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LIFE CYCLE ASSESMENT OF EXTRUDED ALUMINIUM PRODUCTS FOR YEAR 2020

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1. INTRODUCTION

IMPOL GROUP is company engaged in production of aluminium semi products. It is a member of The Aluminium Stewardship Initiative (ASI) and is wants to gain ASI Performance Standard for group of extruded aluminium products. The Entity which would like to gain The ASI Performance Standard is committed to perform "cradle-to-gate" Life Cycle Assessment (LCA). To accomplish this, IMPOL has engaged College of Industrial Engineering to conduct a Life Cycle Assessment (LCA). College of Industrial Engineering is an independent institution.

The environmental indicators analysed in this study include: Primary Energy Demand, Global Warming Potential, Eutrophication, Acidification, Depletion of Abiotic Resources elements, Ozone Layer Depletion and Photo-oxidant Creation. Environmental indicators are calculated for the group of extruded aluminium products.

1.1. The production of aluminium products

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. The major locations of deposits are found in a wide belt around the equator. Bauxite is almost exclusively extracted by open-cast mining. 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. ore prior the leaching process and 2) the residue of the leaching process. Primary aluminium is then produced in electrolysis plants (frequently called "smelters"), where the pure alumina is reduced into aluminium metal by the Hall-Héroult process. The electrical energy required for the primary smelting process constitutes the major part of energy consumption in aluminium primary production. 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 were used in presented study for a generic aluminium ingot covering ingot for rolling (slabs), for extrusion (billets) or for remelting. Before exiting the cast house, the ends of the rolling slabs and extrusion billets are usually sawed.

1.2. The ASI Performance Standard

The Aluminium Stewardship Initiative (ASI) is a non-profit, multi-stakeholder organisation which exists to administer an independent third-party certification program for the aluminium value chain. The ASI Certification program is centred on providing assurance against two voluntary standards: the ASI Performance Standard and the ASI Chain of Custody Standard.

IMPOL GROUP wants to gain The ASI Performance Standard that defines environmental, social and governance principles and criteria, with the aim to address sustainability issues in the aluminium value chain. The ASI Performance Standard contains 11 sections organised into 3 parts (»Governance«, »Environment« and »Social«). Each group is then subdivided into sections. Fourth group of »Governance« is called »Material Stewardship« where it is stated that the Entity which would like to gain The ASI Performance Standard is committed to take a life cycle perspective and to promote resource efficiency, collection and recycling of Aluminium within its operations as well as within the value chain:

1) The Entity shall evaluate life cycle impacts of its major product lines for which Aluminium is considered or used.
2) Upon customer request, the Entity shall provide adequate cradle-to-gate Life Cycle Assessment (LCA) information on its Aluminium (containing) product(s).
3) Any public communication on LCA shall include public access to the LCA information and its underlying assumptions including system boundaries.

The Entity, where engaged in Semi-Fabrication, Material Conversion and/or manufacture or sale of consumer/commercial goods containing Aluminium, shall integrate clear objectives in the design and development process for products or components to enhance sustainability, including the environmental life cycle impacts of the end product.

The following documents provide supporting information to assist with implementing the Performance Standard:

- ASI Performance Standard – Standards Guidance,
- ASI Assurance Manual,
- ASI Claims Guide.

In the ASI Performance Standard – Standards Guidance the following important recommendations are given relevant to the performed LCA analysis:

- If conducting a full Life Cycle Assessment, these should be conducted according to the principles set out in ISO 14040:2006 and ISO 14044:2006
- In life cycle assessments (LCA) that involve recycling of materials, a method for allocation of processes and avoided emissions needs to be chosen to fit the goal and scope definition of the assessment. There are two main approaches to recycling:
    - o End-of-life (EOL) recycling approach (also known as avoided burden). Environmental benefits are only granted for the fraction of material that is recovered and recycled after the use phase.
    - o Recycled content (RC) approach (also known as cut-off). Environmental benefits are only granted for the actual fraction of secondary material in a product.

  The choice of allocation often has a major influence on the results of the LCA for a particular product. Therefore, some sectors and/or product groups are defining preferred standards for dealing with recycling in LCA. Amongst others, the global metals industry has made a 'Declaration by the Metals Industry on Recycling Principles'. This declaration states the following: »For purposes of environmental modelling, decision-making, and policy discussions involving recycling of metals, the metals industry strongly supports the end-of-life recycling approach over the recycled content approach.«

  Independent of the allocation approach used for recycling, the impact or credit from recycling should be provided separately.
- When evaluating life cycle impacts for your products, make use of information and models produced by industry associations and published resources, as relevant.
    - o Contact your association/s to find out what LCA work has been completed or is underway that has relevance to your products. These studies will contain data you can use to evaluate life cycle impacts and identify 'hotspots' in the supply chain.
    - o In evaluating life cycle impacts, consider the impact of the various production stages and of end-of-life recycling. These analyses can also be used to develop plans for impact reductions over time.

