1 Bauxite mining

The common raw material for aluminium production, bauxite is composed primarily of one or more aluminium hydroxide compounds, plus silica, iron and titanium oxides as the main impurities. About 230 million tonnes of bauxite have been mined in 2015 worldwide. The major locations of deposits are found in a wide belt around the equator. Bauxite is currently being extracted in Australia, Central and South America (Jamaica, Brazil, Surinam, Venezuela and Guyana), Africa (Guinea), Asia (India, China), Russia, Kazakhstan and Europe (Greece). Bauxite is almost exclusively extracted by open-cast mining.

The environmental data related to bauxite mining have been collected and developed by the International Aluminium Institute (IAI) for the year 2015 (see Table 4-2).

4.1.2 Alumina production

Bauxite has to be processed into pure aluminium oxide (alumina) before it can be converted to aluminium by electrolysis. This is achieved through the use of the Bayer chemical process in alumina refineries. The aluminium oxide contained in bauxite is selectively leached from the other substances in an alkaline solution within a digester. Caustic soda and lime are the main reactants in this leaching process which takes place in autoclaves at temperature between 100 and 350°C (depending on alumina reactivity). The solution is then filtered to remove all insoluble particles which constitute the bauxite residue (also called “red mud”). On cooling, the aluminium hydroxide is then precipitated from the soda solution, washed and dried while the soda solution is recycled. The aluminium hydroxide is then calcined, usually in fluidised-bed furnaces, at about 1 100°C. The end-product, aluminium oxide (Al_2O_3), is a fine grained white powder. An overview of the alumina production process is available in Figure 4-1.

About 2.2 tonnes of bauxite is used in Europe per tonne of alumina. The calcination process and, to a lesser extent, the leaching process consumes most of the thermal energy. About 9 GJ of thermal energy is used per tonne of alumina as well as 140 kWh/t of electricity (see Table 4-4 for details).

Solid wastes arising in alumina production are composed of two main streams:

- Tailings, inerts and sand which are separated from the bauxite ore prior the leaching process
- The residue of the leaching process: bauxite residue. Even if constituents are mostly non-toxic and largely insoluble, bauxite residue requests special handling due to the residual alkaline content resulting from the extraction process. Depending on the bauxite residue filtration and rinsing process, the alkalinity of the residual solution may vary significantly. Current practice is usually to deposit bauxite residue on or near the site in specially designed sealed ponds from which excess water is returned to the process. With time, the alkali residues react with carbon dioxide from the air to form sodium carbonate. Bauxite residue disposal sites can be re-cultivated once they have dried out. The use of bauxite residue as filler material for road construction or as additive in cement industry is still marginal, but increasing. For more reference about the bauxite residue management please consult the Bauxite Residue Management document available on the European Aluminium website [6].

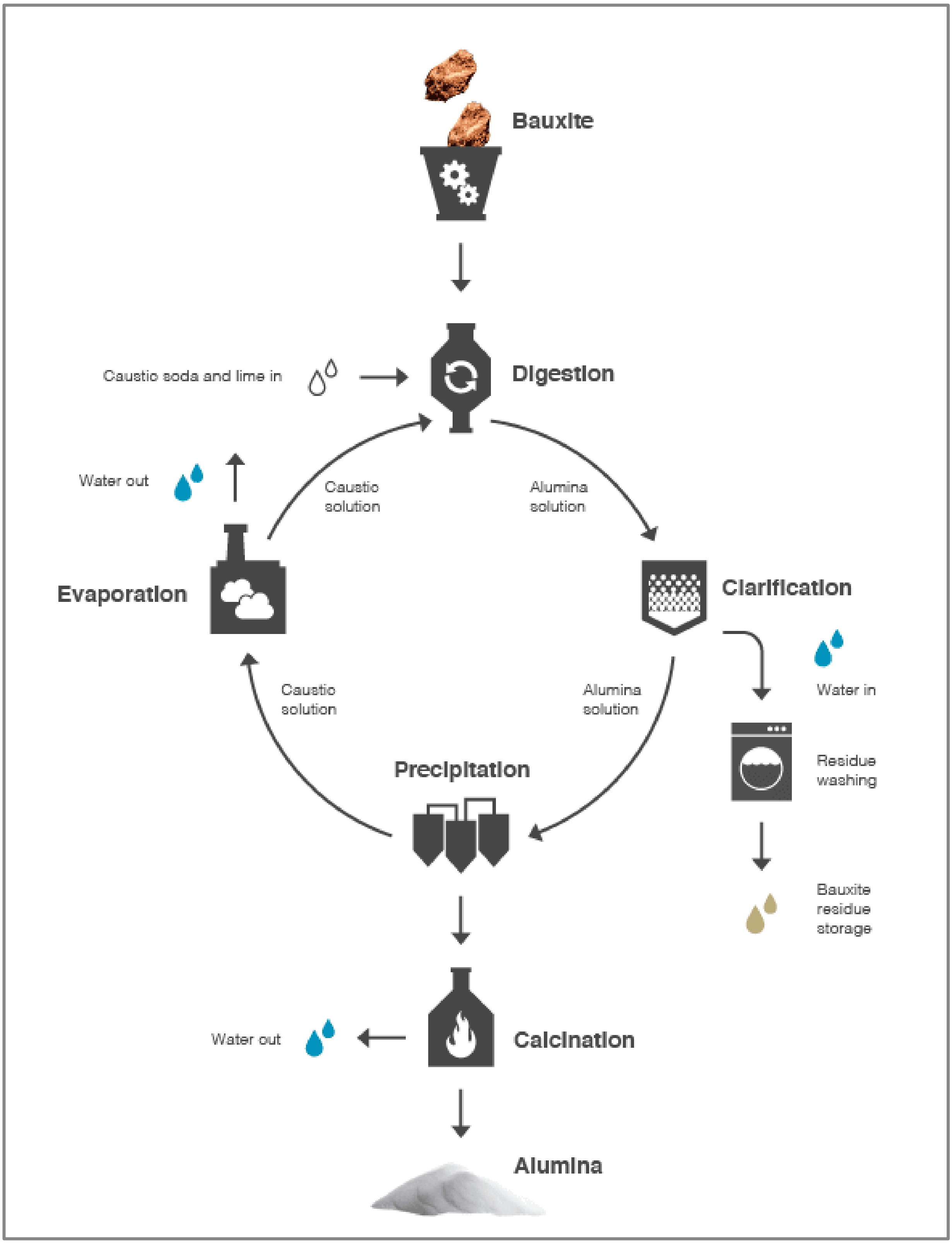

Figure 4-1 *Alumina production process (Source* Hydro Aluminium website*)*

4.1.3 Electrolysis

Primary aluminium is produced in electrolysis plants (frequently called "smelters"), where the pure alumina is reduced into aluminium metal by the Hall-Héroult process. About 2 000 kg of alumina is needed to produce 1 tonne of aluminium. The reduction of alumina into liquid aluminium is operated at around 950 degrees Celsius in a fluorinated bath (i.e. cryolite) under high intensity electrical current. This process takes place in electrolytic cells (or "pots", see Figure 4-2), where carbon cathodes form the bottom of the pot and act as the negative electrode. Carbon anodes (positive electrodes) are held at the top of the pot and are consumed during the process when they react with the oxygen coming from the alumina. There are two major types of cell technology in use. All potlines built in Europe since the early 1970s use the prebake anode technology, where the anodes, manufactured from a mixture of petroleum coke and coal tar pitch (acting as a binder), are ‘pre-baked’ in separate anode plants. In the Söderberg technology, the carbonaceous mixture is fed directly into the top part of the pot, where ‘self-baking’ anodes are produced using the heat released by the electrolytic process. In 2015, 95% of the primary aluminium in Europe was produced using prebake technology.

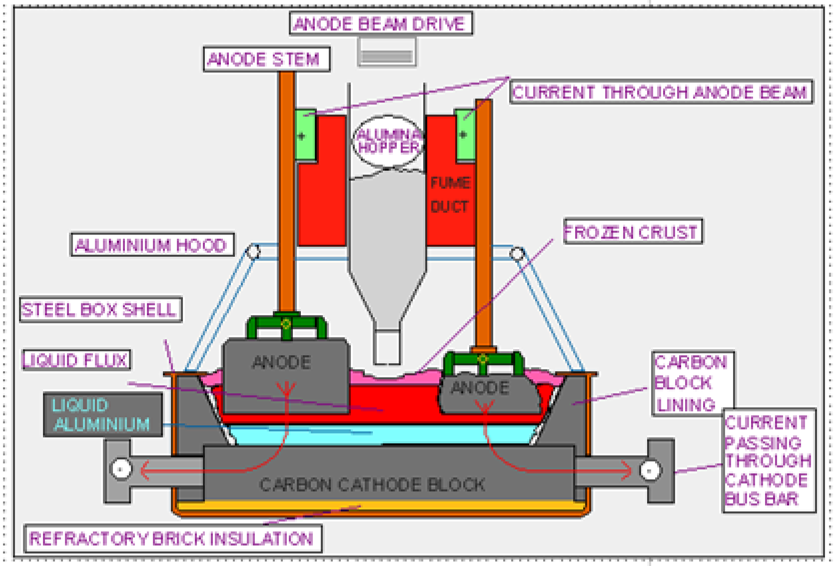

Figure 4-2 *Aluminium electrolytic cell – prebake technology*

The electrical energy required for the primary smelting process constitutes the major part of energy consumption in aluminium primary production and has therefore been very carefully handled. Specific consumption data have been obtained from all smelters in order to calculate a true weighted average. The total consumption consists of the following elements:

- Rectifying loss
- DC power usage
- Pollution control equipment
- Auxiliary power (general plant use)
- Electric transmission losses of 2% have been taken into account from power stations to primary smelters, as all primary smelters have their energy delivered by high voltage lines from power stations located nearby, and operate their own transformer facilities.

In 2015, the average electricity consumption of European smelters is 14 790 kWh/tonne. In 2010, this average electricity consumption was 14 880 kWh/tonne of aluminium produced in Europe. For imported primary aluminium which represents 49% of the use, this average electricity consumption is 15 460 kWh/tonne in 2015. In 2010, this average electricity consumption was 15 500 kWh/tonne of imported aluminium.

Both values of electricity consumption have been increased by 2% in the model for considering the transmission losses between the power plant and the smelters. A specific electricity model is developed under the section 4.4 for the production of the electricity which is used at the electrolysis step.

4.1.4 Cast house

At regular intervals, molten aluminium tapped from the pots is transported to the cast house where it is alloyed (according to the user’s needs) in holding furnaces by the addition of other metals and aluminium scrap cleaned of oxides and gases, and then cast into ingots. Cast houses produce a wide variety of products and alloys. Since it is not possible to produce one dataset for every type of product and alloy, average data have been developed for a generic aluminium ingot covering ingot for rolling (slabs), for extrusion (billets) or for remelting. Rolling slabs and extrusion billets (see Figure 4-3) are produced through Direct Chill (DC) casting technology (liquid metal is poured into short moulds on a platform and then cooled when the platform is lowered into a water-filled pit).

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

Before exiting the cast house, the ends of the rolling slabs and extrusion billets are usually sawed and directly recycled into the holding furnace. In the current model, the product exiting the cast house is a sawn rolling ingot, a sawn extrusion ingot or an ingot for remelting.

Further treatment of rolling and extrusion ingots, such as homogenisation and scalping are covered in the semi-finished product sections (e.g. see sections 5 and 7).

4.2 Data collection and averaging

The yearly input and output data were collected through questionnaires covering the year 2015 and focusing respectively on alumina production, on anode and paste production and on electrolysis and casting. Survey coverage based on the total European production is reported in Table 4-1.

Table 4-1 *European representativity of the primary data*

Process	Total production	Coverage (EU27 + EFTA)
Alumina production	5,9 Mt	87%
Paste and anode production	2,2 Mt	50%
Electrolysis and cast house	4.2 Mt (liquid aluminium)	86%

After aggregation, European averages have been calculated according to the following reference flows:

- Alumina: total tonnage of alumina production
- Paste and anode: total tonnage of paste production plus total tonnage of baked anode production
- Electrolysis: total tonnage of liquid aluminium produced at the electrolysis
- Cast house: total tonnage of sawn ingot production

Details about direct inputs and outputs of each process are given in the next sub-sections.

4.2.1 Bauxite mining

Input and output data have been taken from the worldwide International Aluminium Institute (IAI) survey based on the year 2015. These data, reported in Table 4-2, refer to the extraction and the preparation of 1 tonne of bauxite ready for delivery to the alumina plant.

Table 4-2 *Direct input and output data for the extraction and preparation of 1 tonne of bauxite*

Bauxite production - *relative figure per tonne of bauxite*	**Unit**	**IAI**	
		2010	**2015**
Inputs			
Water used			
Fresh water	m^3/t	0,5	0,5
Sea water	m^3/t	0,7	0,0
Energy			
Coal	MJ/t	0	0
Heavy oil	MJ/t	8	21
Diesel oil	MJ/t	14	78
Natural Gas	MJ/t	0	0
Total thermal energy	MJ/t	23	99
Electricity	kWh/t	0,9	1,5
Output			
Air emissions			
Particulates	kg/t	0,17	0,11
Water discharge			
Fresh water	m^3/t	0,1	0,03
Sea water	m^3/t	0,7	0,0
Solid Waste			
Mine solid waste	kg/t		0,1

In comparison with 2010 report, IAI developed as well additional data related to land occupation and rehabilitation conditions[9]. Full and comprehensive data on rehabilitation of bauxite mines can be accessed on the "bauxite mine rehabilitation survey" report [7] available on IAI website.

Table 4-3 *Land occupation and land rehabilitation in bauxite mining (Source IAI)*

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

The data in Table 4-3 are the first IAI attempt to assess land use and land occupation from aluminium bauxite mining production processes. From the table above, it's estimated that a theoretical value of about 3 km^2 of land occupation related to bauxite production is needed to fulfil the annual production of primary aluminium in Europe[10].

In the future, these data should be further developed by the aluminium industry.

4.2.2 Alumina production

Direct input and output data related to the production of 1 tonne of alumina are reported in Table 4-4. Average European figures of the year 2015 can be compared with figures of 2010 as well with worldwide figures (survey organised by IAI) for the year 2015.

About 2 160 kg of bauxite is used in Europe for producing 1.000 kg of alumina. Bauxite consumption decreased in comparison with 2010 figure. Average bauxite consumption at worldwide level is significantly higher, i.e. 2.850 kg due to the use of lower grade concentrate. European producers uses 48 kg of caustic soda (as 100%) and 30 kg of calcined lime as reactive chemicals. That's represent a significant decrease in comparison with 2010, which reflect an improvement of the process efficiency.

In comparison with 2010 data, European alumina production substituted the heavy oil by natural gas. This significant trend have major impact on the energy consumption and also the air emissions (e.g. SO_2, NO_X, particulates). The thermal energy consumption decreased by 13% (i.e. 8 980 MJ/t) and the SO_2, particulates emissions decreased by more than 90% and the NOx by 74% in comparison with 2010.

In 2010, heavy oil was representing about 56% of the thermal energy used in the alumina refineries in Europe while in 2015, they used almost 100% natural gas. However, at global level, there is a strong increase of the coal consumption as China datasets have been included by IAI. In addition, the total thermal energy used in Europe (i.e. 8 980 MJ/t) is lower than the worldwide average (i.e. 12 300 MJ/t).

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[9] The top soil removed during mining operations in order to access bauxite ore is stored and re-used later during mining rehabilitation operations.

[10] i.e. land occupation factor * primary European production * conversion factor bauxite / primary aluminium = 1.65E-7* 4 000 000 * 5 = 3.3 km^2

Table 4-4 *Direct input and output data for the production of 1 tonne of alumina (Al_2O_3)*

Alumina production - *Relative figures per tonne of alumina (Al_2O_3)*	**Unit**	**European Aluminium**		**IAI**	
		2010	**2015**	**2010**	**2015**
Inputs					
Raw materials					
Bauxite	kg/t	2 251	2 156	2 881	2 847
NaOH (as 100%)	kg/t	53	48	79	73
CaO	kg/t	42	30	40	32
Fresh water used	m^3/t	3,6	3,6	2,6	2,0
Sea water used	m^3/t	0	0,0	0,6	0,2
Energy					
Coal	MJ/t	0	0	1 850	8 564
Heavy oil	MJ/t	5 822	32	3 818	1 065
Diesel oil	MJ/t	1	3	4	46
Natural Gas	MJ/t	4 299	8 942	5 282	2 637
Steam	MJ/t	249			
Total thermal energy	MJ/t	10 371	8 976	10 954	12 312
Electricity	kWh/t	181	141	79	218
Output					
Air emissions					
Particulates	kg/t	0,14	0,01	0,56	0,47
SO_2	kg/t	2,68	0,25	2,40	1,14
NOx	kg/t	1,11	0,29	0,68	0,61
Hg	g/t	0,06		0,24	0,12
Water discharge					
Fresh water	m^3/t	3,1	3,6	1,4	2,0
Sea water	m^3/t	0	0,0	0,6	0,2
Suspended solids	kg/t	0,23	0,16	0,02	4,1E-02
Oil	kg/t	0,10	0	0,77	1,7
Hg	g/t	*1,26E-04*		7,00E-05	4,7E-04
By-products					
Bauxite residue	kg/t	3,8	10,9	2,3	29,5
Other	kg/t			5,6	
Solid Waste					
Bauxite residue	kg/t	671	791	1 354	1 231
Any other solid industrial waste	kg/t	48	48	18	19
Of which any other landfill wastes	kg/t	6,9	37,4	8,5	
Of which any hazardous waste according to local legislation	kg/t	0,2	2,7	9,3	7,7

The aluminium industry has specific guidelines on bauxite residue deposit and rehabilitation. These guidelines are reported in a bauxite residue management document which can be downloaded from the European Aluminium website [6].

In comparison with 2010 report, the aluminium industry developed additional data on the land use occupation and regeneration. These data have been developed by IAI for Europe.

Table 4-5 *Land use and rehabilitation in alumina plants (Source IAI)*

Focus on land use	Unit	Europe
Land occupation	km2/t product	6,54E-07
Land use type before	land use type	Pastureland
Land use type after	land use type	Treated and vegetated

The data in Table 4-5 are the first IAI attempt to assess land use and land occupation from alumina production processes. From the table above, it's estimated that a theoretical value of 5 km^2 of land occupation related to bauxite residue management is needed to fulfil the annual production of primary aluminium in Europe[11].

In the future, these data should be further developed by the aluminium industry.

4.2.3 Anode & paste production

Direct input and output data related to the production of 1 tonne of mixed paste (5%) and anode (95%) are reported in Table 4-6. Average European figures of the year 2015 can be compared with 2010 data as well with worldwide figures (survey organised by IAI) for 2015.

Table 4-6 *Direct input and output data for the production of 1 tonne of anode / paste*

Anode/paste production - ***Relative figures per tonne of a mixed anode and paste***	**Unit**	**European Aluminium**		**IAI**	
		2010	**2015**	**2010**	**2015**
		For 1000 kg of mixed anode (95%) and paste (5%)	For 1000 kg of mixed anode (95%) and paste (5%)	For 1000 kg of mixed anode (89%) and paste (11%)	For 1000 kg of mixed anode (95%) and paste (5%)
Inputs					
Materials					
Calcined Coke	kg/t	717	692	681	676
Pitch	kg/t	152	160	171	155
Butts Used	kg/t	204	164		
Green anodes imported	kg/t	3	1		
Total raw carbon	**kg/t**	**1 076**	**1 017**	**NA**	**NA**
Energy					
Coal	MJ/t	0	0	0	0
Heavy oil	MJ/t	430	609	1 112	681
Diesel oil	MJ/t	16	0	207	5,9
Natural gas	MJ/t	2 225	1 791	1 520	1 747
Other	MJ/t	90			
Total thermal energy	***MJ/t***	***2 760***	***2 400***	***2 839***	***2 434***
Electricity	kWh/t	108	89	108	110
Total energy	***MJ/t***	***3 147***	***2 721***	***3 228***	***2 828***
Other inputs					

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[11] i.e. land occupation factor * primary European production * conversion factor alumina / primary aluminium = 6.54E-7* 4 000 000 * 2 = 5.2 km^2

Anode/paste production - *Relative figures per tonne of a mixed anode and paste*	**Unit**	**European Aluminium**		**IAI**	
		2010	**2015**	**2010**	**2015**
		For 1000 kg of mixed anode (95%) and paste (5%)	For 1000 kg of mixed anode (95%) and paste (5%)	For 1000 kg of mixed anode (89%) and paste (11%)	For 1000 kg of mixed anode (95%) and paste (5%)
Fresh water used	m3/t	5,6	3,9	1,3	2,1
Sea water used	m3/t	12,7	9,7		1,6*
Output					
Air emissions					
Particulates	kg/t	0,25	0,21	0,2	0,19
- Below 2,5 µm	kg/t	-	0,02		0,08*
SO_2	kg/t	0,77	0,92	3,40	4,07
NOx	kg/t	0,45	0,35	0,62	0,47
Part. Fluor	kg/t	2,31E-03	2,24E-03	2,10E-03	7,10E-03*
Gaseous Fluor	kg/t	0,01	0,03	0,01	0,02*
PAH	kg/t	0,06	0,12	0,05	0,05
B(a)P	g/t	0,06	3,73E-03	0,21	0,05
Water discharge					
Fresh water	m3/t	2,2	3,7	1,4	1,8
Sea water	m3/t	14,4	9,7		1,6*
Suspended solids	kg/t	0,14	0,12	0,03	0,09
Fluorides (as F)	kg/t	3,96E-03	3,53E-03		1,20E-02
PAH (6 Borneff components)	g/t	0,96	0,59	0,03	1,06E-02
Oil and grease/total hydrocarbons	kg/t	7,56E-05	2,31E-05		2,03E-02
By-products or solid waste					
Carbon waste output	kg/t	9,6	11,8	16,5	11,7
Steel to be externally recycled	kg/t	1,8	1,3	7,3	4,3*
Refractory material for external recycling	kg/t	8,7	4,6	4,5	8,0*
Refractory material that is not recycled	kg/t	3,0	8,9	4,3	4,8*
Scrubber sludges output	kg/t	0,6	0,2	0,3	0,1
Other externally recycled by product	kg/t	3,2	3,9	9,4	5,3
Other landfill waste	kg/t	4,1	7,3	3,9	4,1
Of which hazardous waste according to local legislation	kg/t	1,4	7,0	2,9	2,4

*data only for anode production as no value is available for paste production

In 2015 compared to 2010, the total raw carbon material decreased by about 5%. These decrease is mainly related to a decrease of the consumption of calcinated coke (i.e. 692 kg/t) and the butts used (i.e. 164 kg/t). Fuel and electricity consumption in Europe (and worldwide) decreasing significantly compared to 2010 averages.

There is a reduction in most of the air emissions in Europe, in particular NOx, which are each reduced respectively by 22% compared to 2010. The same trend is observed as well for the particulates and B(a)P. These improvements could be explained by a decrease of the energy consumption.

However, Gaseous Fluoride emissions increased slightly and are nevertheless still remaining above the world (IAI) average, probably due to anode exhaust fume treatment technology. In addition, it's seems to have an increase of SO_2 emissions. This increase is consistent with the slight increase of heavy oil consumption in comparison with 2010.

4.2.4 Electrolysis (smelter)

Direct input and output data related to the production of 1 tonne of liquid aluminium at the electrolysis step are reported in Table 4-7. Average European figures of the year 2015 can be compared with figures of 2010 as well with worldwide figures (survey organised by IAI) for the year 2015.

Comments on input trends

Alumina consumption decreased slightly to 1 908 kg/t. Gross (503 kg/t) and net (413 kg/t) carbon anode & paste consumption decreased slightly as well in comparison with 2010. These trends which are valid for Europe are also observed at global level (IAI data). Aluminium fluoride consumption (16.4 kg/t) is comparable to world average.

European electricity consumption in 2015 reached 14 790 kWh/t. Average electricity consumption at global level is lower according to IAI data. This lower world average is explained by a very low electricity consumption reported in China (i.e. 13 562 kWh/t) according to IAI data. In the other regions of the world, the average electricity consumption is very similar or higher (e.g. South America) than in Europe.

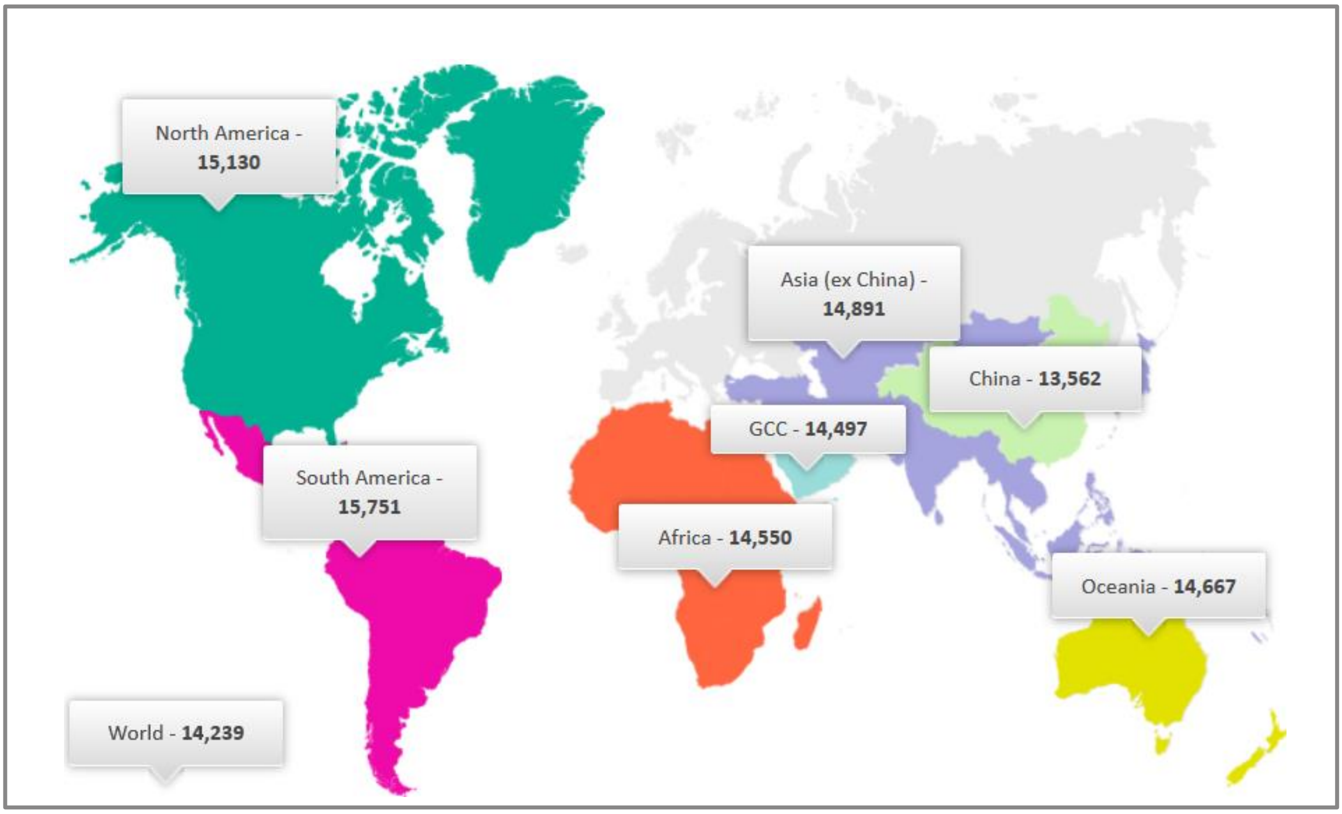

Figure 4-4 *Electricity consumption in the electrolysis process in other regions (IAI data)*

Fresh water is mainly used for cooling but also, in some cases, for wet scrubbing. Fresh water use highly depends on the location of the smelters since big discrepancies appear between water stressed areas, unstressed areas and coastal regions. The data presented in Table 4-7 are purely an arithmetical average for Europe without considering the water stress index of the plant location. Hence, such average has limited significance and the fresh water use should be better considered at local level.

Seawater use is involved for wet scrubbing, i.e. for smelter air cleaning systems. This process is relevant to a limited number of plants located at the coast, but significant quantities are reported, since the principle is based on absorbing smelter air emissions into seawater in harmless concentrations. The data presented in Table 4-7 correspond to an arithmetical average on all reporting plants. Hence, sea water use has limited significance and should be better considered at local level.

Table 4-7 *Direct inputs and outputs for the production of 1 tonne of liquid aluminium at the electrolysis step (smelter)*

Production of liquid aluminium at the electrolysis (smelter) step - *Relative figures per tonne of liquid primary aluminium*	**Unit**	**European Aluminium**		**IAI**	
		2010	**2015**	**2010**	**2015**
		1000 kg of production mix* : 95% PB and 5% SB	1000 kg of production mix* : 95% PB and 5% SB	1000 kg of production mix*: 89% PB and 11% SB	1000 kg of production mix* : 95% PB and 5% SB
Input					
Raw materials					
Alumina	kg/t	1 920	1 908	1 935	1 928
Anode PB gross	kg/t	517	503	477	
Anode PB net	kg/t	415	413	429	463
Paste VS	kg/t	25	22		
Anode/paste (gross)	**kg/t**	**542**	**525**	**477**	
Anode/paste (net)	**kg/t**	**440**	**435**	**429**	**463**
Aluminium Fluoride	kg/t	15,8	16,4	15,9	16,7
Cathode Carbon	kg/t	6,9	5,5	6,0	6,0
Other raw material					
Fresh water used	m3/t	16,9	12,7	8,1	5,7
Sea water used	m3/t	48,5	31,3	6,5	39,5
Refractory materials	kg/t	8,0	6,7	7,4	7,8
Steel (for cathodes)	kg/t	3,8	5,3	3,9	5,4
Energy					
Electricity	MWh/t	14,88	14,79	15,27	14,21
Output					
Air emissions					
Particulates	kg/t	0,84	0,76	2,30	1,37
- Below 2,5 µm	kg/t	-	0,71**	-	0,95**
SO_2	kg/t	7,40	7,69	15,10	12,94
NOx (as NO_2)	kg/t	0,44	0,42	0,26	0,26
Fluoride Particulate (as F)	kg/t	0,18	0,15	0,53	0,23
Fluoride Gaseous (as F)	kg/t	0,34	0,30	0,54	0,39
Total PAH	kg/t	1,28E-02	7,78E-03	5,60E-02	1,81E-02
BaP (Benzo-a-Pyrene)	g/t	0,26	0,16	1,10	0,23
CF_4	kg/t	3,5E-02	1,79E-02	7,1E-02	7,41E-02
C_2F_6	kg/t	4,2E-03	2,05E-03	8,8E-03	4,25E-03
Total PFC	**kg/t**	**4,0E-02**	**2,0E-02**	**8,0E-02**	**7,8E-02**
Water emissions					

Production of liquid aluminium at the electrolysis (smelter) step - *Relative figures per tonne of liquid primary aluminium*	**Unit**	**European Aluminium**		**IAI**	
		2010	**2015**	**2010**	**2015**
		1000 kg of production mix* : 95% PB and 5% SB	1000 kg of production mix* : 95% PB and 5% SB	1000 kg of production mix*: 89% PB and 11% SB	1000 kg of production mix* : 95% PB and 5% SB
Fresh Water	m3/t	15,5	15,3	7,5	10,8
Sea Water	m3/t	48,5	31,3	6,1	39,5
Fluoride (as F)	kg/t	0,35	0,21	0,05	0,14
Oil/Grease	kg/t	7,3E-03	5,1E-03	4,3E-03	2,5E-03**
PAH (6 Borneff components)	g/t	2,7E-01	6,1E-02	3,2E-01	3,7E-01
Suspended Solids	kg/t	1,60	0,17	0,50	0,27
By-products or solid waste					
Waste alumina output	kg/t	3,0	1,4	4,2	4,2
Waste carbon or mix output	kg/t	9,1	12,8	5,6	9,1
Steel output	kg/t	4,5	6,7	6,8	6,2
Scrubber sludges output	kg/t	0,9	0,5	6,2	3,7
Refractory material for external recycling (excluding spent pot lining, SPL)	kg/t	1,3	0,1	5,1	5,5
Refractory material that is not recycled (excluding spent pot lining, SPL)	kg/t	2,3	0,2	1,3	0,3
Spent Pot Lining (SPL)					
Total SPL output from normal operations	**kg/t**	**19,9**	***22,3***	***17,2***	***24,3***
SPL for external recycling	kg/t	8,8	10,0	10,1	16,6
SPL deposited	kg/t	10,3	12,3	7,1	7,7
SPL stored from normal operation	kg/t	0,7	0,0	0,0	0,0

PB: Prebake, SB: Soderberg; * data only for PB production as no value is available for SB production

Comments on output trends:

Air emissions: A significant reduction is recorded for PFC emissions (CF_4 down by 50% and C_2F_6 by 52% compared to 2010). This brings the total PFC emissions down 97% compared to 1990 (80% lower than in 2005, and about 4 time lower than the 2015 world average PFC emissions).

SO_2 emissions are 7.7 kg/t and NO_X emissions are 0.42 kg/t. Both data are in the same order of magnitude in comparison with 2010 data with a slight increase for SO_2 and a slight decrease for the NOx emissions.

Water emissions: Fluoride emissions are 40% down compared to 2010. 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 sea water.

Spent Pot Lining (SPL): The volume of SPL generated in 2015 is in the same order of magnitude with the 2010. Over the year, the SPL production is quite fluctuating. In 2015, about half of the SPL generated is recycled. The rest is stored or landfilled.

4.2.5 Cast house

Direct input and output data related to the production of 1 tonne of sawn ingot at the cast house are reported in Table 4-8. Average European figures of the year 2015 can be compared with figures of 2010 as well with worldwide figures (survey organised by IAI) for the year 2015.

Comments on input trends:

Aluminium input of the cast house is not only composed of liquid aluminium coming from the electrolysis but consists also in 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 2015, the metal input mix is composed of liquid metal (89%), remelt ingot (7%), scrap (2%) and alloy additives (2%).

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

The use of fuels at European level is higher than the global consumption, due to a higher input of solid aluminium, i.e. scrap and remelt ingot. Europe uses more electricity but the consumption stays small compared to the use at the electrolysis step. The natural gas use increase compared to 2010 is due to the increased fraction of remelt ingot used by the primary cast house.

Table 4-8 *Direct inputs and outputs for the production of 1 tonne of sawn aluminium ingot at the cast house.*

Aluminium ingot production - *Relative figures per tonne of casted aluminium*	**Unit**	**European Aluminium**		**IAI**	
		2010	**2015**	**2010**	**2015**
		1 000 kg of casted aluminium	1 000 kg of casted aluminium	1 000 kg of casted aluminium	1 000 kg of casted aluminium
Input					
Metal					
Liquid aluminium (from electrolysis)	kg/t	751	912	971	1 000
Remelt ingot	kg/t	142	69	50	
Al Scraps	kg/t	102	23	23	
Alloy additives	kg/t	24	23	19	
Total metal input (cast house)	**kg/t**	**1 019**	**1 026**	**1 063**	
Other raw material inputs					
Fresh Water	m^3/t	8,3	5,0	3,5	2,2
Sea Water	m^3/t	0,0	0,0		
Chlorine	kg/t	0,05	0,05	0,04	0,01
Argon	kg/t	2,1	5,6		
Nitrogen	kg/t	0,22	0,02		
Energy					
Coal	MJ/t	0	0	24	0
Heavy oil	MJ/t	186	99	113	51
Diesel oil	MJ/t	46	1	32	21
Natural gas	MJ/t	1 349	1 504	761	832
Other source	MJ/t	4	0	0	0
Total thermal energy	**MJ/t**	**1 585**	**1 604**	**930**	**905**
Electricity	kWh/t	98	95	68	53
Total energy consumption	**MJ/t**	**1 936**	**1 945**	**1 175**	**1 095**
Output					
Air emissions					
Particulates	kg/t	0,04	0,04	0,04	0,04
SO_2	kg/t	0,15	0,19	0,12	0,03
NOx (as NO_2)	kg/t	0,21	0,11	0,08	0,08
HCl (Hydrogen Chloride)	kg/t	0,02	0,02	0,03	0,02
Water emissions					

Aluminium ingot production - *Relative figures per tonne of casted aluminium*	**Unit**	**European Aluminium**		**IAI**	
		2010	**2015**	**2010**	**2015**
		1 000 kg of casted aluminium	1 000 kg of casted aluminium	1 000 kg of casted aluminium	1 000 kg of casted aluminium
Fresh Water	m^3/t	8,7	6,5	3,3	1,9
Sea Water	m^3/T	0,0	0,0		0,0
Oil/Grease	kg/t	0,00	0,07	0,04	0,03
Suspended Solids	kg/t	0,34	0,53	0,15	0,27
By-products for external recycling					
Dross	kg/t	17,8	17,2	17,0	13,3
Filter dust	kg/t	0,9	0,4	1,6	0,5
Refractory material	kg/t	0,7	1,0	0,8	0,3
Scrap sold	kg/t	2,9		4,7	
Solid waste					
Dross - landfill	kg/t	0,0	0,0	5,6	0,7
Filter dust - landfill	kg/t	0,5	0,0	0,5	0,0
Other landfill wastes	kg/t	1,1	3,0	0,6	1,0
Of which hazardous waste	kg/t		2,7		0,9
Refractory waste - landfill	kg/t	0,6	0,6	0,5	0,5
Total solid waste	***kg/t***	***2,3***	***3,6***	***7,1***	***2,3***

Comments on outputs:

European averages of air emissions at 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.

Most significant by-product is the dross (mix of aluminium oxide and entrapped aluminium metal). After mechanical hot pressing for extracting 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 are part of the system boundaries as explained in the next section.

4.3 Material flow modelling

Average European data of the year 2015, reported in Table 4-2 to Table 4-8 are used to model the primary production route by combining such processes along the production chain (i.e. from bauxite mining up to sawn primary ingot). Such process combination requires some simplifications and some hypotheses regarding the material flow modelling, which are reported below:

Cast house modelling:

- **Aluminium input**: In practice, aluminium input of the cast house is usually composed not only of liquid aluminium from the smelter but also of solid materials like alloying elements, aluminium scrap and/or ingot for remelting. Solid material represents more than 10% of the input. In the material flow model, only liquid aluminium from the smelter will be considered so that the solid metal input is substituted by liquid primary aluminium.
- **Dross recycling**: the model includes the dross recycling within the system while it is not the case for the Table 4-8. It is assumed that aluminium recovered from dross recycling is returned as input to the cast house.
- **Metal losses at the cast house**: the model considers the metal losses due to the oxidation of the aluminium melt and the aluminium metal which is not recovered from the dross. The model calculates the metal losses to 1 kg/tonne (i.e. 0.1% of metal losses).

Based on above assumption, 1.001 kg of liquid aluminium from the electrolysis are then needed to produce 1 tonne of sawn extrusion or rolling ingot.

Anode and paste production modelling

While carbon paste is entirely consumed during the electrolysis process using the Söderberg technology, carbon anode used in smelters using pre-bake technology is not entirely consumed. When about 80% of the anode is consumed, the so-called anode butt is then removed from the cell (and replaced by a new one). This anode butt is then returned to the anode production facility where it is crushed and recycled into the anode production process. In the modelling process, slight adaptations of the raw material input were needed in order to make it consistent with the recycled input from anode butt which are coming back from the electrolysis process.

Materials flow modelling, European production

Considering above modelling assumptions, the average consumptions of main raw materials for **producing 1 tonne of primary ingot in Europe** have been calculated and are reported in Figure 4-5 and Table 4-9.

Table 4-9 *Main raw materials for the production of 1 tonne of primary ingot, Europe*

Main raw material	Process step	2015	2010
Bauxite (input alumina)	Alumina	4 119	4 326
Caustic Soda (100%)	Alumina	91	102
Lime	Alumina	58	81
Alumina	Electrolysis	1 910	1 922
Anode/paste (net)	Electrolysis	413	440
Liquid aluminium	Casting	1 001	1 001

For the primary aluminium production in Europe, 1 910 tonnes of alumina and 413 kg anodes are needed to produce 1 tonne of cast primary aluminium. 4 119 kg of bauxite are used according to the new model vs. 4 326 kg according to the 2010 model.

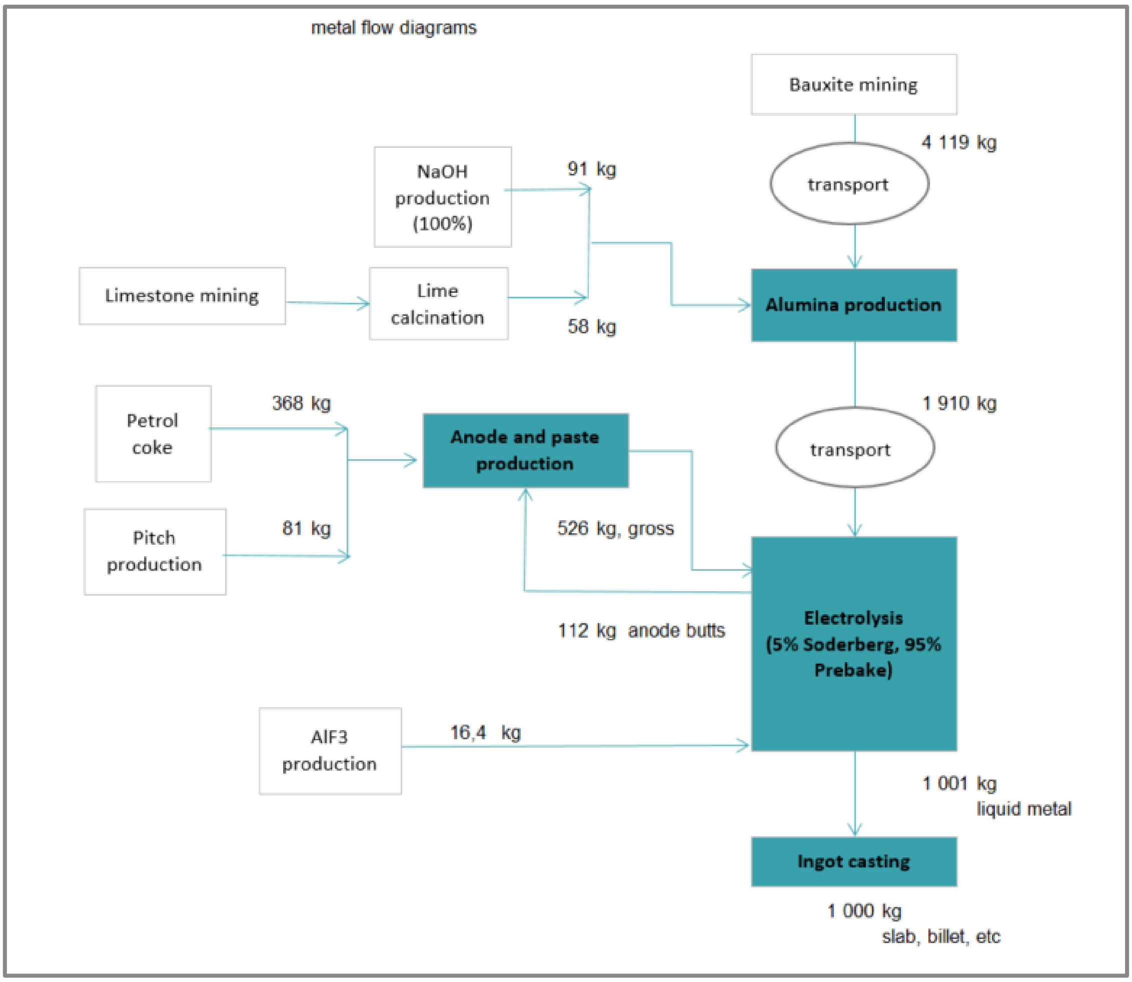

Figure 4-5 *Main raw material inputs for primary aluminium production in Europe*

4.4 European Aluminium electricity models for aluminium electrolysis (smelters)

Since most of the energy used for producing primary aluminium is electricity at the electrolysis step, it is crucial to model precisely this electricity production. As currently 49% of the primary aluminium used in Europe is imported, it is also necessary to take into account specific data relative to the electricity which is used for the production of primary aluminium imported into Europe. The 3 next sub-sections explain how European production and imported primary aluminium are considered.

The following models have been developed:

- Electricity used by European smelters using the pre-bake technology
- Electricity used by European smelters using Soderberg technology
- Electricity used by smelters exporting to Europe

As it has been done in the previous model, the electricity consumption data reported under Table 4-8 have been increased by 2% into the model in order to consider the losses related to the electricity transport.

4.4.1 Overview of European smelters localisation

The map below gives an overview of the localisation of the 26 European (EU28+EFTA) smelters in 2015. Since 2010 report, 4 plants have closed in Europe. Thus, this change in our industry affects as well the average datasets (e.g. electricity mix) of European smelters in comparison with the previous report.

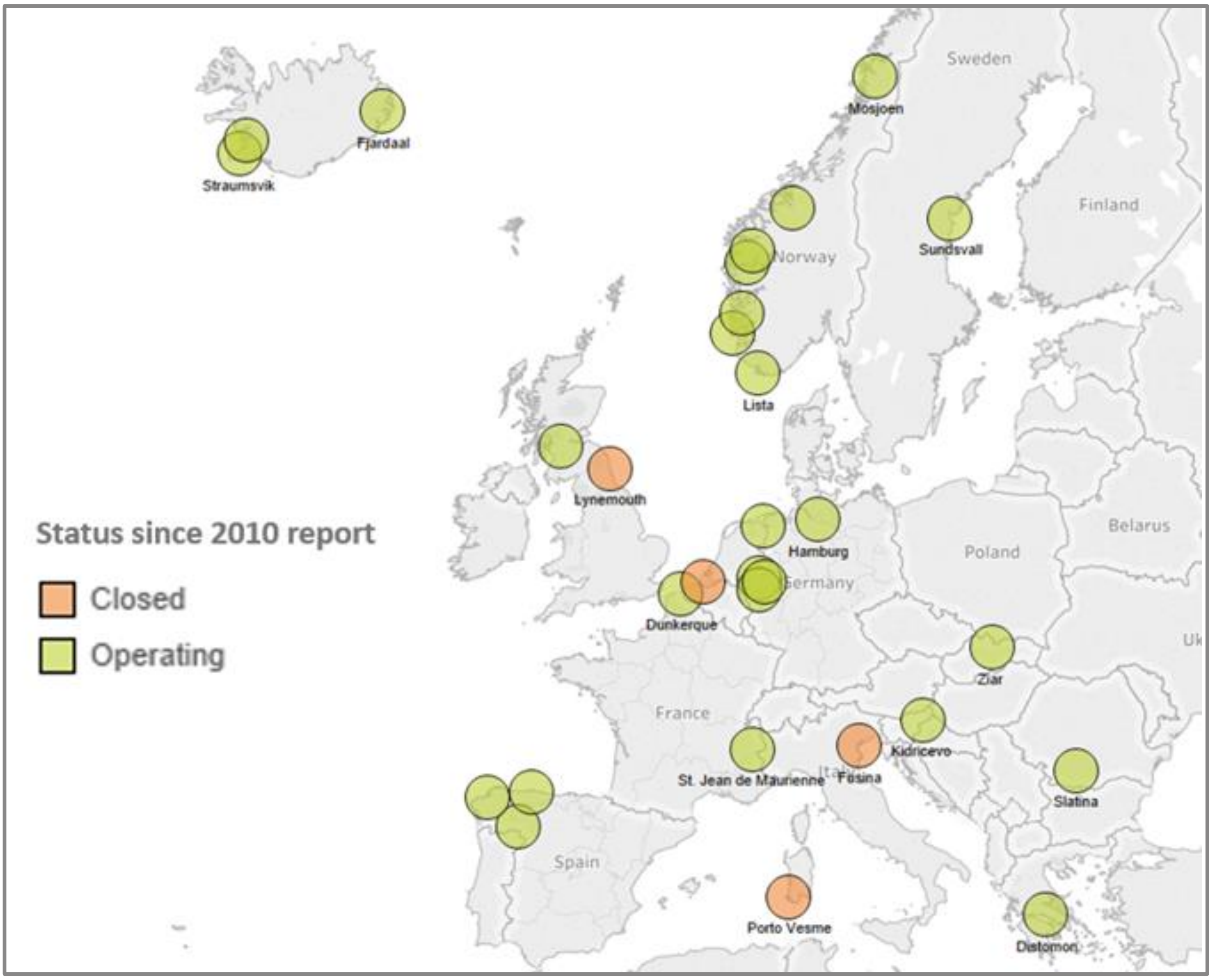

Figure 4-6 *European map of smelters – 2015 vs 2010*

In 2015, EFTA countries (i.e. Iceland and Norway) represented about 50% of the European production while they were representing about 40% of the production 5 years ago.

4.4.2 Electricity used by European primary aluminium smelters – pre-bake technology

The electricity model uses the electricity consumption reported by the various European smelters using the pre-bake technology. This consumption is distributed among various energy sources as stipulated in their electricity contract. The model is developed in several steps which are described below:

1) Consolidation at European level for each energy source.

The electricity consumption reported by the smelters is aggregated by energy sources at European level. This consolidation gives, for the year 2015, a table listing the electricity consumption in TWh or GWh for each energy source. In limited cases *(about 10% of the primary production)*, the national grid mix of the country (based on International Energy Agency data) where the plant is located was used when no direct data were available. In most cases, the national grid mix is expected to have a higher carbon intensity than the direct energy sources of the smelter[12]. Hence, This choice can be considered as a conservative approach.

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[12] Direct data collected from the members which cover about 90% of the production indicated an electricity grid mix composed of 71% hydro energy, 12% nuclear, 10% coal and 6% natural gas.

2) Calculating contribution of the various countries for each energy source

The relative share of each country is then calculated, for each energy source. This scaling allows identifying the main contributors for each electricity source.

3) Modelling the electricity production for each energy source

For each energy source, e.g. hydropower or coal, a simplified model for the production of electricity is calculated based on the main contributing countries. This model uses the various LCI datasets for electricity production, available in the GaBi software, which are country-specific and specific to the energy source. As reported in Table 4-10, the production of 1 kWh of hard coal is based on LCI data from Germany, Spain and Greece.

4) Building the European model

Each of these LCI datasets has been weighted according to their respective contribution in the European electricity model. As example, the LCI dataset for electricity from hydropower contributes to 67% to the total. The combination of these LCI datasets result in LCI datasets related to the production of 1kWh of electricity used in Europe for the production of primary aluminium by pre-bake smelters.

Table 4-10 reports the European consolidation of the energy sources for the electricity production which is used by the European smelters using pre-baked technology as well as the countries used to build the European model.

Table 4-10 *European electricity Model – Year 2015*

Consolidation at European level		***Calculating contribution of the various countries***	**Modelling of the electricity production**
Energy source	Share (in %)	*Main contributing countries (% of country in energy source)*	*LCI data used in the electricity model*
Hydro (or geothermal)	67%	EFTA (Norway and Iceland) countries (77%)	Norway
Nuclear	17%	France (45%); Germany (13%); Spain (12%)	France, Germany, Spain
Coal	9%	Germany (64%), Spain (21%); Greece (11%)	Germany, Spain, Greece
Natural gas	7%	Spain (24%), Germany (21%); Greece (16%)	Spain, Germany, Greece
Oil	0%	-	-
Total	**100%**	**-**	**-**

<u>Highlights:</u>

In comparison with 2010 data, the energy mix of the primary aluminium in Europe is having much more hydro and geothermal electricity (67% in 2015 vs 54% in 2010) and less coal (9% in 2015 vs 17% in 2010). This result is explained by the increase of the production in EFTA countries (Norway and Iceland) and some plants closures in EU28 (see Figure 4-6).
The corresponding indicators based on the model presented above are reported in Table 4-11. The comparison with 2010 data is also presented.

Table 4-11 *Environmental indicators for the production of 1 kWh electricity used by aluminium smelters in Europe*

Environmental indicators[13] per kWh electricity, European model	2015	2010	2015 vs 2010 (in %)
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	9,3E-08	1,1E-07	-13%
Acidification Potential (AP) [kg SO_2-Equiv.]	2,1E-04	5,4E-04	-61%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	2,5E-05	5,1E-05	-51%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	1,3E-01	2,4E-01	-45%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	1,1E-12	2,9E-08	-100%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	1,6E-05	3,9E-05	-59%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	6,0E+00	6,7E+00	-11%
Primary energy from renewable resources (net cal. value) [MJ]	2,9E+00	2,3E+00	+24%
Primary energy from non-renewable resources (net cal. value) [MJ]	3,2E+00	4,4E+00	-29%

4.4.3 Electricity used by European primary aluminium smelters – Soderberg technology

A similar model has been developed for the European smelters using the Soderberg technology. Considering the limited number and contribution of these smelters, this electricity model is not reproduced in this report.

4.4.4 Electricity used for the production of imported aluminium

In 2010, 44% of the primary aluminium used in Europe came from imports. In 2015, **imports of metal into Europe represent 49% of European consumption** (Source: customs statistics - Eurostat).
In 2015, Europe net imports of aluminium was equal to 3.8 Mtonnes. Most of these imports come from Russia (39%), United Arab Emirates (17%) and Mozambique (14%).
The details of the main importing countries is given in the table below. As an example, the "Rest of Europe" area represents 43% of European net imports. Russia represents 90% of the imports from "Rest of Europe".

Table 4-12 *Geographical distribution of the primary aluminium main imports into Europe – 2010 (source Eurostat for EU27 and national customs data for EFTA countries)*

Regions	Imports share[14] (%)	2015 Main countries and percentage share of the region (in %)
Rest of Europe	43%	Russia (90%); Bosnia (5%) and Turkey (2%)
Africa	23%	Mozambique (62%); S. Africa (15%); Egypt (10%) and Cameroon (7%)
Middle East & Central Asia	21%	United Arab Emirates (79%); Bahrain (9%) and Tajikistan (3%)
North America	6%	Canada (93%) and USA (7%)
Central & South America	3%	Brazil (82%)
Asia	3%	India (48%); Malaysia (21%); China (14%)

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[13] A brief presentation of the environmental impact categories is given in Table 2-2.

[14] From the official trade data, some imports data were allocated to no "countries / regions" for various reasons (e.g. confidentiality issues). These volumes represented 3% of the imports and have been re-allocated to the various regions according to their "statistical weight.

Regions	Imports share[14] (%)	2015 Main countries and percentage share of the region (in %)
Oceania	1%	New Zeeland (91%)
Total	**100%**	-

Highlights:

In comparison with 2010 data, the main increase of imports are coming from "Rest of Europe" (43% vs 39% in 2010), Middle East and Central Asia (21% vs 11% in 2010). The main decrease are coming from Africa (23% vs 28% in 2010), N. America (6% vs 11% in 2010) and Central and South America (3% vs 9% in 2012).
Table 4-12 is used to model the electricity production for the primary aluminium imported into Europe. The various steps and hypotheses of this modelling methodology are the following:

- Only countries listed in Table 4-12 have been considered for the model. These countries represent more than 90% of the aluminium imported into Europe.
- Use of the IAI regional smelters electricity grid mixes for the countries listed in Table 4-12 based on data provided by the aluminium producers. For Africa and North America, IAI regional data have been adjusted to better reflect the exports of the producing countries to Europe.
  As a matter of fact, about 93% of the primary aluminium imported in Europe from North America (e.g. Canada) is based on hydropower production while the IAI regional mix is based on 74% hydropower. The same method has been applied for Africa as Mozambique (100% hydropower) is the main African country exporting to Europe. Otherwise, data from the International Energy Agency have been used to determine the national grids for electricity production [13].
- Weighting and consolidation of the country grid mixes have been done at regional and global levels. Consolidated figures are reported in Table 4-13.
- For each of these regions, modelling of the electricity production is based on a simplified electricity grid mix using power plant data which are representative for major sources of imports, e.g. electricity from hydropower and nuclear sources for Russia, natural gas for S. Arabia and hard coal for South Africa.
- Consolidation of the electricity production data at global level. The consolidation of the energy sources for the electricity production which is used by imported aluminium is reported in Table 4-13.

Table 4-13 *Energy sources for the electricity used for the production of imported primary aluminium*

		Energy mix of the importing regions into Europe					
Regions (2015 data)	**Share of European imported volumes (%)**	**Hydropower**	**Coal**	**Oil**	**Natural gas**	**Nuclear**	**Total**
Rest of Europe	43%	96%	3%	0%	0%	1%	**100%**
Africa	23%	82%	14%	2%	2%	1%	**100%**
Middle East & Central Asia	21%	0%	0%	0%	100%	0%	**100%**
North America	6%	94%	3%	0%	2%	1%	**100%**
Central & South America	3%	72%	0%	0%	27%	0%	**100%**
Asia	3%	14%	86%	0%	0%	0%	**100%**
Oceania	1%	27%	73%	0%	0%	0%	**100%**
Total for Europe	**100%**	**69%**	**8%**	**0%**	**22%**	**1%**	**100%**

In comparison with 2010 data, there is a decrease of the imports supplied by hydroelectricity (from 79% in 2010 to 69% in 2015) and a strong increase of the imports based on natural gas. The increase of aluminium produced by natural gas is related to the high increase of the imports from Middle East. Otherwise, the share of the other energy sources (e.g. coal, oil, nuclear) remained stable.

Table 4-14 *Electricity mix of European imports (2015 vs 2010 data)*

Electricity mix of European imports	Hydro	Coal	Oil	Natural Gas	Nuclear	Total
2015 update	69%	8%	0%	22%	1%	100%
2010 data	79%	8%	1%	12%	0%	100%

From Table 4-13, an LCI proxy have been used in Gabi software to model the energy production. For each energy source, the LCI from the corresponding country is given in the table below:

Table 4-15 *Representative country for each energy source for the electricity imports model*

Energy source	Hydropower	Coal	Oil	Natural gas	Nuclear
Representative country	Russia	South Africa	-	Saudi Arabia	Russia

The main environmental indicators corresponding to the production of 1 kWh of electricity used by the smelters importing aluminium to Europe is reported in Table 4-16. The comparison with 2010 data is presented as well.

Table 4-16 *Environmental indicators per kWh of electricity used by aluminium smelters exporting to Europe*

Environmental indicators[15] per kWh electricity, Imports model	2015	2010	2015 vs 2010 (in %)
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	9,7E-08	1,7E-07	-43%
Acidification Potential (AP) [kg SO_2-Equiv.]	1,8E-03	1,7E-03	+7%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	1,2E-04	9,6E-05	+30%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	2,7E-01	2,0E-01	+32%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	8,1E-12	3,3E-10	-98%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	9,1E-05	9,2E-05	-1%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	6,8E+00	6,1E+00	+12%
Primary energy from renewable resources (net cal. value) [MJ]	3,0E+00	3,4E+00	-13%
Primary energy from non-renewable resources (net cal. value) [MJ]	3,8E+00	2,6E+00	+44%

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[15] A brief presentation of the environmental impact categories is given in Table 2-6

4.5 European LCI dataset and environmental indicators for primary aluminium

The GaBi software was used to calculate the European LCI dataset for primary aluminium in accordance with the modelling hypotheses reported in sections 4.3 and 4.4 summarised in Figure 4-7 below.

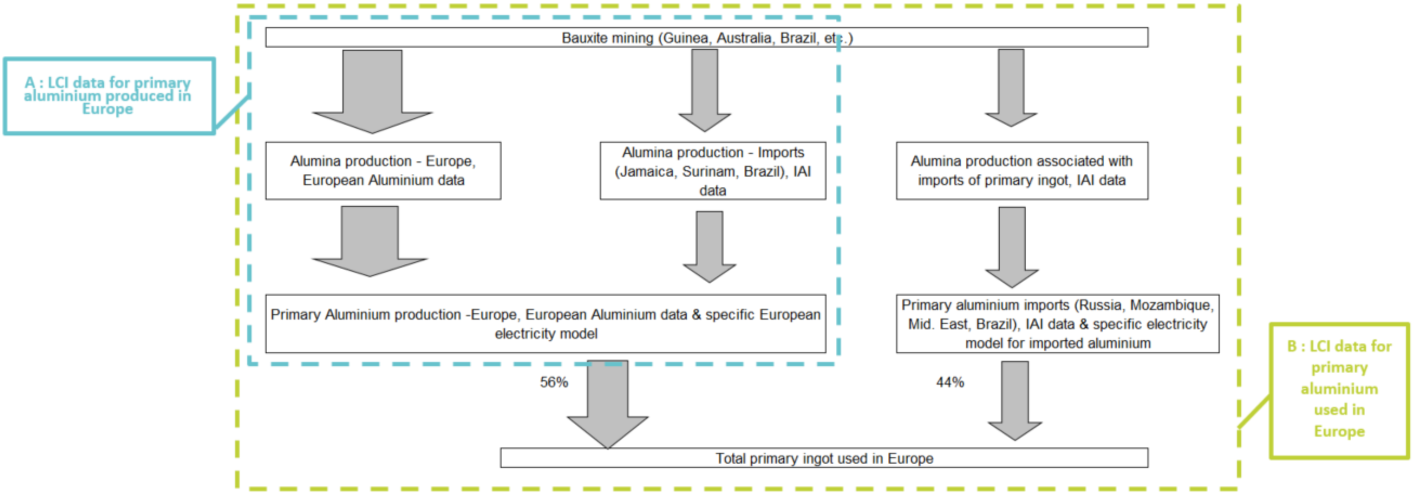


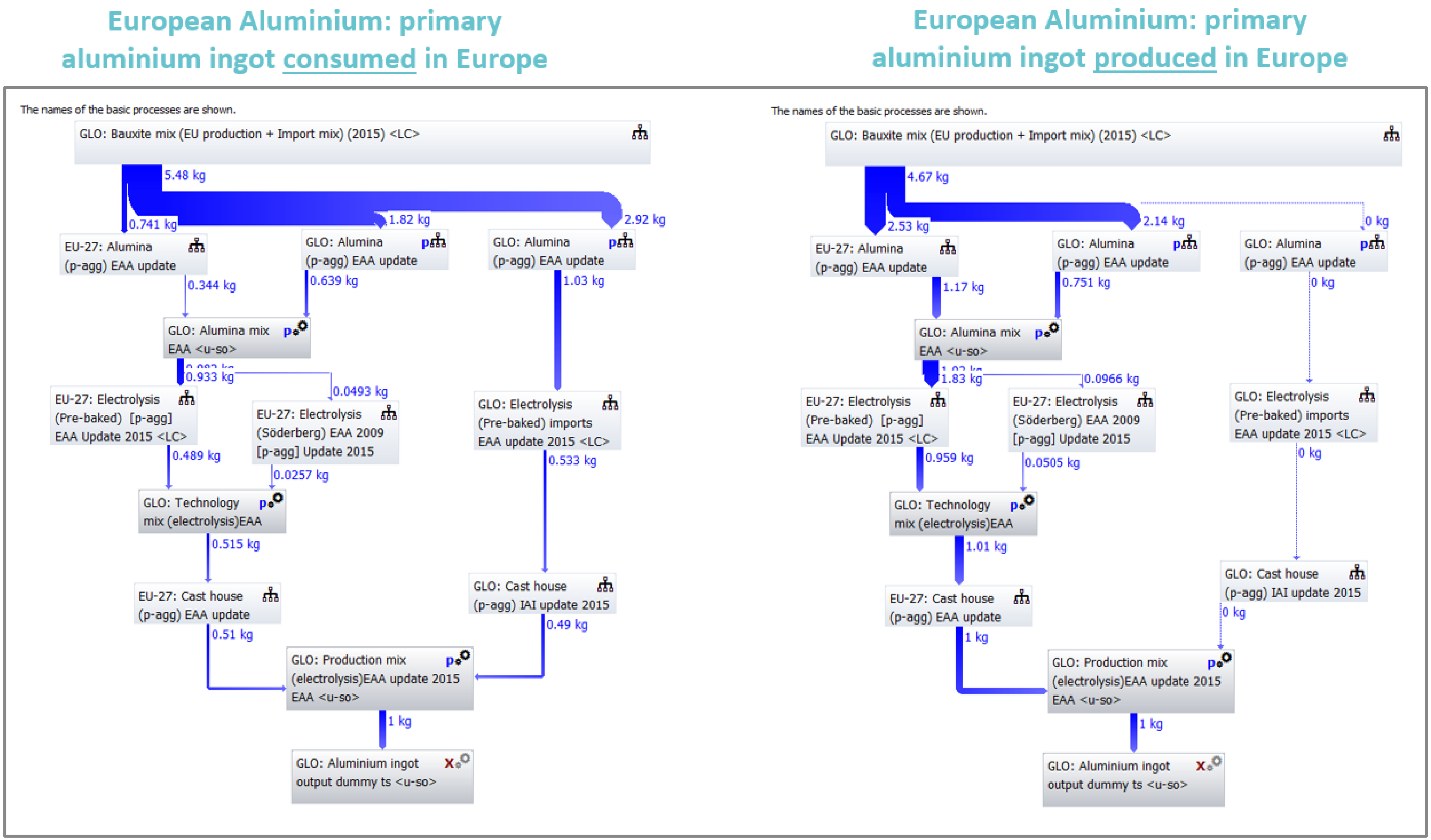
Figure 4-7 *Modelling principle for generating the European LCI datasets for primary aluminium*

Two types of LCI datasets have been generated:

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

For the aluminium ingots used in Europe, a combined model for the primary production in Europe (PFPB and VSS) and imports has been used. For each of these models, specific input and output data, together with specific modelling electricity sources have been developed as previously described.

Figure 4-8 below shows how the primary aluminium data have been modelled in the GaBi software.



European Aluminium: primary aluminium ingot <u>consumed</u> in Europe

European Aluminium: primary aluminium ingot <u>produced</u> in Europe

Figure 4-8: *Modelling using Gabi software (RER = Europe; GLO = Global): primary aluminium ingot*

The full LCI datasets are available on request at lci@european-aluminium.eu while the corresponding set of Environmental indicators are reported in Table 4-17 for the "used in Europe" LCI dataset and in Table 4-18 for the 'produced in Europe" LCI dataset.

4.5.1 Environmental indicators

Associated environmental indicators for the predefined impact categories are reported in Table 4-17 and Table 4-18. **These sets of environmental indicators are purely informative and should not be used for evaluating the environmental impact of the 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, is scientifically sound.**

Table 4-17 *Main environmental indicators (per tonne of ingot) for the "used in Europe" LCI primary aluminium dataset.*

European Aluminium indicators (per tonne of primary ingot used) - cradle to gate -	Total 2015	Process and auxiliary	Thermal energy	Electricity	Transport
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**4,2E-03**	62%	1%	37%	0%
Acidification Potential (AP) [kg SO2-Equiv.]	**4,3E+01**	37%	12%	37%	14%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**2,8E+00**	18%	16%	43%	23%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**8,6E+03**	31%	28%	38%	3%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**1,2E-07**	1%	1%	98%	0%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**2,3E+00**	32%	16%	37%	15%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**1,6E+05**	13%	19%	66%	2%
Primary energy from renewable resources (net cal. value) [MJ]	**4,7E+04**	2%	0%	98%	0%
Primary energy from non-renewable resources (net cal. value) [MJ]	**1,1E+05**	18%	27%	52%	3%

Table 4-18 *Main environmental indicators (per tonne of ingot) for the "produced in Europe" LCI primary aluminium dataset*

European Aluminium indicators (per tonne of primary ingot produced) - cradle to gate -	Total 2015	Process and auxiliary	Thermal energy	Electricity	Transport
CML2001 - Nov. 2010, Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**3,8E-03**	58%	2%	40%	0%
CML2001 - Nov. 2010, Acidification Potential (AP) [kg SO_2-Equiv.]	**2,3E+01**	53%	13%	17%	17%
CML2001 - Nov. 2010, Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**1,5E+00**	25%	19%	29%	27%
CML2001 - Nov. 2010, Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**6,7E+03**	37%	28%	33%	2%
CML2001 - Nov. 2010, Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**9,9E-08**	2%	1%	97%	0%
CML2001 - Nov. 2010, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**1,4E+00**	43%	20%	22%	15%

European Aluminium indicators (per tonne of primary ingot produced) - cradle to gate -	**Total 2015**	**Process and auxiliary**	**Thermal energy**	**Electricity**	**Transport**
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**1,4E+05**	14%	18%	67%	1%
Primary energy from renewable resources (net cal. value) [MJ]	**4,5E+04**	19%	27%	52%	2%
Primary energy from non-renewable resources (net cal. value) [MJ]	**9,8E+04**	2%	0%	98%	0%

From Table 4-17 and Table 4-18, it's appearing that most of the environmental impacts are related to the electricity production and from the aluminium and auxiliaries processes. For instance, both categories cover about 70% of the impacts related to the Global Warming Potential (GWP).

In addition, the environmental impacts of primary aluminium produced in Europe are lower that the environmental impacts of aluminium used in Europe for all environmental indicators. For instance, 1 tonne of primary aluminium ingot produced in Europe emits 23% less kg CO2e *(i.e. 1 973 kg CO2e less per tonne)* than 1 tonne of primary aluminium ingot used (European production and import) in Europe.

The two tables below compare the results of the environmental performance of primary aluminium in Europe. In comparison with 2010 data, the environmental performance of the primary aluminium produced in Europe improved significantly for most environmental indicators. This strong improvement is explained by a strong decrease of the direct emissions / consumption of the aluminium industry and as well by a strong increase of the share of hydroelectricity (e.g. from about 50% to 70%) in European smelters electricity mix.
Regarding the primary aluminium consumed in Europe, the environmental performance of primary aluminium used in Europe is quite stable for most indicators. On the one hand, there is a strong improvement of the environmental performance of the domestic production but on the other hand, there is a slight increase of the environmental performance of the imports. Basically, Europe is importing more from gas producing countries to cover its additional demand of primary aluminium. In addition, European imports dependency of primary aluminium increased as well from 44% to 49%.
For instance, the GWP of the primary aluminium produced in Europe decreased by 21% from 2015 to 2010 while the GWP of the primary aluminium consumed in Europe slightly decreased by 1%.

Table 4-19 *Comparison environmental performance of primary aluminium consumed in Europe (2015 vs 2010 data)*

European Aluminium indicators (per tonne of primary ingot used in Europe) - cradle to gate -	**2015**	**2010**	**2015 vs 2010 (in %)**
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	4,2E-03	4,9E-03	**-15%**
Acidification Potential (AP) [kg SO2-Equiv.]	4,3E+01	4,7E+01	**-9%**
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	2,8E+00	2,5E+00	**+13%**
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	8,6E+03	8,8E+03	**-1%**
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	1,2E-07	2,6E-04	**-100%**
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	2,3E+00	2,7E+00	**-16%**
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	1,6E+05	1,6E+05	**-1%**
Primary energy from renewable resources (net cal. value) [MJ]	4,7E+04	4,6E+04	**+3%**
Primary energy from non-renewable resources (net cal. value) [MJ]	1,1E+05	1,1E+05	**-3%**

Table 4-20 *Comparison environmental performance of primary aluminium produced in Europe (2015 vs 2010 data)*

European Aluminium indicators (per tonne of primary ingot produced in Europe) - Cradle to gate -	**2015**	**2010**	**2015 vs 2010 (in %)**
CML2001 - Nov. 2010, Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	3,8E-03	4,1E-03	**-8%**
CML2001 - Nov. 2010, Acidification Potential (AP) [kg SO_2-Equiv.]	2,3E+01	3,3E+01	**-31%**
CML2001 - Nov. 2010, Eutrophication Potential (EP) [kg Phosphate-Equiv.]	1,5E+00	1,9E+00	**-21%**
CML2001 - Nov. 2010, Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	6,7E+03	8,5E+03	**-21%**
CML2001 - Nov. 2010, Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	9,9E-08	4,4E-04	**-100%**
CML2001 - Nov. 2010, Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	1,4E+00	2,1E+00	**-34%**
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	1,4E+05	1,6E+05	**-8%**
Primary energy from renewable resources (net cal. value) [MJ]	4,5E+04	3,7E+04	**+23%**
Primary energy from non-renewable resources (net cal. value) [MJ]	9,8E+04	1,2E+05	**-18%**

For both tables above, the strong decrease of the Ozone Layer Depletion Potential (ODP) is explained by a change in Gabi LCIA methodology as highlighted in section 2.2.4. and 2.2.5.2.

4.5.2 Main elementary flows

For each environmental indicators presented in the tables above, the main contributing elementary flows and processes are presented in Table 4-21 and Table 4-22. **These main elementary flows are contributing to more than 80% of the respective indicator**.

For instance, for the primary aluminium consumed in Europe (see Table 4-21) , 89% of the Global Warming Potential (GWP) is coming from carbon dioxide emissions and about 5% from halogenated organic emissions to air. These carbon dioxide emissions are coming from electricity production at 43%, from fuels (i.e. thermal energy) at 28% and from the aluminium process (e.g. anode consumption) at 19%.

Table 4-21 *Main elementary flows / processes: primary aluminium consumed in Europe*

		Main elementary flows and main related processes: primary aluminium consumed in Europe		
Abiotic Depletion	Elementary flows	Sodium chloride (rock salt) : 51%	Copper: 23%	Molybdenum: 9%
	(Sub) Process	Auxiliary (100%)	Electricity (97%)	Electricity (99%)
Acidification Potential	Elementary flows	Sulphur dioxide: 76%	Nitrogen oxides: 22%	
	(Sub) Process	Electricity (39%) ; Process (39%)	Electricity (50%); Transport (25%)	
Eutrophication Potential	Elementary flows	Nitrogen oxides: 87%	Hydrocarbons to fresh water: 8%	
	(Sub) Process	Electricity (50%); Transport (25%)	Process (98%)	
Global Warming Potential	Elementary flows	Carbon dioxide: 89%	Halogenated organic emissions to air: 5%	
	(Sub) Process	Electricity (43%); Fuel (28%); Process (19%)	Process (100%)	
Ozone Layer Depletion Potential	Elementary flows	R 114 (dichlorotetrafluoroethane): 92%	R 22 (chlorodifluoromethane): 8%	
	(Sub) Process	Electricity (98%)	Electricity (96%)	
Photochem. Ozone Creation Potential	Elementary flows	Sulphur dioxide: 56%	Nitrogen oxides: 22%	Methane: 6%
	(Sub) Process	Electricity (39%); Process (38%)	Electricity (50%); Transport (25%)	Electricity (49%); Fuel (32%); Auxiliary (17%)
Primary energy demand: total	Elementary flows	Primary energy from hydro power: 28%	Natural gas: 26%	Hard coal: 23%
	(Sub) Process	Electricity (100%)	Electricity (66%); Fuel (27%)	Electricity (49%); Fuel (39%)
Primary energy from renewable resources	Elementary flows	Primary energy from hydro power: 95%		
	(Sub) Process	Electricity (100%)		
Primary energy from non-renewable resources	Elementary flows	Natural gas: 36%	Hard coal: 32%	Crude oil: 16%
	(Sub) Process	Electricity (66%); Fuel (27%)	Electricity (49%); Fuel (39%)	Auxiliary (63%); Fuel (19%)

Table 4-22 *Main elementary flows / 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) : 49%	Copper: 23%	Molybdenum: 9%
	(Sub) Process	Auxiliary (100%)	Electricity (97%)	Electricity (99%)
Acidification Potential	Elementary flows	Sulphur dioxide: 76%	Nitrogen oxides: 21%	
	(Sub) Process	Process (55%); Electricity (14%), Transport (14%)	Transport (32%); Electricity (28%), Auxiliary (10%)	
Eutrophication Potential	Elementary flows	Nitrogen oxides: 83%	Hydrocarbons to fresh water: 7%	
	(Sub) Process	Transport (32%); Electricity (28%), Fuel (22%)	Process (96%)	
Global Warming Potential	Elementary flows	Carbon dioxide: 90%	Halogenated organic emissions to air: 4%	
	(Sub) Process	Electricity (35%); Fuel (29%); Process (25%)	Process (100%)	
Ozone Layer Depletion Potential	Elementary flows	R 114 (dichlorotetrafluoroethane): 84%	R 22 (chlorodifluoromethane): 16%	
	(Sub) Process	Electricity (97%)	Electricity (98%)	
Photochem. Ozone Creation Potential	Elementary flows	Sulphur dioxide: 51%	Nitrogen oxides: 20%	Methane: 6%
	(Sub) Process	Process (55%); Electricity (14%), Transport (14%)	Transport (32%); Electricity (28%); Fuel (22%)	Electricity (38%); Fuel (37%); Auxiliary (24%)
Primary energy demand: total	Elementary flows	Primary energy from hydro power: 30%	Natural gas: 20%	Uranium: 19%
	(Sub) Process	Electricity (100%)	Fuel (59%); Electricity (33%)	Electricity (100%)
Primary energy from renewable resources	Elementary flows	Primary energy from hydro power: 96%		
	(Sub) Process	Electricity (100%)		
Primary energy from non-renewable resources	Elementary flows	Natural gas: 30%	Uranium: 28%	Hard coal: 25%
	(Sub) Process	Fuel (59%); Electricity (32%)	Electricity (97%)	Electricity (57%); Fuel (27%); Auxiliary (17%)

5. Aluminium sheet production

5.1 Localisation of aluminium rolling mills in Europe

About 75 rolling mills are operating in Europe (including Turkey here). This number is quite stable in comparison with 2010 survey. Less than 10 companies are representing about 70% of the installed capacity.

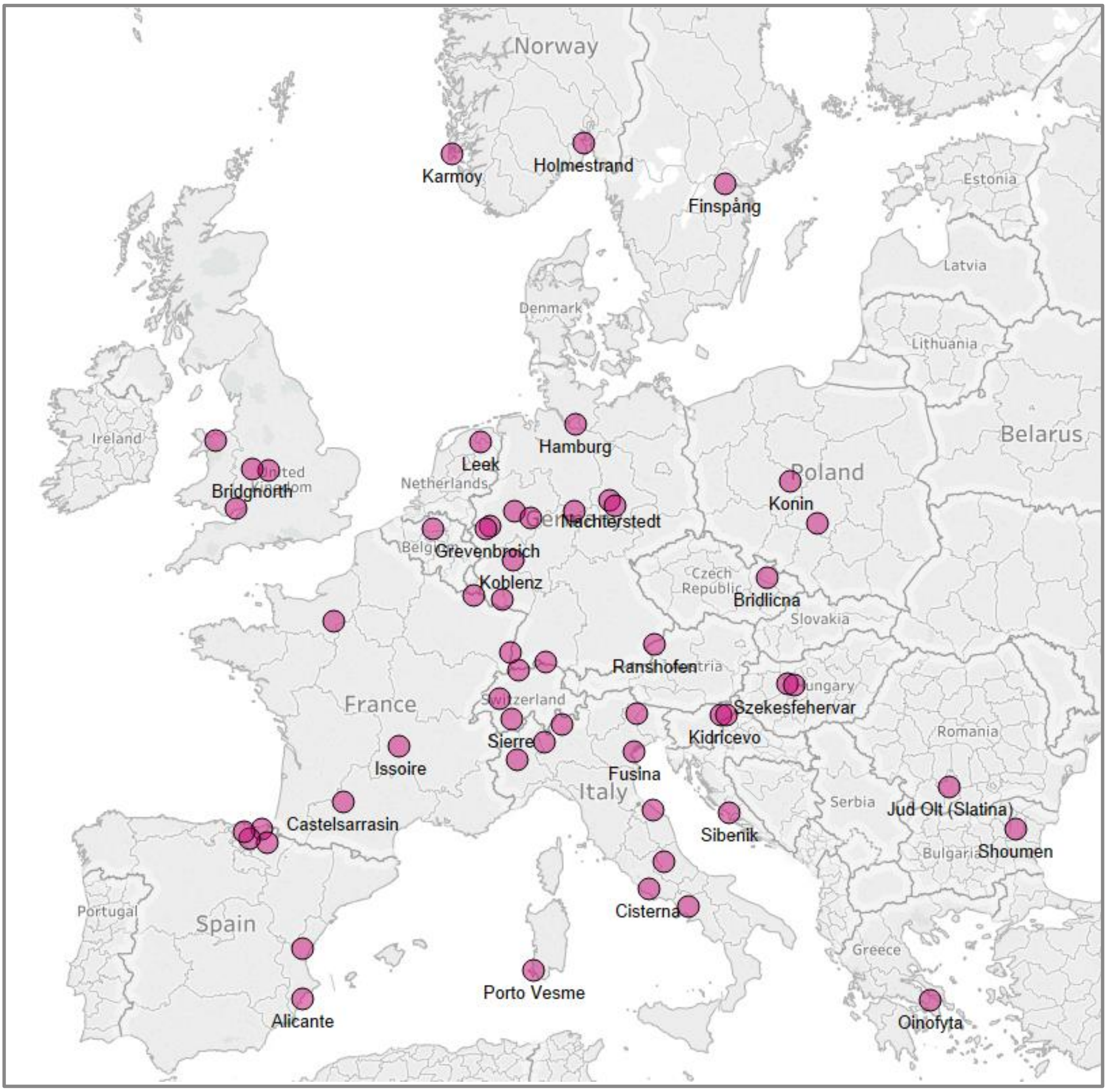


Figure 5-1 *Mapping of the aluminium rolling mills in Europe*

5.2 Process steps description

With a thickness comprised between 0.2 and 6 mm, sheet is the most common aluminium rolled product. The starting stock for most rolled products is the DC (Direct Chill semi-continuous cast) ingot. The size of the ingot depends on the size of the DC unit available, the hot rolling mill capacity, volume required for a particular end use and to some extent the alloys being cast. Ingots up to over 32 tons in weight, 500 - 600 mm thick, 2.000 mm wide and 9.000 mm long are produced. Before rolling operations, the rolling ingot is machined to cut the ends (sawing) and to even the surfaces (scalping).

According to alloy grade, a thermal treatment of homogenisation may be applied (see Figure 5-2). The DC ingot is then pre-heated to around 500°C prior to successive passes through a hot rolling mill where it is reduced in thickness to about 4 - 6 mm. The strip from the hot rolling mill is coiled and stored before cold rolling which is usually done in the same site. Cold mills, in a wide range of types and sizes are available; some are single stand, others 3 stands and some 5 stands. Final thickness of the cold rolled strip or sheet is usually comprised between 0.2 and 2 mm.

Finishing operations include:

- Sizing, e.g. trimming, slitting and blanking
- Annealing according to alloy grades
- Final surface preparation (excluding coating and/or painting)

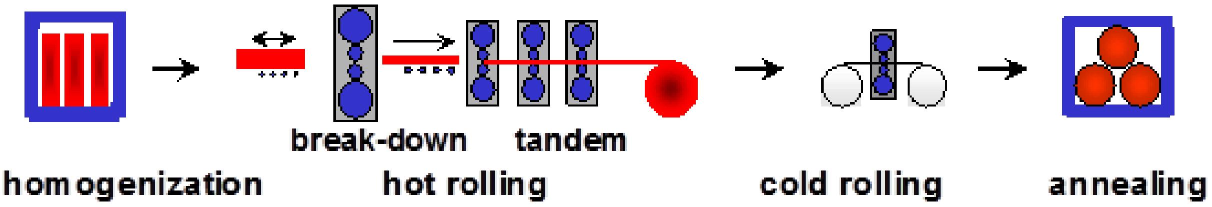


Figure 5-2 *Main process steps in aluminium sheet production*

The sheet production from sawn ingot up to finished sheet generates about 347 kg of scrap by tonne of sheet. These scraps are recycled into new ingots through remelting which is usually performed on-site in integrated cast houses. This internal recycling of process scrap is part of the LCI dataset for the sheet production as illustrated in Figure 5-3.

5.3 Data collection, averaging and modelling

The LCI dataset related to sheet production were developed through an European Aluminium survey covering European aluminium rolling mills as well as their integrated cast house in which process scrap are remelted into rolling ingots (slabs).

The European Aluminium survey coverage for the year 2015 reaches 88% for the cold rolled sheet production in Europe which is equivalent to about 4.3 Mtonnes. Detailed figures are reported in Table 5-1.

Table 5-1 *European Aluminium survey coverage for European rolling mills*

	Total production in Europe (in Mt)	**Total reported production (in Mt)**	**Survey coverage (%)**
Cast-house (slabs)[16]	~3.1	2.8*	88%
Rolling mills[17]	4.9	4.3	88%

*including direct strip casting

Few specific data were reported about the type of alloys used in the process. However, the data reported are representative of the main aluminium flat rolled products market (i.e. mainly 50% packaging including foil stocks, 23% transport and 13% building and construction) in Europe. Thus, these average results can differs based on the types of alloys used or based on the specifications required for the final product and could require a deeper assessment.

The LCI datasets for sheet production includes the sheet production chain and the recycling of process scrap produced at the various process steps of the sheet production as well as the dross recycling process. The flow diagram of this LCI dataset for sheet production is reported in Figure 5-3.

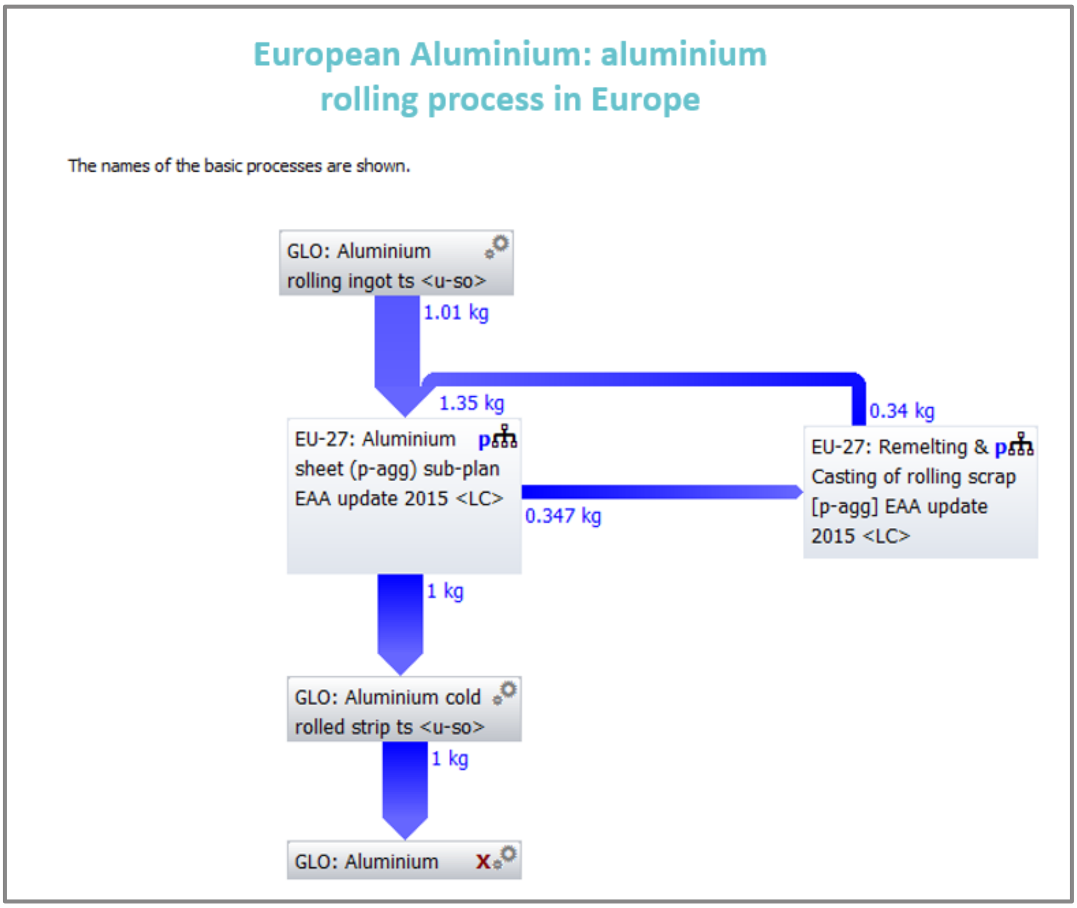


Figure 5-3 *Flow diagram for aluminium sheet production (RER: EU27 + EFTA countries)*

Direct inputs and outputs data related to the sheet production chain and the remelting of process scrap are reported in Table 5-2. These inputs and outputs are normalised to 1.000 kg of finished aluminium sheet.

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[16] The total production from rolling casthouses in Europe is an estimate as follows: total slab requirement for 4.9 Mt rolled products is 6.2 Mt (from survey average ingot-to-cold rolled sheet factor 1.26) minus ingot supplied from primary smelters i.e. about 3.1 Mt.

[17] Total strip cold rolled, no further finishing or treatment

Table 5-2 *Direct inputs and outputs for the sheet production and the corresponding scrap remelting – Figures scaled to 1.000 kg of finished sheet.*

Sheet production and scrap remelting *Figures for 1 tonne of finished sheet*		**Sheet production**	**Scrap remelting**	**Total 2015**	**Total 2010**
Inputs	**Unit**	**2015 data**	**2015 data**		
Unscalped rolling ingots	kg/t	1 004		**1 004**	**1 004**
Clean scrap	kg/t		347		
Energy inputs	**MJ/t**				
Thermal energy (i.e. fuels)	**MJ/t**	**1 983**	**1 115**	**3 098**	**3 443**
Heavy Oil	MJ/t	2	25	**26**	**31**
Diesel and light fuel Oil	MJ/t	16	16	**33**	**28**
Natural Gas	MJ/t	1 965	1 074	**3 039**	**3 302**
Other energy source (propane)	MJ/t	0	0	**0**	**81**
Purchased electricity	kWh/t	479	52	**531**	**569**
Total energy (i.e. fuels + electricity)	**MJ/t**	**3 708**	**1 303**	**5 011**	**5 490**
Auxiliary products, inputs					
Fluxing salts	kg/t		7,5	**7,5**	**9,0**
Argon	kg/t	0,2	0,7	**0,9**	**0,7**
Nitrogen	kg/t	21,5	0,3	**21,8**	**8,9**
Chlorine	kg/t		0,1	**0,1**	**0,1**
Absorbant for exhaust gas treatment	kg of CaOeq/t		0,1	**0,1**	**0,3**
Emulsion, hot rolling (oil content)	kg/t	1,0		**1,0**	**1,4**
Oil, cold rolling	kg/t	2,1		**2,1**	**2,0**
Filter earths for cold rolling oil	kg/t	0,7		**0,7**	**0,8**
Paper & cardboard for packaging	kg/t	2,0		**2,0**	**0,6**
Wood for packaging	kg/t	6,2		**6,2**	**11,2**
Steel for packaging	kg/t	0,3		**0,3**	**0,3**
Plastic for packaging	kg/t	0,6		**0,6**	**0,4**
Water inputs					
Process water	m^3	0,2	0,0	**0,3**	**1,0**
Cooling water	m^3	3,7	2,9	**6,6**	**9,6**
Total water supply	**m^3**	**3,9**	**2,9**	**6,8**	**9,0**
Outputs					
Aluminium outputs					
Finished cold rolled strip	kg/t	1 000		**1 000**	**1 000**
Emissions to air					
Chlorine (as Cl_2)	g/t		0,2	**0,2**	**0,5**
Other inorganic chlorinated compounds (expressed as HCl)	g/t		3,7	**3,7**	**6,4**
Hydrogen Fluoride (as HF)	g/t		0,1	**0,1**	
Dust/particulates, total	g/t	13,7	10,9	**24,5**	**37,8**
NOx, as nitrogen dioxide	g/t	171,8	104,2	**276,0**	**420,6**
SO_2	g/t	6,0	18,1	**24,1**	**32,1**

Sheet production and scrap remelting *Figures for 1 tonne of finished sheet*		**Sheet production**	**Scrap remelting**	**Total 2015**	**Total 2010**
Total gaseous organic carbon (TOC)	g/t	285,6	22,6	**308,2**	**340,9**
Emissions to water					
Water output	M^3/t	3,4	2,8	**6,2**	**9,8**
COD, chemical oxygen demand (direct discharge)	g/t	1,4	0,0	**1,4**	**14,3**
Waste (excluding dross, aluminium scrap & demolition waste)					
Hazardous waste for land-filling	kg/t	0,4	0,5	**0,9**	**2,0**
Hazardous waste for incineration	kg/t	0,9	0,0	**0,9**	**0,8**
Hazardous waste for recycling or further processing	kg/t	9,0	0,8	**9,8**	**9,2**
Total hazardous waste	**kg/t**	**10,2**	**1,3**	**11,5**	**11,9**
Non-haz. waste for land-filling	kg/t	1,3	0,2	**1,5**	**1,0**
Non-haz. waste for incineration	kg/t	1,0	0,0	**1,0**	**0,3**
Non-hazardous waste for recycling or further processing	kg/t	6,4	0,7	**7,1**	**5,8**
Total non-hazardous waste	**kg/t**	**8,7**	**0,9**	**9,6**	**7,0**
By products					
Metal scrap for recycling, excluding aluminium	kg/t	1,1	0,1	**1,1**	**1,9**

5.4 Environmental indicators and main elementary flows for sheet production

The GaBi software was used to calculate the European gate to gate dataset for sheet production in accordance with the flow diagram described in Figure 5-3. This full dataset is available on request at lci@european-aluminium.eu. The associated environmental indicators and main elementary flows are presented in Table 5-3 to Table 5-5.

5.4.1 Environmental indicators

Table 5-3 *Environmental indicators for the sheet production*

European Aluminium indicators (per tonne of aluminium sheet) - gate to gate -	**Total 2015**	**Direct & auxiliary processes**	**Thermal energy**	**Electricity**
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**3,2E-04**	71%	3%	26%
Acidification Potential (AP) [kg SO_2-Equiv.]	**8,6E-01**	27%	16%	57%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**1,2E-01**	39%	17%	44%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**4,3E+02**	4%	48%	48%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**8,2E-09**	3%	3%	94%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**1,1E-01**	45%	23%	32%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**9,0E+03**	8%	37%	55%

European Aluminium indicators (per tonne of aluminium sheet) - gate to gate -	Total 2015	Direct & auxiliary processes	Thermal energy	Electricity
Primary energy from renewable resources (net cal. value) [MJ]	**1,9E+03**	12%	3%	85%
Primary energy from non-renewable resources (net cal. value) [MJ]	**7,1E+03**	7%	46%	47%

From Table 5-3, it's appearing that most of the environmental impacts are related to the energy production and from the aluminium and auxiliaries processes. For instance, for Global Warming Potential (GWP) and for total primary energy demand, each category are covered mainly by the energy processes (thermal and electrical energy). For some other indicators like ozone layer depletion most of the impacts are coming from the electricity while for abiotic depletion or photochemical ozone creation potential, most of the impacts are coming from direct and auxiliary processes.

In comparison with 2010 data, the environmental performance of the aluminium rolling mill process in Europe improved significantly for most environmental indicators. This strong improvement is explained by a strong decrease of the direct emissions / consumption in the industry as highlighted above.
For instance, the GWP and the primary energy demand decreased respectively by 25% and 16% from 2015 to 2010. In addition, indicators like acidification and eutrophication potential decreased as well by 52% and 25%.
The increase of the abiotic depletion indicator (ADP) is mainly explained by the strong increase (+326%) of ADP impact of the electricity production in Europe from 2010 to 2015. This trend is related to the impacts of precious and rare metals entering in the composition of photovoltaic cells and wind mills which are more and more used in EU electricity grid mix (see Table 2-5 and chapter 2.2.5.2). For instance, in 2010, direct electricity consumption was representing about 19% of the impacts related to ADP while its weights in 2015 is about 26% of the ADP impacts.

The strong decrease of the Ozone Layer Depletion Potential (ODP) is explained by a change in Gabi LCIA methodology as highlighted in section 2.2.4. and 2.2.5.2.

Table 5-4 Comparison e*nvironmental indicators for the sheet production (2015 vs 2010)*

European Aluminium indicators (per tonne of aluminium sheet) - gate to gate -	2015	2010	2015 vs 2010 (in %)
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	3,2E-04	1,2E-04	**+162%**
Acidification Potential (AP) [kg SO_2-Equiv.]	8,6E-01	1,8E+00	**-52%**
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	1,2E-01	1,6E-01	**-25%**
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	4,3E+02	5,7E+02	**-25%**
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	8,2E-09	2,0E-05	**-100%**
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	1,1E-01	1,9E-01	**-42%**
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	9,0E+03	1,1E+04	**-16%**
Primary energy from renewable resources (net cal. value) [MJ]	1,9E+03	8,8E+02	**+110%**
Primary energy from non-renewable resources (net cal. value) [MJ]	7,1E+03	9,8E+03	**-28%%**

5.4.2 Main elementary flows

For each environmental indicators presented in the tables above, the main contributing elementary flows and processes are presented below. **These main elementary flows are contributing to more than 80% of the respective indicator**.

Table 5-5 Main elementary flows / processes: rolling process

		Main elementary flows and main related processes: rolling production		
Abiotic Depletion	Elementary flows	Sodium chloride (rock salt) : 58%	Lead: 23%	Silver: 7%
	(Sub) Process	Auxiliary (100%)	Auxiliary (63%); Electricity (25%)	Electricity (59%); Auxiliary (34%)
Acidification Potential	Elementary flows	Sulphur dioxide: 50%	Nitrogen oxides: 43%	
	(Sub) Process	Electricity (69%) ; Fuel (15%); Auxiliary (8%)	Electricity (38%); Process (36%); Fuel (19%)	
Eutrophication Potential	Elementary flows	Nitrogen oxides: 81%	Chemical oxygen demand: 5%	Nitrate: 4%
	(Sub) Process	Electricity (38%); Process (36%); Fuel (19%)	Electricity (80%); Auxiliary (9%)	Electricity (81%); Auxiliary (16%)
Global Warming Potential	Elementary flows	Carbon dioxide: 92%	Methane: 7%	
	(Sub) Process	Electricity (47%); Fuel (47%)	Fuel (54%); Electricity (34%)	
Ozone Layer Depletion Potential	Elementary flows	R 114 (dichlorotetrafluoroethane): 91%	R 22 (chlorodifluoromethane): 9%	
	(Sub) Process	Electricity (94%)	Electricity (93%)	
Photochem. Ozone Creation Potential	Elementary flows	NMVOC to air: 34%	Nitrogen oxides: 19%	Sulphur dioxide: 16%
	(Sub) Process	Process (89%); Fuel (5%)	Electricity (38%); Process (36%); Fuel (19%)	Electricity (69%); Fuel (15%); Process (8%)
Primary energy demand: total	Elementary flows	Uranium: 14%	Hard coal: 12%	Solar energy: 10%
	(Sub) Process	Electricity (93%)	Electricity (91%); Auxiliary (7%)	Electricity (69%); Auxiliary (21%)
Primary energy from renewable resources	Elementary flows	Solar power: 48%	Hydro power: 28%	Wind power: 24%
	(Sub) Process	Electricity (69%); Auxiliary (21%)	Electricity (96%)	Electricity (94%)
Primary energy from non-renewable resources	Elementary flows	Natural gas: 55%	Uranium: 18%	Hard coal: 15%
	(Sub) Process	Fuel (80%); Electricity (18%)	Electricity (93%)	Electricity (91%); Auxiliary (7%)

For instance, 92% of the Global Warming Potential (GWP) is coming from carbon dioxide emissions and 7% from methane emissions. These carbon dioxide emissions are coming from electricity production at 47% and from fuels (i.e. thermal energy) at 47% as well.

6. Aluminium foil

6.1 Process steps description

There are two major successive stages in the production of aluminium foil: 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 sheet. It uses an aluminium rolling ingot (slab) as starting material, which is first hot rolled and then cold rolled into foil stock in the form of reel. The other route – continuous casting – consists of casting the molten aluminium directly into a strip which is then cold rolled into foil stock. Today, the hot rolling route accounts for about half 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 intermediate and/or final stage), surface treatment and slitting to the width needed for the application.

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

6.2 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 2014. They cover about 80% of the production of foil in Europe (including here Turkey and Russia).

The European Aluminium dataset for the production of aluminium sheet (2015) has been used as proxy for the production of foil stock through the hot rolling (see section 5 above). The use of updated European Aluminium data (2015) also applies to the remelting of process scraps when this operation is done externally (see section 8 below).

In comparison with 2010 datasets, the 2015 data include as well the hot rolling mill process which generates the foilstock entering in one of the foiling route. This update and clarification of the scope should facilitate the use of foil datasets and avoid misunderstanding. For this reason, no direct comparison with 2010 data will be done in this report.

The flow diagram for foil production is illustrated in Figure 6-1.

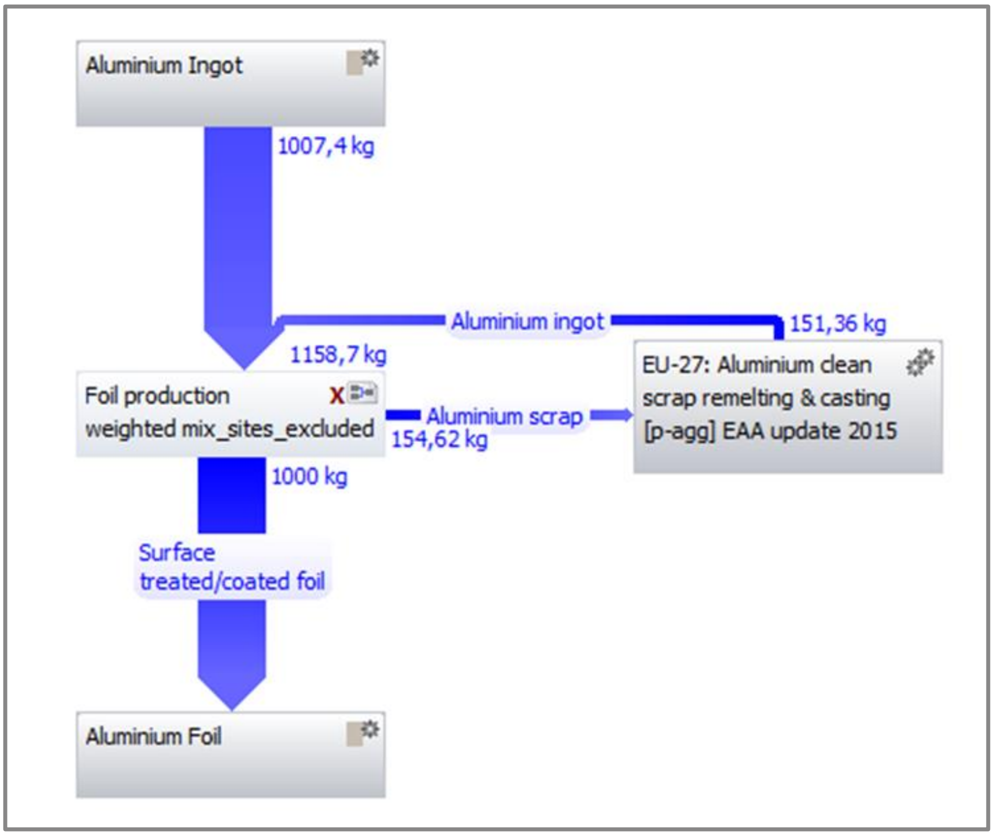


Figure 6-1: Flow diagram for aluminium foil production

Direct inputs and outputs data related to the foil production chain and the remelting of process scrap are reported in Table 6-1. These inputs and outputs are normalised to 1.000 kg of finished aluminium foil.

Table 6-1: Direct inputs and outputs for foil production and the corresponding scrap remelting – Figures normalised to 1.000 kg of finished foil

Foil production and scrap remelting *Figures for 1 tonne of finished foil*		**Foil production**	**Scrap remelting**	**Total**
Inputs	**Unit**	**2014 data**	**2015 data**	
Ingots	kg/t	1 007		**1 007**
Clean scrap	kg/t		155	
Energy inputs	**MJ/t**			
Thermal energy (i.e. fuels)	**MJ/t**	**5 831**	**454**	**6 286**
Heavy Oil	MJ/t	36	10	**46**
Diesel and light fuel Oil	MJ/t	557	7	**564**
Natural Gas	MJ/t	5 239	438	**5 677**
Other energy source (propane)	MJ/t	0	0	**0**
Purchased electricity	kWh/t	1173	21	**1195**
Total energy (i.e. fuels + electricity)	**MJ/t**	**10 055**	**531**	**10586**
Auxiliary products, inputs				
Fluxing salts	kg/t	0,1	3,0	**3,1**
Argon	kg/t	0,0	0,3	**0,3**
Nitrogen	kg/t	0,0	0,1	**0,1**
Chlorine	kg/t	0,0	0,02	**0,02**

Foil production and scrap remelting *Figures for 1 tonne of finished foil*		**Foil production**	**Scrap remelting**	**Total**
Absorbant for exhaust gas treatment	kg of CaOeq/t		0,04	**0,04**
Rolling and lubricant oil	kg/t	1,6		**1,6**
Filter material	kg/t	2,7		**2,7**
Paper & cardboard for packaging	kg/t	0,6		**0,6**
Wood for packaging	kg/t	31,1		**31,1**
Steel for packaging	kg/t	2,8		**2,8**
Plastic for packaging	kg/t	0,6		**0,6**
Water inputs				
Total water supply	m^3	36,6	1,2	**37,8**
Outputs				
Aluminium outputs				
Finished cold rolled strip	kg/t	1 000		**1 000**
Emissions to air				
Chlorine (as Cl_2)	g/t		0,10	**0,10**
Other inorganic chlorinated compounds (expressed as HCl)	g/t		1,51	**1,51**
Hydrogen Fluoride (as HF)	g/t		0,02	**0,02**
Dust/particulates, total	g/t	3,7	4,4	**8,2**
NOx, as nitrogen dioxide	g/t	0,0	42,5	**42,5**
SO_2	g/t	125,5	7,4	**132,9**
VOC	g/t	1 240	9	**1 249**
Emissions to water				
Water output	M^3/t	5,7	1,1	**6,9**
Waste (excluding dross, aluminium scrap & demolition waste)				
Hazardous waste for land-filling	kg/t	1,1	0,2	**1,3**
Hazardous waste for incineration	kg/t	1,93	0,01	**1,9**
Hazardous waste for recycling or further processing	kg/t	2,3	0,3	**2,6**
Total hazardous waste	**kg/t**	**5,4**	**0,5**	**5,9**
Non-haz. waste for land-filling	kg/t	0,5	0,1	**0,6**
Non-haz. waste for incineration	kg/t	0,1	0,0	**0,1**
Non-hazardous waste for recycling or further processing	kg/t	11,2	0,3	**11,5**
Total non-hazardous waste	**kg/t**	**11,8**	**0,4**	**12,2**
By products				
Metal scrap for recycling, excluding aluminium	kg/t	1,7	0,0	**11,7**

6.3 Environmental indicators for foil production

The GaBi software was used to calculate the European gate to gate dataset for foil production in accordance with the flow diagram described in Figure 6-1. This dataset is available on request at lci@european-aluminium.eu and associated environmental indicators are presented in Table 6-2.

Table 6-2 *Environmental indicators for the production of 1 tonne of aluminium foil*

European Aluminium indicators (per tonne of aluminium foil) - gate to gate -	**Total 2015**	**Direct & auxiliary processes**	**Thermal energy**	**Electricity**
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**2,5E-03**	90%	1%	9%
Acidification Potential (AP) [kg SO_2-Equiv.]	**2,7E+00**	52%	13%	35%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**3,8E-01**	64%	13%	22%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**1,3E+03**	41%	34%	25%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**2,3E-08**	34%	2%	64%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**3,2E-01**	63%	19%	19%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**2,9E+04**	40%	26%	34%
Primary energy from renewable resources (net cal. value) [MJ]	**6,3E+03**	31%	1%	68%
Primary energy from non-renewable resources (net cal. value) [MJ]	**2,3E+04**	42%	32%	25%

As explained earlier, the foil gate to gate dataset cover the full process (including the production of foil stock from the slab) i.e. both classical and continuous casting routes, which was not the fully case for previous dataset (2010 data). For this reason, no comparison with 2010 data will done in this report.

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.

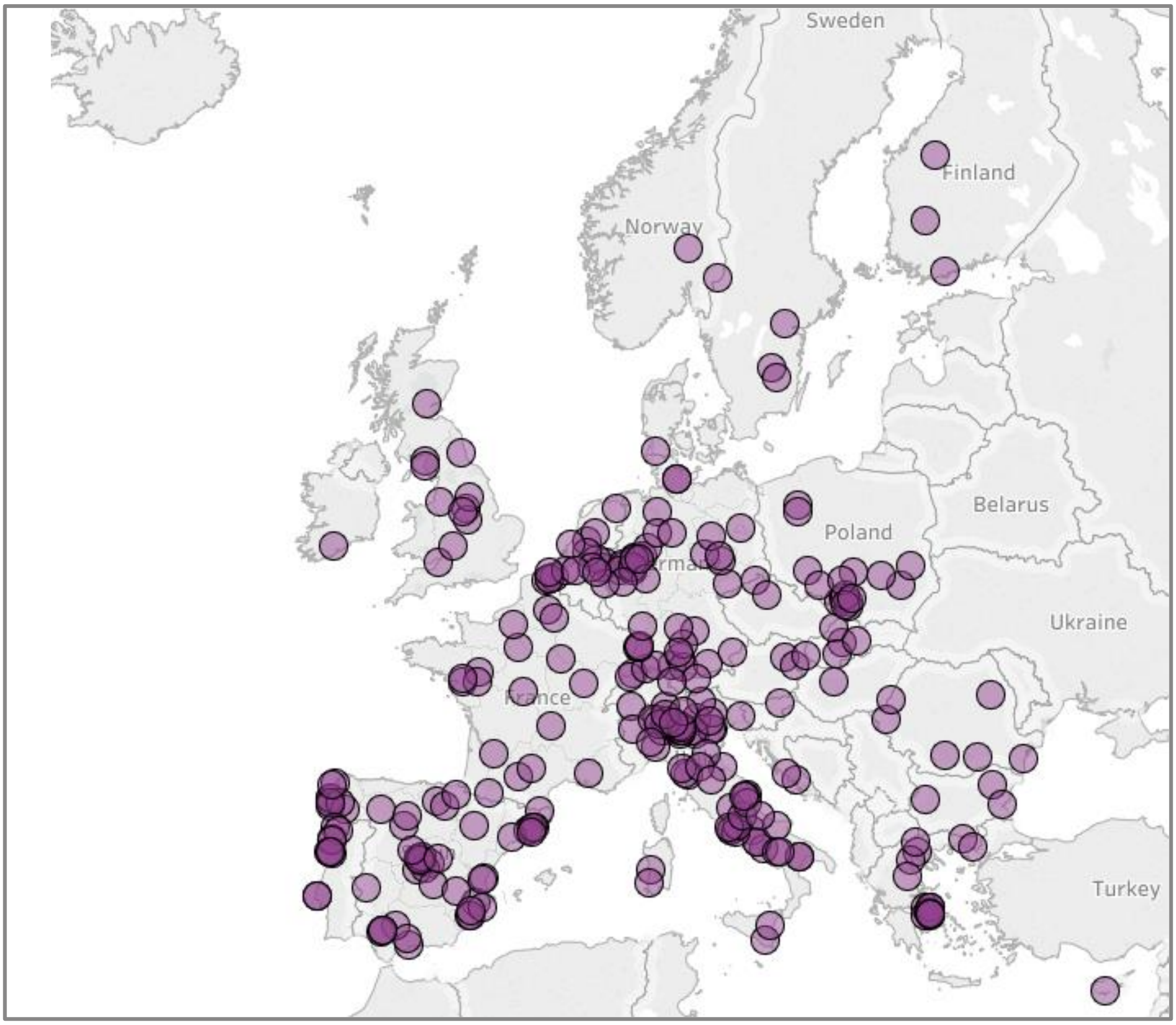


Figure 7-1 Mapping of extrusion plants in Europe

7.2. Process steps description

Aluminium profiles are produced by the extrusion process. The term extrusion is usually applied to both the process, and the product obtained, when a hot cylindrical billet of aluminium is pushed through a shaped die.

The starting material for aluminium extrusion production is an extrusion ingot (usually called log or billet), i.e. a several meters long cylinder with a diameter typically comprised between 20 and 50 cm. These billets are usually produced by DC casting technology. The ends (tops and tails) of the billets are usually sawed at the cast house for direct remelting. Depending on the extrusion presses, the billet can be cut in smaller cylinder pieces before the extrusion process. Just before extrusion, the billet is pre-heated usually around 450 °C - 500 °C. At these temperatures the flow stress of the aluminium alloys is very low and by applying pressure by means of a ram to one end of the billet the metal flows through the steel die, located at the other end of the container to produce a profile, the cross sectional shape of which is defined by the shape of the die. The resulting profile (see Figure 7-2) can be used in long lengths or cut into short parts for use in structures, vehicles or components.

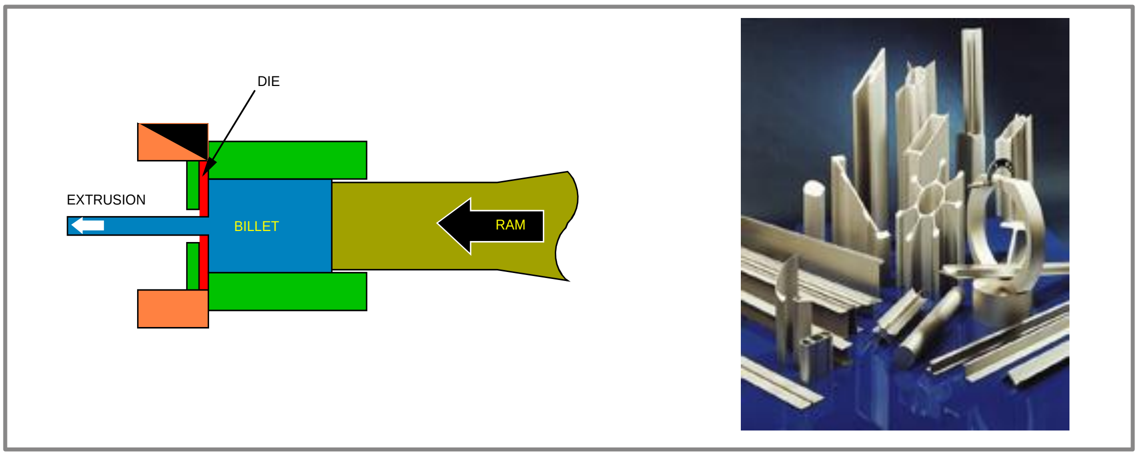


Figure 7-2 *Extrusion process principle and some aluminium extruded products*

The extrusion from cast billet up to finished profile generates about 320 kg of scrap by tonne of extrusion. These scrap are recycled into new ingot through remelting which is performed either on-site in integrated cast houses or externally. The recycling of process scrap is part of the dataset for the extrusion gate to gate production as illustrated in Figure 7-3.

7.3. Data consolidation, averaging and modelling

About 70 plants have been integrated in the consolidation process representing about 800 kt of extrusion output, i.e. about 30% of the European production as reported in Table 7-1. This coverage is in the same range of 2010 data (~30%).

Table 7-1 *Survey coverage for aluminium extrusion*

	Total production in Europe (in Mt)	**Total reported production (in kt)**	**Survey coverage (%)**
Extrusion / profiles	2,8	800	29%

The data reported are representative of the main aluminium extrusion market (i.e. mainly: 45% building & construction, 28% transport and 16% engineering) in Europe. This average dataset may not be representative for some specific types of alloys used (e.g. hard alloys) or for highly complex specifications required for the final product (e.g. extrusion with very thin walls). In such case, an assessment should be performed to check if the use of the average dataset is appropriate.

The flow diagram for extrusion is reported in Figure 7-3. In Table 7-2, the specific inputs and outputs are reported respectively for the extrusion production chain and for the process scrap remelting. These data are normalised to the production of 1 tonne of extrusion.

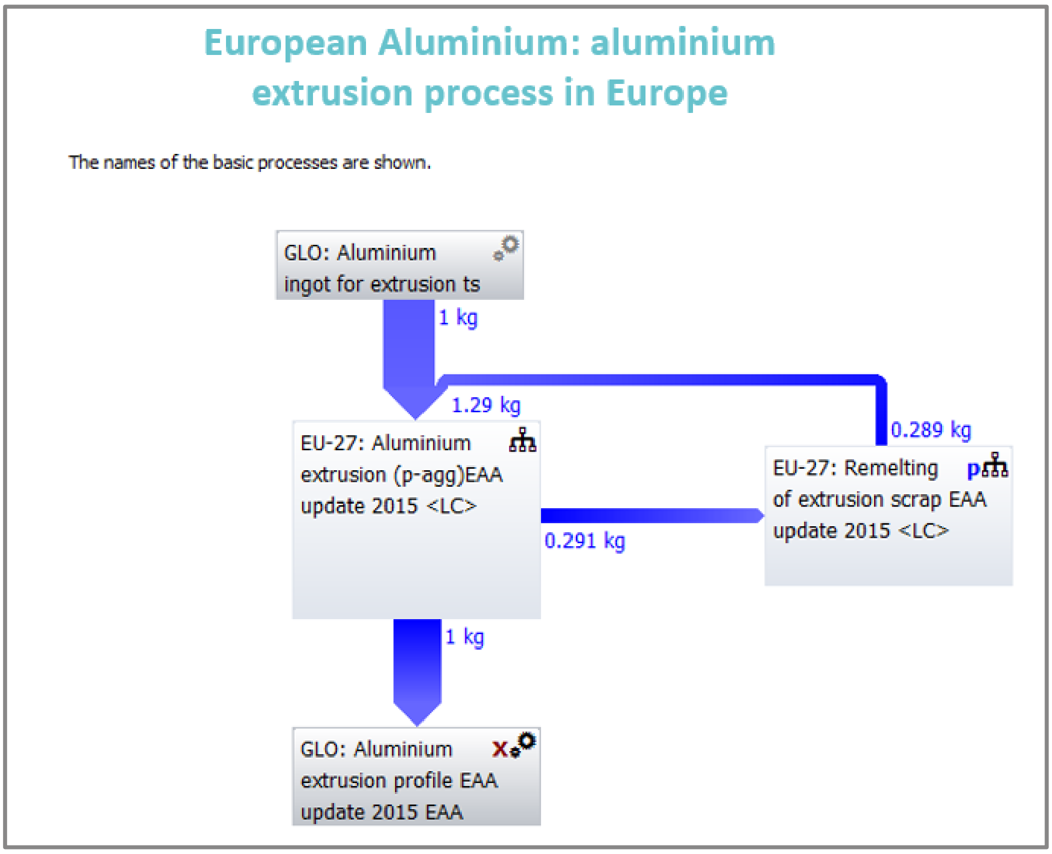


Figure 7-3 *Flow diagram for extrusion production (RER: EU28 + EFTA countries).*

Table 7-2 *Direct inputs and outputs for extrusion and the corresponding scrap recycling – Figures normalised to 1.000 kg of finished extruded product.*

Extrusion production and scrap remelting *Figures for 1 tonne of extrusion*		**Extrusion & packaging**	**Remelting**	**Total 2015**	**Total 2010**
Inputs	**Unit**	**2015 data**	**2015 data**		
Extrusion ingots	kg/t	1 003		1 003	1000
Remelt: Clean scrap	kg/t		291		
Energy supply					
Thermal energy (i.e. fuels)	**MJ/t**	**2 105**	**1 292**	**3 538**	**3 425**
Heavy Oil	MJ/t	2	0	2	16
Diesel and light fuel Oil	MJ/t	80	25	111	77
Natural Gas	MJ/t	1 980	1 266	3 379	3 332
Other thermal energy source (steam)	MJ/t	43	0	46	
Purchased electricity	KWh/t	766	69	784	959
Total energy (i.e. fuels + electricity)	**MJ/t**	**4 861**	**1 541**	**6 362**	**6 879**
Ancillaries		0	0	0	
Fluxing salts	kg/t		0,3	0,3	0,3
Argon	kg/t		0,9	0,9	0,3
Nitrogen	kg/t			0,0	1,4
Chlorine	kg/t		0,02	0,02	0,02

Extrusion production and scrap remelting *Figures for 1 tonne of extrusion*		**Extrusion & packaging**	**Remelting**	**Total 2015**	**Total 2010**
Absorbant for exhaust gas treatment	kg/t		0,2	0,2	0,0
H_2SO_4, calculated as 100% H_2SO_4	kg/t	7,0	0,7	7,7	5,7
Alkalis, calculated as 100% NaOH	kg/t	14,5	2,4	16,9	12,0
Paper & cardboard for packaging	kg/t	15,1		15,1	7,1
Wood for packaging	kg/t	34,6		34,6	11,0
Steel for packaging	kg/t	0,1		0,1	0,3
Plastic for packaging	kg/t	6,6		6,6	1,4
Other ancillary product input	kg/t	0,5	1,6	2,1	
Water					
Process water	m^3/t	0,1	0,1	0,2	0,9
Cooling water	m^3/t	3,3	2,5	5,8	7,7
Total water supply	**m^3/t**	**3,4**	**4,4**	**7,8**	**8,6**
Outputs					
Aluminium output					
Finished profile	kg/t	1 000		1 000	1 000
Emissions to air					
Chlorine (as Cl_2)	g/t		0,2	0,2	3,4
Other inorganic chlorinated compounds (expressed as HCl)	g/t		5,3	5,3	
NO_X, as nitrogen dioxide	g/t	55,2	51,6	106,9	131,3
SO_2	g/t	10,3	8,9	19,2	21,5
Dust/particulates, total	g/t		11,1	11,1	
Total gaseous organic carbon (TOC)	g/t		2,2	2,2	6,4
Water					
Water output	**m^3/t**	1,7	3,2	4,9	6,4
Hazardous waste					
Spent caustic bath/sludge for land-filling	kg/t	0,4	0,1	0,7	2,4
Other hazardous waste for land-filling	kg/t	0,8	0,5	1,7	1,2
Hazardous waste for incineration	kg/t	4,3	0,2	4,3	6,6
Hazardous waste for recycling or further processing	kg/t	9,1	3,3	11,8	1,1
Total hazardous waste	***kg/t***	**14,6**	**4,2**	**18,4**	**11,3**
Non-hazardous waste					
Non-hazardous waste for land-filling	kg/t	4,1	0,9	4,8	1,3
Non-hazardous waste for incineration	kg/t	1,6	0,5	2,0	1,3
Non-hazardous waste for recycling or further processing	kg/t	2,7	3,8	6,4	7,5
Total non-hazardous waste	***kg/t***	**8,4**	**5,2**	**13,2**	**10,1**
Other outputs / by products					
Metal scrap for recycling, excluding aluminium	kg/t	5,0	1,3	6,3	4,1
Spent caustic bath/sludge for further processing	kg/t	35,1	4,6	39,7	30,3

7.4. Environmental indicators and main elementary flows for extrusion production

The GaBi software was used to calculate the European gate to gate dataset for extrusion production in accordance with the flow diagram described in Figure 7-3. The dataset is available on request at lci@european-aluminium.eu. The associated environmental indicators and main elementary flows are listed in Table 7-3 to Table 7-5.

7.4.1 Environmental indicators

Table 7-3 *Environmental indicators for the production of 1 tonne of aluminium extrusion from an ingot*

European Aluminium indicators (per tonne of aluminium profile) - gate to gate -	Total 2015	Direct & auxiliary processes	Thermal energy	Electricity
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**4,6E-04**	63%	2%	35%
Acidification Potential (AP) [kg SO_2-Equiv.]	**1,6E+00**	15%	10%	75%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**1,7E-01**	20%	15%	65%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**6,8E+02**	2%	33%	65%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**1,9E-08**	1%	1%	98%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**1,2E-01**	12%	23%	65%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**1,6E+04**	12%	25%	63%
Primary energy from renewable resources (net cal. value) [MJ]	**4,0E+03**	25%	1%	74%
Primary energy from non-renewable resources (net cal. value) [MJ]	**1,2E+04**	8%	30%	62%

From Table 7-3, it's appearing that most of the environmental impacts are related to the energy production and from the aluminium and auxiliary processes. For instance, for Global Warming Potential (GWP) and for total primary energy demand, each category are covered mainly by the energy processes (thermal and electrical energy). For some other indicators like ozone layer depletion most of the impacts are coming from the electricity while for abiotic depletion or photochemical ozone creation potential, most of the impacts are coming from direct and auxiliary processes.

In comparison with 2010 data, the environmental performance of the aluminium extrusion process in Europe improved significantly for most environmental indicators. This strong improvement is explained by a strong decrease of the direct emissions / consumption in the industry as highlighted above.
For instance, the GWP and acidification indicators decreased respectively by 11% and 37% from 2015 to 2010. It seems to have a slight increase of the total primary energy demand but driven mainly by an increase of energy from renewable raw materials used for the packaging (e.g. paper and wood). As a matter of fact, in 2010, wood and paper were representing in total about 10% of the primary energy from renewable raw materials while they represent about 36% in 2015.
The increase of the abiotic depletion indicator (ADP) is mainly explained by the strong increase (+326%) of ADP impact of the electricity production in Europe from 2010 to 2015. This trend is related to the impacts of precious and rare metals entering in the composition of photovoltaic cells and wind mills which are more and more used in EU electricity grid mix (see Table 2-5 and chapter 2.2.5.2). For instance, in 2010, direct electricity consumption was representing about 12% of the impacts related to ADP while its weights in 2015 is about 35% of the ADP impacts.

The strong decrease of the Ozone Layer Depletion Potential (ODP) is explained by a change in Gabi LCIA methodology as highlighted in section 2.2.4. and 2.2.5.2.

Table 7-4 Comparison e*nvironmental indicators for the production of 1 tonne of aluminium extrusion from an ingot (2015 vs 2010)*

European Aluminium indicators (per tonne of aluminium profile) - gate to gate -	**Total 2015**	**Total 2010**	**2015 vs 2010 (Evolution in %)**
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	4,6E-04	3,1E-04	**+48%**
Acidification Potential (AP) [kg SO_2-Equiv.]	1,6E+00	2,4E+00	**-37%**
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	1,7E-01	1,7E-01	**+0%**
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	6,8E+02	7,6E+02	**-11%**
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	1,9E-08	3,1E-05	**-100%**
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	1,2E-01	1,8E-01	**-32%**
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	1,6E+04	1,4E+04	**+8%**
Primary energy from renewable resources (net cal. value) [MJ]	4,0E+03	1,4E+03	**+184%**
Primary energy from non-renewable resources (net cal. value) [MJ]	1,2E+04	1,3E+04	**-11%**

7.4.2 Main elementary flows

For each environmental indicators presented in the tables above, the main contributing elementary flows and processes are presented below. **These main elementary flows are contributing to more than 80% of the respective indicator**.

Table 7-5 Main elementary flows / processes: extrusion process

		Main elementary flows and main related processes: extrusion		
Abiotic Depletion	Elementary flows	Sodium chloride (rock salt) : 59%	Copper: 10%	Lead: 8%
	(Sub) Process	Auxiliary (98%)	Electricity (92%)	Electricity (73%); Fuel (17%)
Acidification Potential	Elementary flows	Sulphur dioxide: 62%	Nitrogen oxides: 31%	
	(Sub) Process	Electricity (81%) ; Auxiliary (9%)	Electricity (60%); Fuel (16%); Auxiliary (10%)	
Eutrophication Potential	Elementary flows	Nitrogen oxides: 74%	Chemical oxygen demand: 7%	Nitrate: 4%
	(Sub) Process	Electricity (60%); Fuel (16%); Process (11%)	Electricity (77%); Auxiliary (7%)	Electricity (86%); Auxiliary (11%)
Global Warming Potential	Elementary flows	Carbon dioxide: 93%	Methane: 6%	
	(Sub) Process	Electricity (60%); Fuel (31%)	Electricity (49%); Fuel (42%)	
Ozone Layer Depletion Potential	Elementary flows	R 114 (dichlorotetrafluoroethane): 90%	R 22 (chlorodifluoromethane): 9%	
	(Sub) Process	Electricity (97%)	Electricity (96%)	
Photochem. Ozone Creation Potential	Elementary flows	Sulphur dioxide: 32%	Nitrogen oxides: 22%	Carbon monoxide: 11%
	(Sub) Process	Electricity (81%); Fuel (7%)	Electricity (60%); Fuel (16%); Process (11%)	Electricity (59%); Fuel (17%); Auxiliary (12%)
Primary energy demand: total	Elementary flows	Natural gas: 31%	Uranium: 19%	Solar energy: 17%
	(Sub) Process	Fuel (67%); Electricity (26%)	Electricity (95%)	Electricity (56%); Auxiliary (44%)
Primary energy from renewable resources	Elementary flows	Solar power: 68%	Wind power: 17%	Hydro power: 15%
	(Sub) Process	Electricity (56%); Auxiliary (43%)	Electricity (94%)	Electricity (96%)
Primary energy from non-renewable resources	Elementary flows	Natural gas: 42%	Uranium: 25%	Hard coal: 15%
	(Sub) Process	Fuel (67%); Electricity (26%)	Electricity (95%)	Electricity (92%)

For instance, 93% of the Global Warming Potential (GWP) is coming from carbon dioxide emissions and 6% from methane emissions. These carbon dioxide emissions are coming from electricity production at 60% and from fuels (i.e. thermal energy) at 31%.

8. Aluminium recycling

Aluminium has been recycled since the metal first began to be used commercially in the opening decades of the 20th century. Since that time a large number of remelters and refiners have been established, converting new and old aluminium scrap into new ingot, deoxidiser for the steel industry and master alloys. It is estimated that 75% of the aluminium ever produced is still in use today.

There are very good commercial reasons why this recycling has always taken place. The high intrinsic value of aluminium makes remelting economically attractive. Using today's technology aluminium and its alloys can potentially be melted and reused without loss of quality. Remelting the aluminium metal into a new ingot requires much less energy than the primary aluminium production from its ore. Aluminium recycling thus saves raw materials and energy, and also reduces demands on landfill sites.

Recycling is a major consideration in continued aluminium use, representing one of the key attributes of this metal, with far-reaching economic, ecological and social implications. More than half of all the aluminium currently produced in the Europe (EU28+EFTA) originates from recycled raw materials and that trend is on the increase. In view of growing end-use demand and a lack of sufficient domestic primary aluminium production in this part of the world, Europe has a huge stake in maximising the collection of all available aluminium, and developing the most resource-efficient scrap treatments and melting processes.

8.1. Scrap terminology

A wide variety of aluminium scrap is processed by the secondary industry. Aluminium scrap terms and definitions are covered in EN 12258-3 [11].

New scrap (also called process scrap or pre-consumer scrap) is surplus material that arises during the production and fabrication of aluminium products up to the point where they are sold to the final consumer. Thus extrusion discards, sheet edge trim, turnings, millings and dross could all be described as new scrap.

Old scrap (also called post-consumer scrap) is the aluminium material which is recovered after an aluminium product or component has been produced, used and finally collected for recycling. Old scrap could be a used aluminium beverage can, a car cylinder head, window frames or electrical conductor cable

8.2. Remelting and refining of aluminium scrap

Once aluminium scrap is collected, sorted and treated, the recovered aluminium is recycled by being remelted or refined. Refiners produce casting alloys and remelters generates wrought alloys for sheets, strips and extrusion. This results in new raw material for a wide variety of applications. For example, refined aluminium can be found in cast engine blocks, while remelted aluminium will be used for products like car bodies or beverage cans.

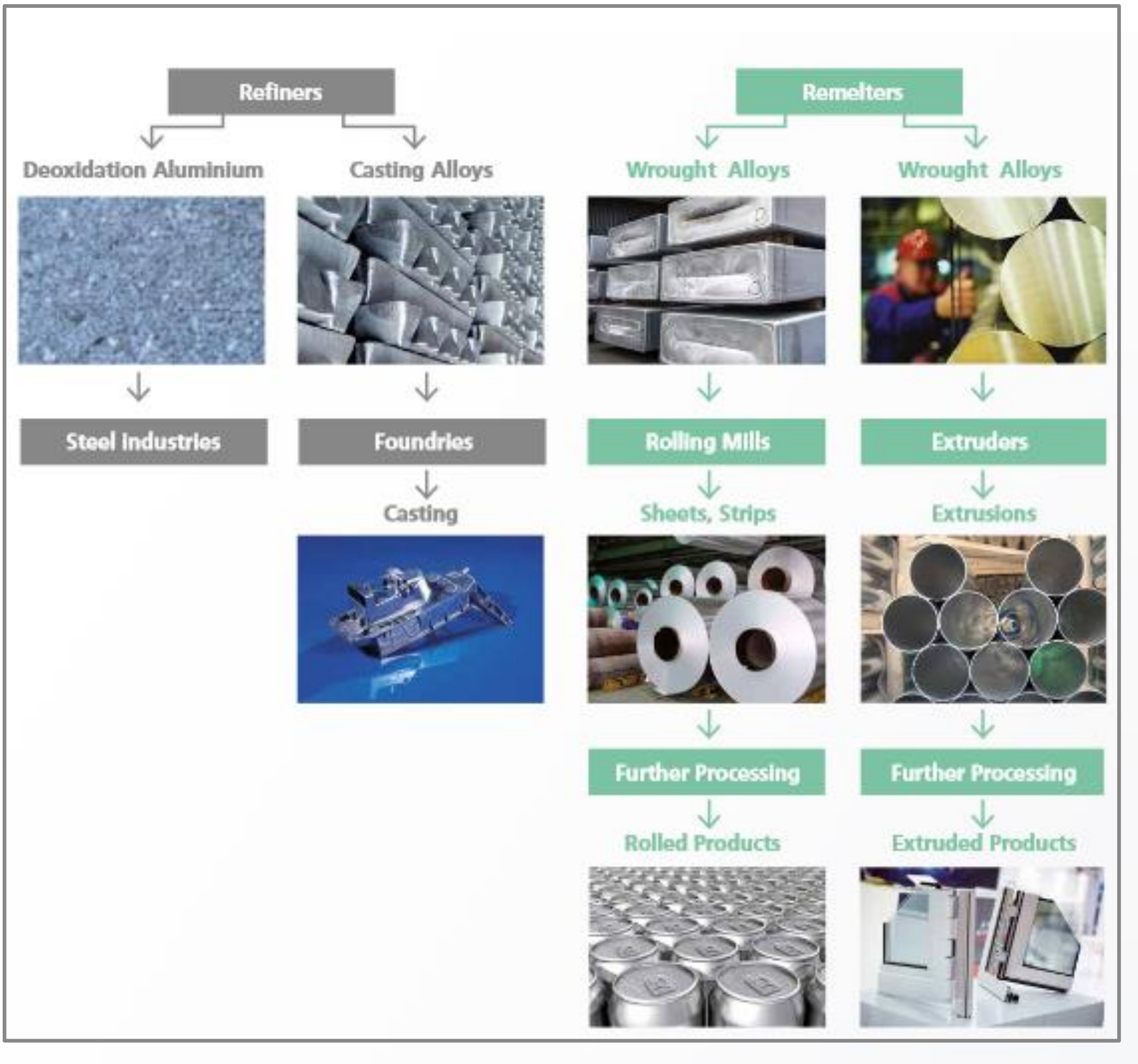


Figure 8-1 Aluminium refiners and remelters

8.3. Mapping of the recycling plants in Europe

The aluminium recycling (refiners and remelters) industry is composed of more than 220 plants. Many of them are small and medium sized enterprises and family owned business.

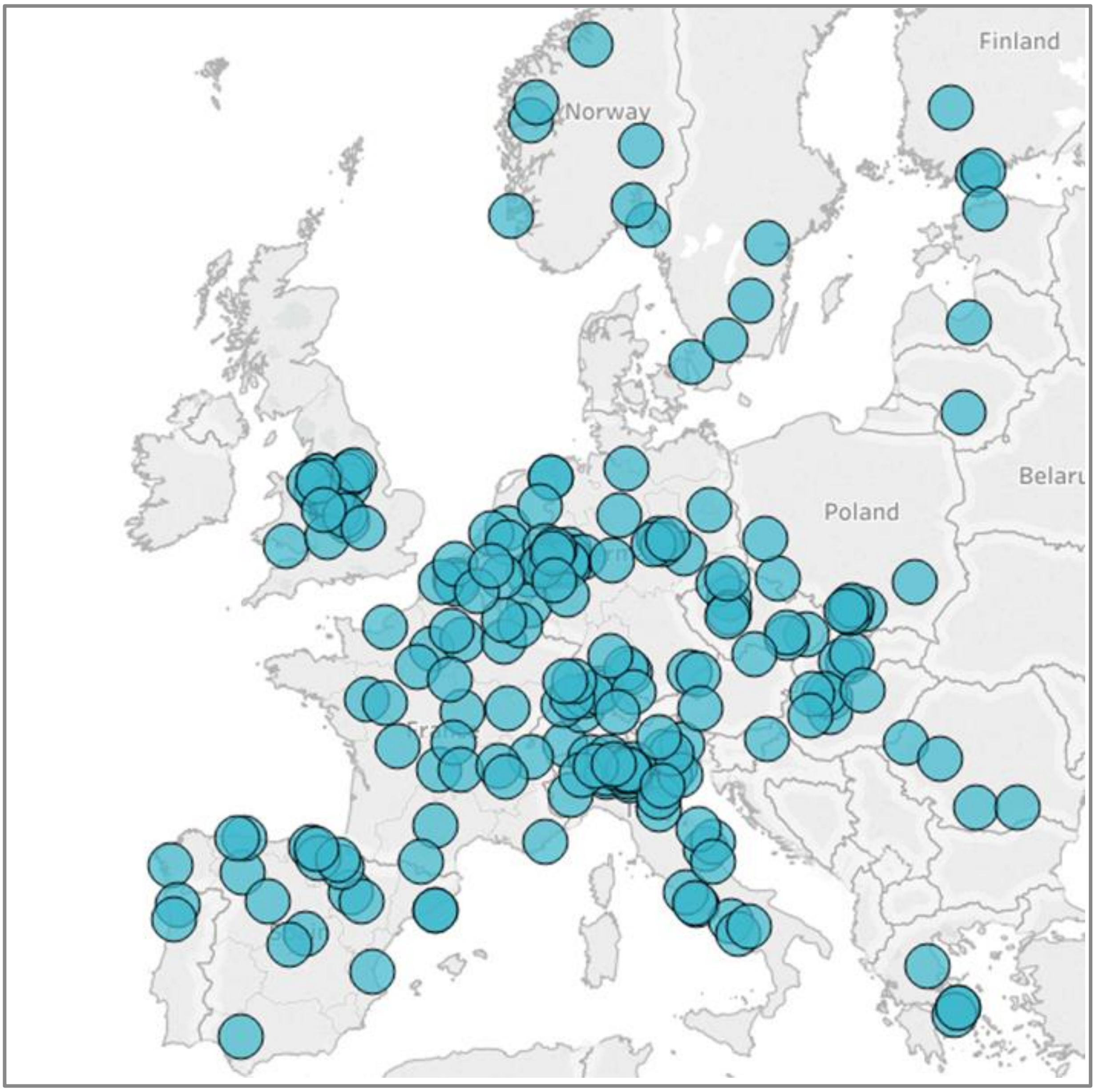
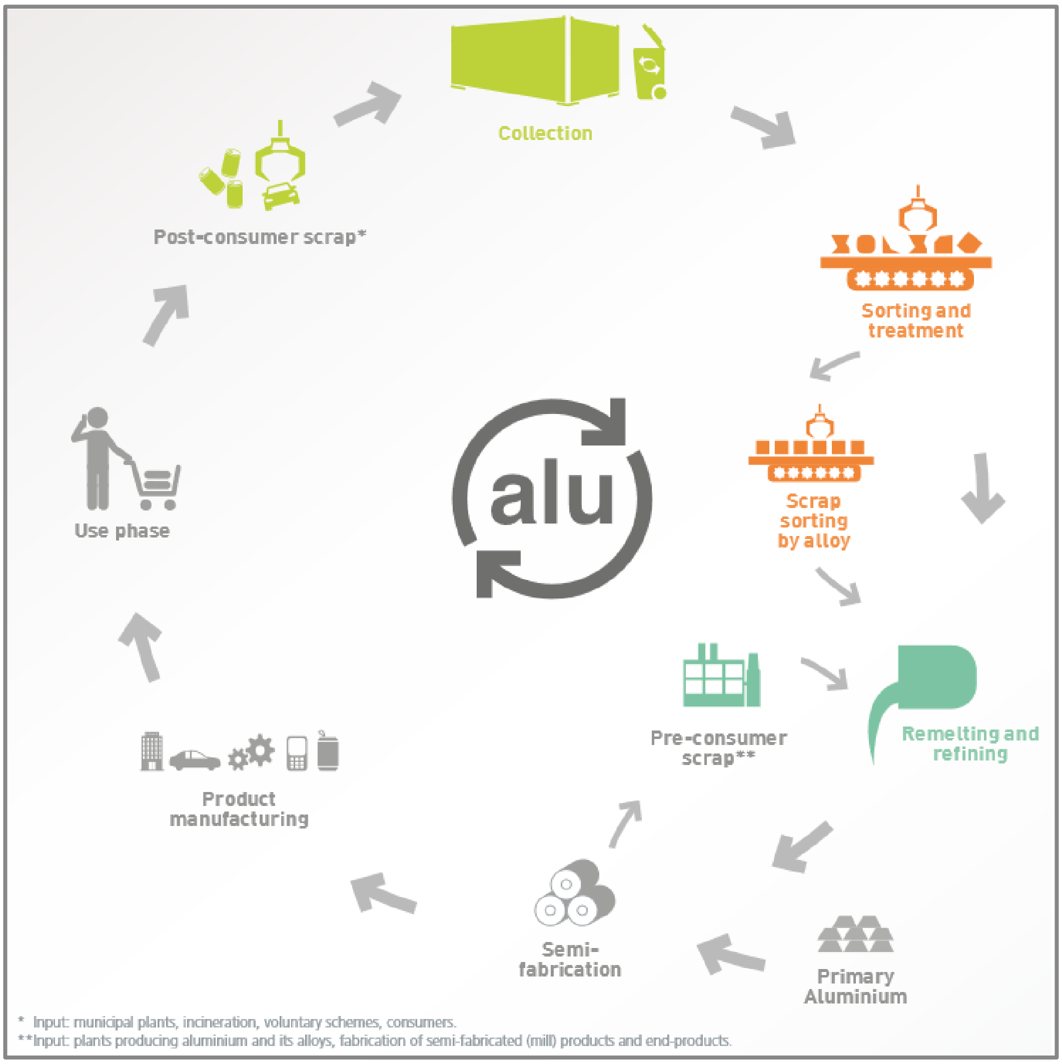


Figure 8-2 Mapping of the aluminium recycling industry in Europe

8.4. Scrap recycling route and corresponding models

Most new aluminium scrap comes into the recycling industry directly from the fabricators. It is therefore of known quality and alloy and is often uncoated. It can then be melted with little preparation, apart perhaps from baling. Such scrap are usually collected by the so-called remelters and melted in reverbatory furnaces (see description in Table 8-1) in order to produce new wrought aluminium alloys. Some new scrap that arises during semi-finishing processes may be coated with paints, ink or plastics. This scrap can be decoated by passing scrap through an oven or a mesh conveyer whilst hot gases are circulated through the mesh to volatilise or burn off the coating. De-coating is usually the only significant scrap preparation step which can be applied to the scrap input by the remelters.
The first model called "scrap remelting" will address this specific recycling route organised through the remelters. **No scrap preparation phase occurring outside the recycling plant is included.**

Old aluminium scrap comes into the recycling industry via a very diversified and efficient network of metal merchants and waste management companies which have the technology to recover aluminium from vehicles, household goods, etc. This is often done using heavy equipment such as shredders, together with magnetic separators, to remove iron, sink-and-float installations, or by the use of eddy current installations to separate aluminium from other materials.
After collection, sorting and preparation, these old scrap are usually purchased by the so-called refiners and are melted mostly into casting alloys, also called foundry alloys. Refiners recycle not only scrap from end-of-life aluminium products but also, scrap from foundries, turnings, skimmings (dross) and aluminium metallics. **The second model called "scrap recycling" will specifically address this recycling route organised through the refiners.**
A bird's eye view of the aluminium recycling route is available on the figure below:



* Input: municipal plants, incineration, voluntary schemes, consumers.
**Input: plants producing aluminium and its alloys, fabrication of semi-fabricated (mill) products and end-products.

Figure 8-3 Overview of the aluminium recycling sector

8.5. Furnace technologies

Several melting processes are used. The choice of process depends upon a number of variables. These include the composition of the scrap, the processes available within a given plant, and economic and scheduling priorities. A breakdown of the most common melting technologies is given in Table 8-1. Molten metal fluxing (to treat the molten metal: chemical adjustment, cleaning, yield maximisation, degassing, etc.) and filtration technology (to remove any unwanted materials prior to casting) has been developed to produce aluminium alloys of the correct quality.

Remelters use mainly reverbatory furnaces so that the “scrap remelting” model is based on this furnace technology only. Refiners use a combination of rotary and reverbatory furnaces which represent about 90% of their furnace technology while induction technology is quite marginal. As a result, the “scrap recycling” model is based on a mix of rotary and reverbatory furnace technologies.

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

Furnace type	Variations	Principal application	Specificities / features	Comments
Reverberatory	Standard	Melting larger volumes of clean scrap and primary feedstock	- Large metal capacity (<=100t). - Few restrictions on feed stock sizes. - Low or no salt flux use - Main co-products: mainly dross	- High yields due to quality of feedstock - Molten metal pumps sometimes used
	Side Well	As above, but enables efficient recovery of some finer feedstocks.	- Large metal capacity. - Wide range of feedstock possible. - Main co-products: dross only	- High yields possible depending upon quality of feedstock - Molten metal pumps sometimes used
	Sloping Hearth	Separation of Al from higher melting point metal contamination (i.e. iron/steel)	- Very efficient at removing high melting point contaminants. - Lower thermal efficiency - Main co-product: mainly dross	- Sometimes incorporated into other furnace types. - Yield dependent on level of contamination.
Rotary	Fixed Axis	Recycling a wide range of feedstocks	- No feedstock restrictions - Large charge volumes possible (<50t) - Feedstock size may be restricted - Relatively high usage of salt flux. - Main co-product: salt slag	Resultant salt slags can be reprocessed.
	Tilting	As above	- As above, but lower use of salt flux. - Feedstock size may be restricted - Main co-product: salt slag	Tends to be used for lower scrap grades.
Induction (not used in models)	Coreless	Melting of cleaner scrap or primary feedstock	- High yields obtained. - No salt flux required. - Flexible use (batch and continuous processing possible) - Relatively small load (<10t) - Restricted feedstock type - Feedstock size may be restricted	High cost (electricity)

Furnace type	Variations	Principal application	Specificities / features	Comments
	Channel	As above.	- High yields obtained. - No combustion gases - No salt flux required -As above, but able to have larger capacities(~20-25t)	High cost (electricity)

The temperature of the molten metal is adjusted and alloying additions may be made with a combination of primary metals, recovered metals and master alloys to ensure the correct chemical composition of the melt.

The main co-product from the reverbatory furnaces is the dross while rotary furnaces which use salt as fluxing agent, produces salt slag. Both co-products are usually treated in order to recover the aluminium metal and to regenerate the salt. Such treatments are part of the two models.

8.6. Products from the aluminium recycling industry

Whether billets or slabs are produced by primary aluminium smelters or remelters, the alloy type produced is still only a function of the composition of the metal and the input added in their respective cast houses. Filtration, degassing, casting and homogenising technology ensure equivalent product quality.

The aluminium refiners convert most of their materials into foundry ingot, generally based on the aluminium-silicon alloy system with additions of other metals such as copper and magnesium. These ingots, complying with national, international or aerospace specifications, are used to produce aluminium castings. The casting processes include sand and permanent mould casting, high- and low-pressure casting and investment casting.

The actual mix of recycling techniques applied to a specific product depends on many factors. The treatment of recycling in each specific LCA study should preferably be discussed with aluminium industry representatives (more information at lci@european-aluminium.eu)

8.7. Dross recycling and salt slag treatment [10]

In absence of fluxing salt, melting aluminium usually produces residues such as dross or skimmings which is mainly composed of aluminium oxides and entrapped aluminium metal. Depending on the scrap input quality and size, between 20 and 100 kg of dross can be produced per tonne of ingot with a metal content varying from 30 to 60%. Aluminium metal contained in dross or skimmings, is recycled as part of the aluminium refiners' operations. Large pieces of metal are separated from cool skimmings by manual sorting before skimmings are fed to impact or ball mills in which the more friable aluminium oxide is ground up; finer metal fractions may then be recovered with subsequent screening operations. Aluminium metallics, as a product of skimmings recycling operations, are recovered by a variety of methods with varying yield. Skimmings can also be fed directly into rotary furnaces and treated with more or less salt flux. No specific data have been collected to update the model dross/skimmings recycling: this work should be done in the future within a dedicated task force within European Aluminium.

Salt flux is used mainly in rotary furnace in order to clean the melt and to collect the contaminants within the so-called salt slag. Salt slag contains between 5 and 20% of aluminium metal. Most of the salt slag is treated to recover the aluminium metal. This treatment includes a crushing and grinding process aiming at recovering the metal granulate which contains about 80% of aluminium metal. This metal granulates are melted in rotary furnaces. The non-metallic residue is then leached and the residual metal is oxidised. The oxides and others insoluble compounds are then separated from the leaching solution through filtration. The last step consists in a crystallisation process to regenerate the salt flux. By applying the Best Available Technique (BAT), 100% of the salt slag can be valorised. No specific input and output data have been collected in order to model this salt slag treatment and associated aluminium recovery: this work should be done in the future within a dedicated task force within European Aluminium.

8.8. Remelting model

8.8.1 Data consolidation, averaging and modelling

Input and output data used in the "scrap remelting" model have been collected by European Aluminium. These data are representative for integrated cast houses which are part of rolling plants. From the survey, European Aluminium cover a total of 88% of the integrated cast houses production.
Such integrated cast houses usually uses a mixed aluminium input composed mainly of clean process scrap (65-75%), ingot for remelting (20-25%) and alloying elements (1%) and some liquid aluminium (5-10%).

For simplification, only scrap inputs are considered, i.e. other aluminium inputs are substituted by aluminium scrap. Table 8-2 reports the consolidated direct inputs and outputs calculated for 1 tonne of ingot.

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

Scrap remelting production *(in integrated cast house)* *Figures for 1 tonne of ingot*	**Unit**	**Remelting & ingot casting**	**Remelting & ingot casting**
Inputs		**2015 data**	**2010 data**
Aluminium scrap	kg/t	1 019	1 041
Energy inputs			
Thermal energy (i.e. fuels)	**MJ/t**	**3 211**	**3 828**
Heavy Oil	MJ/t	71	77
Diesel and light fuel Oil	MJ/t	47	67
Natural Gas	MJ/t	3 093	3 532
Other energy source	MJ/t	0	151
Purchased electricity	kWh/t	150	124
Total energy (thermal + electricity)	**MJ/t**	**3 752**	**4 275**
Auxiliary products, inputs			
Fluxing salts	kg/t	21,5	
Argon	kg/t	1,9	1,7
Nitrogen	kg/t	0,8	0,5
Chlorine	kg/t	0,2	0,3
Absorbant for exhaust gas treatment	kg of CaOeq/t	0,3	0,8
Other ancillary material input	kg/t		0,5
Water inputs			
Process water	m^3	0,0	0,9
Cooling water	m^3	8,2	4,9
Total water supply	**m^3**	**8,3**	**5,9**
Aluminium outputs			
Unscalped rolling ingots	kg/t	1 000	1 000
Dross/skimmings	kg/t	51	50
Metal content of dross/skimmings	%	44%	70%
Emissions to air			
Chlorine (as Cl_2)	g/t	0,7	1,3
Other inorganic chlorinated compounds (expressed as HCl)	g/t	10,6	15,6

Scrap remelting production *(in integrated cast house)* *Figures for 1 tonne of ingot*	Unit	Remelting & ingot casting	Remelting & ingot casting
Dust/particulates, total	g/t	31,3	52,5
NOx, as nitrogen dioxide	g/t	300,0	353,3
SO_2	g/t	52,2	64,7
Total gaseous organic carbon (TOC)	g/t	65,1	57,0
Emissions to water			
Water output	M^3/t	8,1	5,4
Waste (excluding dross, aluminium scrap & demolition waste)			
Hazardous waste for land-filling	kg/t	1,3	0,8
Hazardous waste for incineration	kg/t	0,0	0,0
Hazardous waste for recycling or further processing	kg/t	2,4	5,9
Total hazardous waste	**kg/t**	**3,8**	**6,6**
Non-haz. waste for land-filling	kg/t	0,6	0,1
Non-haz. waste for incineration	kg/t	0,0	0,1
Non-hazardous waste for recycling or further processing	kg/t	2,1	5,7
Metal scrap for recycling, excluding aluminium	kg/t	0,2	0,8
Total non-hazardous waste	**kg/t**	**2,7**	**6,6**

About 3 200 MJ of thermal energy are used to melt the scrap and to cast the aluminium. This figure can be compared to the theoretical energy value of 1 140 MJ/tonne which is needed to heat up and to melt pure aluminium from 20°C up to 720°C [15]. In comparison with 2010, data the total energy consumption have been reduced by 12%.

In comparison with 2010, the total scrap consumption to produce 1 tonne of ingot decreased from 1 041 to 1 019 kg. Regarding the metal output, the volume of dross / skimming generated is quite stable (50 kg/t). However, the metal content of the dross seem to have decreased from 70% in 2010 to 44% in 2015.

8.8.2 Environmental indicators and main elementary flows for scrap remelting

The GaBi software was used to calculate the European gate to gate dataset for producing 1 tonne of sawn ingot from clean scrap in accordance with the data reported in Table 8-2. The model includes the dross recycling. The dataset is available on request at lci@european-aluminium.eu and environmental indicators are listed in Table 8-3.

Environmental indicators

Table 8-3 *Environmental indicators for the production of 1 tonne of aluminium wrought alloys ingot from scrap (without scrap benefits / burdens)*

European Aluminium indicators (per tonne of wrought ingot from scrap) - gate to gate -	Total 2015	Direct & auxiliary processes	Thermal energy	Electricity
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**1,2E-04**	65%	10%	25%
Acidification Potential (AP) [kg SO_2-Equiv.]	**6,8E-01**	41%	28%	31%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**9,3E-02**	52%	28%	21%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**3,3E+02**	1%	76%	23%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**3,5E-09**	1%	7%	92%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**6,0E-02**	24%	53%	23%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**5,9E+03**	0%	70%	30%

European Aluminium indicators (per tonne of wrought ingot from scrap) - gate to gate -	**Total 2015**	**Direct & auxiliary processes**	**Thermal energy**	**Electricity**
Primary energy from renewable resources (net cal. value) [MJ]	**4,8E+02**	2%	7%	91%
Primary energy from non-renewable resources (net cal. value) [MJ]	**5,4E+03**	0%	75%	25%

From Table 8-3, it's appearing that most of the environmental impacts are related to the energy production and from the aluminium and auxiliaries processes. For instance, for Global Warming Potential (GWP) and for total primary energy demand each category are covered mainly by the energy processes (thermal and electrical energy). For some other indicators like ozone layer depletion most of the impacts are coming from the electricity while for eutrophication most of the impacts are coming from direct and auxiliary processes.

In comparison with 2010 data, the environmental performance of the aluminium extrusion process in Europe improved significantly for most environmental indicators. This strong improvement is explained by a strong decrease of the direct emissions / consumption in the industry as highlighted above.
For instance, the GWP and primary energy demand indicators decreased respectively by 9% and 4% from 2015 to 2010. In addition, indicators like acidification and eutrophication decreased as well by 19% and 3%.
The increase of the abiotic depletion indicator (ADP) is mainly explained by the strong increase (+326%) of ADP impact of the electricity production in Europe from 2010 to 2015. This trend is related to the impacts of precious and rare metals entering in the composition of photovoltaic cells and wind mills which are more and more used in EU electricity grid mix (see Table 2-5 and chapter 2.2.5.2). For instance, in 2010, direct electricity consumption was representing about 8% of the impacts related to ADP while it's weights in 2015 is about 25% of the ADP impacts.

The strong decrease of the Ozone Layer Depletion Potential (ODP) is explained by a change in Gabi LCIA methodology as highlighted in section 2.2.4. and 2.2.5.2.

Table 8-4 Comparison e*nvironmental indicators for the processes for 1 tonne of aluminium wrought alloy ingot from scrap (without scrap benefits / burdens) - 2015 vs 2010*

European Aluminium indicators (per tonne of wrought ingot from scrap) - gate to gate -	**2015**	**2010**	**2015 vs 2010 (Evolution in %)**
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	1,2E-04	7,0E-05	**+72%**
Acidification Potential (AP) [kg SO_2-Equiv.]	6,8E-01	8,4E-01	**-19%**
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	9,3E-02	9,6E-02	**-3%**
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	3,3E+02	3,7E+02	**-9%**
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	3,5E-09	4,7E-06	**-100%**
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	6,0E-02	7,6E-02	**-21%**
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	5,9E+03	6,2E+03	**-4%**
Primary energy from renewable resources (net cal. value) [MJ]	4,8E+02	1,9E+02	**+154%**
Primary energy from non-renewable resources (net cal. value) [MJ]	5,4E+03	6,0E+03	**-9%**

Main elementary flows:

For each environmental indicators presented in the tables above, the main contributing elementary flows and processes are presented below. **These main elementary flows are contributing to more than 80% of the respective indicator**.

Table 8-5 Main elementary flows and processes: remelting process

		Main elementary flows and main related processes: remelting		
Abiotic Depletion	Elementary flows	Sodium chloride (rock salt) : 65%	Lead: 11%	Copper: 8%
	(Sub) Process	Auxiliary (100%)	Fuel (60%); Electricity (39%)	Electricity (88%); Fuel (10%)
Acidification Potential	Elementary flows	Nitrogen oxides: 48%	Sulphur dioxide: 47%	
	(Sub) Process	Process (54%); Fuel (28%); Electricity (16%)	Electricity (44%); Fuel (29%); Process (25%)	
Eutrophication Potential	Elementary flows	Nitrogen oxides: 91%	Chemical oxygen demand to fresh water:3%	
	(Sub) Process	Process (54%); Fuel (28%); Electricity (16%)	Electricity (63%); Process (28%)	
Global Warming Potential	Elementary flows	Carbon dioxide: 92%	Methane: 7%	
	(Sub) Process	Electricity (73%); Fuel (26%)	Fuel (78%); Electricity (16%)	
Ozone Layer Depletion Potential	Elementary flows	R 114 (dichlorotetrafluoroethane): 91%	R 22 (chlorodifluoromethane): 9%	
	(Sub) Process	Electricity (92%); Fuel (7%)	Electricity (91%); Fuel (8%)	
Photochem. Ozone Creation Potential	Elementary flows	Nitrogen oxides: 30%	Sulphur dioxide: 21%	Methane: 9%
	(Sub) Process	Process (54%); Fuel (28%); Electricity (16%)	Electricity (44%); Fuel (29%); Process (25%)	Fuel (78%); Electricity (15%)
Primary energy demand: total	Elementary flows	Natural gas: 69%	Uranium: 9%	Hard coal: 6%
	(Sub) Process	Fuel (94%); Electricity (6%)	Electricity (91%); Fuel (8%)	Electricity (91%); Fuel (8%)
Primary energy from renewable resources	Elementary flows	Solar power: 49%	Wind power: 26%	Hydro power: 23%
	(Sub) Process	Electricity (90%)	Electricity (91%)	Electricity (91%)
Primary energy from non-renewable resources	Elementary flows	Natural gas: 76%	Uranium: 10%	Hard coal: 6%
	(Sub) Process	Fuel (94%); Electricity (6%)	Electricity (91%); Fuel (8%)	Electricity (91%); Fuel (8%)

For instance, 92% of the Global Warming Potential (GWP) is coming from carbon dioxide emissions and 7% from methane emissions. These carbon dioxide emissions are coming from electricity production at 73% and from fuels (i.e. thermal energy) at 26%.

8.9. Refining model

Recycling efficiency and recycling routes highly depend on scrap origin and quality. As a result, for specific aluminium applications or products, it is highly recommended to analyse more closely the recycling scenario(s) and the recycling routes in order to develop more adapted models and associated LCI datasets.

European Aluminium members are developing an ad hoc task force to address these topics. Thus, no specific update is already available for these datasets. The 2010 data presented in the previous report [1] are kept constant.

This dataset corresponds to the production of 1 tonne of casting alloys aluminium ingot (i.e. casting ingots used by foundries) from the modelled mix of the European scrap market. This dataset includes the melting, purifying and casting operations. It also includes the salt slag processing. These refining datasets were based on the recycling of the European scrap mix according to the ESSUM model [10].

Table 8-6 *Environmental indicators for the processing of 1 tonne of foundry aluminium alloys ingot from scrap (without scrap benefits / burdens)*

European Aluminium indicators (per tonne of foundry ingot from scrap) - gate to gate -	**Total 2010**	**Direct, auxiliary and thermal processes**	**Electricity**
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	**6,9E-04**	99%	1%
Acidification Potential (AP) [kg SO_2-Equiv.]	**8,9E-01**	55%	45%
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	**7,4E-02**	71%	29%
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	**5,1E+02**	81%	19%
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	**6,9E-06**	11%	89%
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	**9,2E-02**	74%	26%
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	**8,5E+03**	78%	22%
Primary energy from renewable resources (net cal. value) [MJ]	**2,7E+02**	12%	88%
Primary energy from non-renewable resources (net cal. value) [MJ]	**8,3E+03**	80%	20%

8.10. LCA & aluminium recycling

Preserving the aluminium metal during the whole product life cycle and during 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 to credit properly the ability of aluminium to be efficiently recycled without losing its properties. The European aluminium industry recommends using the so-called substitution methodology which considers that recycled aluminium substitutes primary aluminium so that only metal losses during the whole life cycle needs to be balanced by primary aluminium. Details about such methodology are given in the technical document "LCA & aluminium recycling" which can be downloaded from the European Aluminium website.

This allocation methodology will be explained through the following example for an aluminium can. The key parameter is the end of life recycling rate, the fraction of the product at end of life which is effectively recycled into a new ingot. If such recycling rate reaches for example 80% for the modelled product. This means that the material acquisition in the product model will be based on 80% on recycling and 20% on primary production. In such a way, the life cycle burdens of the aluminium cans are directly connected to their performances in term of end of life recycling rates, providing a strong impetus to metal conservation and the development of optimal collection and recycling schemes.

9. Interpretation

9.1 Identification of the significant issues

9.1.1 Functional unit definition

For each dataset related to the aluminium production or transformation, the functional unit and the system boundary have been defined in the various chapter 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) uses 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 to a customer requirement regarding the metal composition (e.g. alloys) or a defined thickness (e.g. aluminium sheet or foil processing). Thus, in case of 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 reasonable proxy for most of the wrought aluminium alloys which usually contain less than 5% of alloying elements.
For cast alloys, it is recommended to the user to 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

The various environmental data have been considered as robust and representative of the European aluminium industry. For instance, the overall completeness of the data survey is about 90% for the primary production and the sheet production. Regarding the extrusion production, the overall completeness is more limited (i.e. about 30%). However, based on experts' judgements the plants covered (more than 70) are representative of the various end uses market of extrusion in Europe.

With a continuous focus on energy (e.g. electricity consumption for primary), air emissions and the inclusion of new inventory flows such as land occupation and transformation for the bauxite mining and alumina production (based on IAI datasets), the coverage of the various inputs/outputs can be considered to have been improved.

For water use (e.g. sea water), the data are very dependent from the local situation (e.g. plant location) of each aluminium facility. Thus, water consumption should be better tackled from a local context (e.g. plant location for the use of sea water or for water stress index) and the European average figure may not be representative for the local context.

9.1.3 Modelling and methodological choices

For most datasets and environmental impacts, energy (e.g. thermal or electricity) represents a significant part of the impacts. It's especially the case for the primary aluminium production which is electricity-intensive.

Within European Aluminium electricity model (see chapter 4.4), **90% is based on a direct reporting of companies which provide the share of the various energy carriers for producing the electricity they consume**. For the rest, the national grid mix of the country (based on International Energy Agency data) where the plant is located was used when no direct data were available or reported. Using a 100% industry electricity mix would have been more appropriate. However, the default choice of using national grid mix could be seen as a conservative approach as explained above.

In addition, regarding the electricity imports model, few specific background data in Gabi 7 database is existing to model the production of electricity from gas in the Middle East (e.g. United Arab Emirates or Qatar). Middle East represents about 20% of European imports of aluminium. The Middle East smelters have their own on site electricity generation and have the best available technologies for production of electricity from natural gas [24], [25], [26], [27], [28]. Thus, in the Gabi model, a proxy based on S. Arabia dataset which is considered as conservative (i.e. not referring fully to combined cycle turbine datasets[18]) by experts' judgment has been used. The importance of the right dataset for modelling the electricity from gas for Middle East smelters is highlighted in the chapter 9.2.2 below.

Regarding the other background datasets, in some cases, 2015 data were not yet available in Gabi 7 database. Thus, the latest background dataset available was used (e.g. 2011 data for pitch production or 2013 data for petroleum coke 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 2015 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 in relation to their emissions in storage or landfilling sites. This proxy has been considered based on discussions with experts.

As much as possible, allocation has been avoided for the foreground data by expanding the system boundaries as explained in chapter 2.2.3. As far the background datasets, the allocation rules used in Gabi 7 database [12] 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 lead by the European Commission, up to date impact categories and methodologies have been proposed / presented in the latest PEF guidance document [21]. These PEF guidance documents are frequently revised / modified as part of the process.

Thus, 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 the previous reports.**

Once the final PEF guidance documents will be published *(i.e. probably after the conclusion of the Environmental Footprint transition phase 2018-2020)*, European Aluminium selection of impacts categories could be adjusted when relevant.

9.1.5 Significant contribution from life cycle stages, unit or groups of processes

- Energy

As explained above, the energy has got a significant part of the environmental footprint of aluminium production, thus a specific electricity model has been developed for the primary aluminium production. For semis production and recycling, European electricity grid mix has been used. Within the aluminium value chain, only the upstream processes (e.g. smelting) can be considered as an energy intensive segment [18], [19]. In addition, some of the European Aluminium smelters are having their own electricity production process [19]. **Thus, it's important to use industry specific power mixes for the primary aluminium production.** For the transformation and recycling process, European electricity grid mix can be considered as a consistent average / proxy.

- Transport

For the primary ingot datasets (i.e. cradle to gate), only the transport of bauxite, alumina and ingots (for the primary aluminium used in Europe) has been included. The transport module includes sea boat, barge, road and rail (as explained in chapter 2.2.5.2.) as the sourcing of these products are mostly coming from outside Europe (see Figure

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[18] The 6 smelters in the Middle East are new plants and have their own on site electricity generation based on combined cycle gas and steam turbine technology which is the among most advanced technologies to generate electricity from natural gas.

2-4). The transport of the other raw materials (e.g. caustic soda, aluminium fluoride) into the plant has not been included. These other raw materials are sourced at regional level and are used in a limited quantity (e.g. producing 1 tonne of liquid aluminium via the electrolysis process requires about 2 tonnes of alumina versus 16 kg of aluminium fluoride). Thus, the environmental impacts of the transport of these other raw materials is expected to be negligible.

Regarding the transformation and recycling processes, transport of raw materials (including the scrap or ingots) inside the plant is not included in the system boundaries. As mentioned above, the datasets are gate to gate processes i.e. 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 as well as the raw materials inputs are sourced at local (or at regional) level.

- Scrap preparation

As mentioned above in chapter 8.4, no additional scrap preparation has been included in the Gabi model. All the scrap preparation phases which are occurring on the remelting 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 in consideration when assessing the environmental impacts of the recycling production.

9.2 Evaluation of the completeness, sensitivity and consistency checks

9.2.1 Completeness check

European Aluminium is collecting and developing LCI datasets for more than 15 years. This exercise is conducted on 5 years basis. Thus, the set of data collected is consistent over the year and has been improved based on the experience gained from the previous exercises (e.g. land occupation and rehabilitation collected by IAI).

As it was done for the previous exercise, the 2015 industry data have collected, analysed and consolidated to generate European average in collaboration with the Technical Working Group (TWG) of the Sustainability Committee. When relevant, the differences between 2015 and 2010 datasets have been highlighted and explained in the report.

In addition, European Aluminium worked in collaboration with external LCA experts acting as consultants: the Gabi models / plans have been developed in collaboration with ThinkStep and the Environmental Profile Report have been checked and reviewed by Prof. Dr. Matthias Finkbeiner and Prof. Dr. Walter Klöpffer. The recommendations of these experts involved at the various steps of the project (i.e. interactive process) have been integrated to the final report. The data reported in the report are satisfying the goal and scope of the LCI project which is to provide updated environmental and LCI data related to aluminium processes in Europe.

9.2.2 Sensitivity check

No significant sensitivity analysis was conducted in the framework of the report. However, when needed experts judgements and the expertise gained from the previous reports were considered and integrated in the report. In addition, limitations / proxy used are presented in the report and allocation is usually avoided through system expansion (e.g. inclusion of scrap remelting into the system boundary).

Thus, the uncertainties in the data, allocations methods (should) have a limited effect on the reliability of the final results and on the conclusions.

Nevertheless, a comparison has been done regarding the impacts of 3 different datasets to model the electricity production from natural gas used in the Middle East region. As highlighted above, about 50% of the European consumption of primary aluminium metal is coming from imports. From 2010 to 2015, the share of the imports from

Middle East increased from 11% to 21%. Thus, the share of the electricity mix of European imports based on natural gas increased from 12% in 2010 to 22% in 2015.

The 6 smelters in the Middle East are new plants and have their own on site electricity generation [24], [25], [26], [27], [28] based on combined cycle gas and steam turbine technology which is the among most advanced technologies to generate electricity from natural gas. However, in Gabi professional database, no ready-made datasets were already available to model a full combine cycle gas and steam turbine technology for generating electricity from natural gas.

Thus, **for information purpose** a comparison between 3 datasets for producing 1kWh electricity from natural gas is provided in Table 9-1 below. The comparison is done for the following datasets:

- Russia: which was used by default for Middle East in the **previous results based on 2010 data**
- S. Arabia: which is a new "ready-made" dataset available in the new Gabi database and **used as default dataset for the updated 2015 results**
- Germany: which is commonly used as a proxy for the Europe (i.e. best technology available in Europe)

Table 9-1: *Environmental impacts for producing 1kWh electricity from natural gas between from 3 different datasets*

- Production of 1 kWh electricity from natural gas based on various country data -	**Russia (absolute value)**	**Russia (in %*)**	**S. Arabia (in %*)**	**Germany (in %*)**
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	6,2E-08	100 %	1 %	39 %
Acidification Potential (AP) [kg SO_2-Equiv.]	1,2E-03	100 %	91 %	28 %
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	2,5E-04	100 %	87 %	20 %
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	7,7E-01	100 %	83 %	65 %
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	1,0E-14	100 %	7 %	163 %
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	1,4E-04	100 %	66 %	44 %
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	1,3E+01	100 %	86 %	61 %
Primary energy from renewable resources (net cal. value) [MJ]	3,7E-03	100 %	18 %	539 %
Primary energy from non-renewable resources (net cal. value) [MJ]	1,3E+01	100 %	86 %	61 %

*Index based on Russia = 100%

From the table above, it's appearing that the Global Warming Potential (GWP) for producing 1 kWh electricity from natural gas in S. Arabia is 17% lower than the one in Russia and 35% lower than the one in Germany.

When it comes to the consolidated dataset and indicators for the primary aluminium used in Europe, the GWP for the primary aluminium used in Europe is 2% lower with the dataset related to S. Arabia and 5% lower with the dataset related to Germany in comparison with the Russian datasets as default proxy (used in the previous report based on 2010 data).

Regarding the 2015 results, they are based the S. Arabia datasets. This could be considered as a conservative approach as the technology used by the aluminium producers in the Middle East is closer to the technology used in Germany. In the future, the aluminium industry should develop more specific and accurate datasets representative of the combine cycle gas and steam turbine technology used by aluminium smelters in the Middle East.

Table 9-2: *Influence of the choice of the dataset for electricity production from gas in the Middle East on the environmental impacts of the primary aluminium used in Europe*

- Results per tonne of primary ingot used in Europe - - cradle to gate -	Russia (absolute value)	Russia (in %*)	S. Arabia (in %*)	Germany (in %*)
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	4,3E-06	100 %	98 %	99 %
Acidification Potential (AP) [kg SO_2-Equiv.]	4,3E-02	100 %	100 %	97 %
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	2,9E-03	100 %	98 %	88 %
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	8,9E+00	100 %	98 %	95 %
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	1,2E-10	100 %	100 %	100 %
Photochem. Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	2,4E-03	100 %	97 %	95 %
Primary energy demand from ren. and non ren. resources (net cal. value) [MJ]	1,6E+02	100 %	98 %	95 %
Primary energy from renewable resources (net cal. value) [MJ]	4,7E+01	100 %	100 %	100 %
Primary energy from non-renewable resources (net cal. value) [MJ]	1,1E+02	100 %	97 %	92 %

*Index based on Russia = 100%

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 differences and limitations are consistent with the purpose of the study.

In addition, in some cases, some conservative approaches might have been used during the modelling phase as highlighted above (e.g. background datasets for the electricity generation from gas).

9.3 Conclusions, limitations and recommendations

9.3.1 Identification of significant issues

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 to a specific customer requirement regarding the metal composition (e.g. alloys) or to 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 as robust and representative of the European aluminium industry**. In addition, the data quality have been continuously improved in comparison with the previous report. As far (fresh or sea) water consumption, it should be taken in consideration within the local context.
- **Some background datasets in the Gabi model could be judged as "conservative"** by using of proxy which has a higher environmental impact that the reality of the industry process.
- Impacts categories: the impacts categories presented in the report are given for information to allow a comparison between 2015 and 2010 data. In the framework of the PEF, some additional or new LCIA methods are under discussion. At the end of the PEF transition period in 2020, **European Aluminium selection of impacts categories could be adjusted when relevant**.

- Energy contributes significantly to the environmental impact of aluminium production. **Thus, it's important to use industry specific power mixes especially for the 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 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 in consideration when assessing the environmental impacts of the recycling production**.

9.3.2 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 are satisfying 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), allocations methods (2.2.3) highlighted above (should) have a limited effect on the reliability of the final results and on the conclusions.
- 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 consistent with the purpose of the study.
- In addition, in some cases, some conservative approaches might have been used during the modelling phase as highlighted above (e.g. see 9.1.3 and 9.2.2).

9.3.3 Conclusions and recommendations

European Aluminium's Environmental Profile Report 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 product 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 membership who provide data for each of their own process steps. Therefore, our report provides the **most up-to-date data averages available for these processes, and it is recommended that they shall be used for LCA purposes**, **whenever generic aluminium data for Europe are 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. lightweighting, endless 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, is 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 are coming from the aluminium industry (i.e. via European Aluminium Technical Working Group) and Thinkstep. In addition, the final report has been externally reviewed by two renowned experts (i.e. Prof. Dr. Matthias Finkbeiner and Prof. Dr. Walter Klöpffer). This critical review recognises the continuous efforts made by the aluminium industry regarding LCA as stressed in the following statement: "*To sum up, this project is an excellent example for generic data acquisition, consolidation and presentation. It contributes to the Life Cycle Assessment development by providing reliable data for one important material and continues a tradition of one and a half decade in an exemplary way*".

Regarding the results, the updated data demonstrate a **strong improvement of the environmental performance of the aluminium industry in Europe**. First, the environmental impacts of the primary aluminium production in Europe decreased significantly (e.g. -21% for Global Warming Potential) and the environmental performance of the primary aluminium consumed in Europe remained stable.
Secondly, as for the semi-fabrication (rolling and extrusion) and the recycling industry, the updated data also indicate **a strong improvement of the environmental performance of those processes** in Europe.

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. This work could also complement the European Commission's efforts to develop a Product Environmental Footprint (PEF) compliant database. Therefore, European Aluminium new LCI datasets shall be used to generate PEF-compliant LCI datasets.

10. Appendix

10.1 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
Annealing	Thermal treatment to soften metal by reduction or removal of stress resulting from cold working and/or by coalescing precipitates from the solid solution.
Blank	Piece of metal of regular or irregular shape taken from a flat wrought product intended for subsequent processing such as bending, stamping or deep drawing.
Can stock	Sheet or strip used for the fabrication of rigid cans, including lids and tabs, formed by drawing or pressing operations. Can stock covers can body stock, lid stock and tab stock.
Casting (process)	Process in which molten metal is poured into a mould and solidified.
Casting alloy	Alloy primarily intended for the production of castings.
Converter foil	Rolled aluminium in the gauge range 5 µm to 200 µm, produced either by double rolling (5µm to 70 µm), or single rolling (35 µm to 200 µm), typically annealed soft and supplied for further processing such as colouring, printing, embossing or laminating
Direct chill (DC) casting	Semi-continuous casting technique in which molten metal is solidified in a water-cooled open-ended mould.
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 though 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.

Term	Definition
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.
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.

10.2 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
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.
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

Term	Definition
	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: Recycling input rate: Recycled aluminium produced from traded new scrap and old scrap as a percentage of total aluminium (primary and recycled sources) supplied to fabricators. Overall recycling efficiency rate: Recycled aluminium produced from traded new scrap and old scrap as a percentage of aluminium available from new and old scrap sources. End-of-life recycling efficiency rate: Recycled aluminium produced from old scrap as a percentage of aluminium available from old scrap sources. The end-of-life collection rate: Aluminium collected from old scrap as a percentage of aluminium available for collection from old scrap sources. The end-of-life processing rate: Recycled aluminium produced from old scrap as a percentage of aluminium collected from old scrap sources.

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10.4 List of figures

10.5 List of tables

11. Report from the independent reviewers

FINAL 01.02.2018

Report from the independent reviewers

Walter Klöpffer and Matthias Finkbeiner

Chapter 11 of the European Aluminium Environmental Profile Report (version 15th December 2017), pp. 101 ff

11.1 The critical review in Life Cycle Assessment (LCA)

It is clearly stated in the LCA-related ISO standards [1-4] that comparative assertions, based on LCA studies, are only allowed if the performance of a LCA study is strictly done with a "critical review". Without comparative assertions, a review by one expert is sufficient. If, however, the superiority (or equality) of one system studied over one or more competing systems is claimed, a critical review panel with at least one chair and two other experts is needed. The study by European Aluminium is not intended to be used in a comparative assertion to be disclosed to the public. European Aluminium decided to select two individual experts for the critical review as no panel review is necessary for the study at hand. The experts performed the review as individuals, not representing any organization.

11.2 European Aluminium Environmental Profile Report

The title of the study does not mention "Life Cycle Assessment", although the data collected are to be used in LCA or related studies for European conditions. "European" means Al metal produced in or imported to Europe, the two ways being roughly equal. A full LCA study always needs additional data (e.g. end of life) which can only be provided case by case. It is also not always possible to create full LCAs according to the ISO rules [1,2], but well-structured information about the use of imported and/or exported Aluminium products and precursors is necessary for economic, environmental and other purposes.

An important aspect in data collection and distribution to the users is update. The report described here is the 4th:

Reference year	Publication year
2002	2005
2005	2008
2010	2013
2015	2018

This regular update can be considered as a big asset, since not only the import/export data change, but also the number and quality/size/location of production sites. To support the use of Al in many applications it is necessary to know the environmental properties and LCA profile.

The data are collected and evaluated under the guidance of European Aluminium. Some data are provided by the International Aluminium Institute (IAI London). Both institutions together have an excellent survey of the global situation of Al. Even so, some data related to the aluminium refining process could not be provided in due time for inclusion in this report. In such cases, the data from the last report (2010/2013) were used for evaluation.

Another data source for frequently used chemicals is GABI, a commercial database for LCA-related chemicals. As reported by the authors, the GABI-data were used as reported in the database so that weightings – if present – were introduced. We do not expect, however, that this will change the outcome of the calculations significantly.

Using the measurements and calculations (inputs and outputs of chemicals) allow us to estimate selected parameters of the Life Cycle Impact Assessment (LCIA), e.g. per kg of Al metal or finished product. The following indicators have been used:

Abiotic Depletion (ADP elements) [kg Sb-Equiv.]

Acidification Potential (AP) [kg SO2-Equiv.]

Eutrophication Potential (EP) [kg Phosphate-Equiv.]

Global Warming Potential (GWP 100 years) [kg CO2-Equiv.]

Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]

Photochemical Ozone Creation Potential (POCP) [kg Ethene -Equiv.]

Primary energy demand from renewable and non-renewable resources (net cal. Value) [MJ]

Primary energy from renewable resources (net cal. Value) [MJ]

Primary energy from non-renewable resources (net cal. Value) [MJ]

We may conclude that such an “LCI” or “LCA” is not a full life cycle (inventory or assessment), but much more than a simple data collection (given the great amount of work put into the data collection and -documentation). The data collected and evaluated can be used for a better understanding of the system “Aluminium in Europe”. They can be used for a better understanding of the system and for improvements; and as basis for the next round of data collection.

11.3 Main Aspects and partly new structure of the European Aluminium profile report

Compared to the previous profile reports by former EAA, the already high level could be preserved. The highest aim seems to be the production of useful and reliable data.

We can agree with the statements by the authors under the claim to “maintain the positive elements from previous exercises”:

- Scopes of the project (e.g. aluminium produced in Europe vs. aluminium used in Europe)
- Description of the process, aluminium value and plants location (*)
- Consistency in the data collection and excellent data coverage
- Consistency in the LCA modelling to allow a reliable monitoring of the key trends
- Consistency in the frequency of updates [see section 11.2] and reviewing (i.e. industry experts, LCA modelling experts and critical review [see next section])
- Specific focus on electricity grid mix for smelters (*)
- Environmental categories/indicators (*)
- Inputs and outputs table for each major processes (*)

…………………………………

(*) with some explanations about the main trends

The authors claim further that the following suggestions made by the reviewers were observed:

- Improving the structure of the report to better reflect the ISO standard
- Adding an interpretation chapter

A general statement out of the 2013 European Aluminium review report [5] seems appropriate to end this section:

"To sum up, this project is an excellent example for generic data acquisition, consolidation and presentation. It contributes to the Life Cycle Assessment development by providing reliable data for one important material and continues a tradition of one and a half decade in an exemplary way."

11.4 Quality check according to the international standards ISO 14040 and 14044

For the structure of critical reviews the following 5 items out of ISO 14040 are useful:

"The critical review process shall ensure that:

- ***the methods used to carry out the LCA are consistent with the international Standard;***
- ***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 interpretations reflect the limitations identified and the goal of the study;***
- ***the study report is transparent and consistent."***

These requirements apply to full LCAs prepared according to the international standards ISO 14040 and 14044 [1,2]. For the special case of this study we have to consider that many LCAs of Aluminium are truncated (end-of-life or recycling missing). The quality demand is nevertheless high, since the not complete (e.g. cradle-to-gate) LCA may serve as basis for full LCAs. This is especially important for Aluminium due to the possibility of repeated recycling. We shall keep this in mind and refer to the report submitted for critical review.

Consistency with the international standard:

The consistency is given if the full life cycle is used as basis for the calculations. If no information is available, a set of realistic assumptions may be used for model calculations. It should be taken into account that in case of comparative environmental or toxicity assessments a panel of at least three experts (one acting as chair) is necessary [2].

Methods scientifically and technically valid

Given the long experience of European Aluminium (formerly EAA) with life-cycle methods there can be no doubt that the most recent methods have been used and implemented. The same is true for associated organizations, such as the International Aluminium Institute (IAI) and people with GABI. Primary data are derived from original analyses and checked by comparison.

Data appropriate and reasonable in relation to the goal of the study

Data are produced by cooperation with organizations working at the production (e.g. smelters) or collecting environmental samples; statistics are another way to gain trustworthy information. Comparison between different samples and organizations may be the most useful quality check. For the critical reviewer it is an advantage to work for a sponsor over a long time.

Interpretation of limitations and goal of the study

This is a topic clearly belonging to the critical review. A distance is needed between the practitioner(s) – including the managers - and the outcome of the study. Publishing the results in the open scientific literature – if possible – is another good way to collect alternative opinions.

In this specific work related to European datasets, no strong limitations were detected. A world model of all Al-relevant activities and data should remain a big goal even if at global level several countries (e.g. China) are not giving full details for their aluminium activities.

Transparency and Consistency in reporting

The reporting has achieved a high level. We assume that the final report will be available via the internet. A short version in a scientific Journal may be advisable. The Int. J. Life Cycle Assess. already once served for a similar purpose [6].

11.5 Outlook

The most important task in our opinion is the continuation of the regular updates, the already "traditional" five years intervals being a very good choice.

With regards to the Life Cycle Assessment categories, a category on "soil protection" should be added in the near future. The extraction of Al mineral as well as the conversion to Al_2O_3 require processes relevant to the Life Cycle Inventory and should be given more consideration for the LCI and LCIA of Aluminium.

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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. Through environmental and technical expertise, economic and statistical analysis, scientific research, education and sharing of best practices, public affairs and communication activities, European Aluminium promotes the use of aluminium as a material with permanent properties that is part of the solution to achieving sustainable goals, while maintaining and improving the image of the industry, of the material and of its applications among their stakeholders. Our 80+ members include primary aluminium producers; downstream manufacturers of extruded, rolled and cast aluminium; producers of recycled aluminium and national aluminium associations are 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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