- Consider finding or developing a cradle-to-gate LCA information document that can be easily made available to customers upon request.
    - o 'Cradle-to-gate' LCA is an assessment of a partial product life cycle from resource extraction (cradle) to the factory gate (i.e., before it is transported to the next step in the value chain). The use phase and disposal/recycling phase of the product are omitted in this case. In other words, cradle-to-gate information covers your own production plus upstream impacts.
    - o A number of associations including the International Aluminium Institute (IAI), The Aluminium Association and European Aluminium publish LCA information for production and use sectors. This could be cradle-to-gate, or simply 'gate-to-gate' if focused on a specific supply chain step.
        - ➢ For example, the European Aluminium (EA) Environmental Profile Report provides industry average data for the various steps of aluminium production and processes. It does not consider the full life cycle since this information is not available across all markets and products but can be collected case by case via LCA.
        - ➢ Relevant life cycle information can also be contained in Environmental Product Declarations (EPDs). EN 15804 and EN 15978 require that auditors review and validate data associated with Environmental product Declarations (EPD's). For example, EPDs developed by The Aluminium Association in accordance with ISO14025 and independently validated include those for Hot-Rolled Aluminium, Cold-Rolled Aluminium, Extruded Aluminium, Primary Ingot and Secondary Ingot. EPDs developed by European Aluminium include a set for building products.
- When publicly communicating about LCA information or assessment results, there should be public access to the LCA information and its underlying assumptions. This is to support transparency, accuracy and consistency.
    - o Ideally, such public communication on LCA information or assessment results should be based on 3rd party verified LCAs conducted in accordance to ISO 14040 and 14044, and in line with ISO 14021 or 14025 (see references below).
    - o Note that confidentiality of site-specific or commercial-in-confidence data can be maintained. Background data used to prepare LCA information is often sourced from third party Life Cycle Inventory databases (such as GaBi, EcoInvent, etc). This can include data which makes a significant contribution to impact categories, but is proprietary and often difficult to interrogate. "Public access" to these aspects can therefore be problematic.
    - o Where appropriate, the Entity should contribute to the development of average LCI databases in the region/s where they operate. This could be via direct provision of data or other resources, or via industry associations or other collaborative groups or initiatives. Entities are encouraged to actively provide data to industry level LCA studies organized by industry groups or trade associations, to improve the quality and representativeness of industry wide LCA information.

2. GOAL OF THE STUDY

The goal of this LCA is to understand the environmental impacts of the extruded aluminium products and provide life cycle assessment in a format that is required for gaining ASI Performance Standard. To enable this, a »cradle-to-gate« LCA was conducted. Six types of products are included into the group of the extruded aluminium products. The study goal does not include the comparison of every particular products within the group of the extruded aluminium products.

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

3. SCOPE OF THE STUDY

The following section describes the general scope of the project to achieve the stated goal. This includes the identification of the specific products group that were assessed, the supporting product systems, the boundaries of the study, the allocation procedures, and the cut-off criteria used.

3.1. Definition of Product System

This Life Cycle Assessment (LCA) evaluates the "cradle-to-gate" environmental impacts of the products system for production of the extruded aluminium products, produced at IMPOL GROUP company. The examples of extruded aluminium products are presented in Figure 1 and are produced from primary aluminium ingot and Al scrap.

Figure 1: Examples of extruded aluminium products produced at IMPOL GROUP

The results in the study corresponds to production of semi-products named extruded aluminium products, ready for delivery to the user. The processes used in the production process are melting, holding, homogenisation, turning of billets, extrusion, straightening, cutting, thermal treatment and packaging.

3.2. Functional unit

All impacts were related to the functional unit, which is defined as the production of 1 tonne of the extruded aluminium products ready for delivery to the user at the gate (i.e. out) of the system boundary.

3.3. System boundary

This study includes the »cradle-to-gate« environmental impacts. Model includes all impacts associated with the upstream production of all materials and energy used. Table 1 summarizes what is included and excluded in this study.

Table 1: System Boundary – Inclusions and Exclusions

Inclusions	Exclusions
Production of raw materials (including ancillary materials)	Construction of capital equipment
Energy production	Maintenance and operation of support equipment
Processing of materials	Human Labour
Operation of primary production equipment	Loses in trade and transport of raw materials
Transport of raw materials to IMPOL GROUP	Wholesale and/or retail activities connected to raw materials
Internal transportation of materials within production facilities	
Treatment of waste from production processes	
Packaging of products	
Overhead – heating and lighting of manufacturing facilities and warehouses.	
Manufacture and transport of packaging materials not associated with final product	

Additional details describing the modelled contents of each stage in the life cycle are included in Section 4: Life Cycle Inventory (LCI).

3.4. Selection of Impact Assessment Categories and Indicators

For LCI dataset, environmental indicators "from-cradle-to gate" have been calculated and reported for a pre-defined set of impact categories. 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 while Table 3 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 publically available LCA reports submitted to ASI.

Table 2: Included impact categories

Impact categories	Unit	Methodology
Depletion of Abiotic Resources elements (ADP)	[kg Sb-Equiv.]	CML2001 - Jan. 2016
Acidification Potential (AP)	[kg SO2-Equiv.]	CML2001 - Jan. 2016
Eutrophication Potential (EP)	[kg Phosphate-Equiv.]	CML2001 - Jan. 2016
Greenhouse Gas emission (GWP 100 years)	[kg CO2-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 3: 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.
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.
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.

3.5. Normalization, Grouping and Weighting

Additional optional Life Cycle Impact Assessment (LCIA) steps include normalization, grouping and weighting. In the presented study no normalization, grouping and weighting was applied due to their subjective nature.

3.6. Data Collection

In modelling a product system, it helps to consider the foreground system and the background system separately which were collected from different sources.

3.6.1. Foreground data

The foreground data used in the study have been collected at manufacturing facility of IMPOL GROUP. Production line data was collected from equipment dedicated for production of extruded aluminium by member the Ecology department of IMPOL GROUP during year 2020. Other data was extracted from information system and other sources. In practice, foreground data are a mixture of measured, calculated and estimated data as required in the data collection surveys. For each segment, the various data collected are available in the report (e.g. see Tables 4, 5 and 6).

The suppliers of key raw materials had been asked for foreground data (Environmental Product Declaration documents), but there had been no reply from any of them.

3.6.2. Background data

In addition to the environmental data collected directly by IMPOL GROUP, additional inventory datasets (background data) have been used. These datasets are included in the EcoInvet 3.7.1 database. The most important background data are (list not exhaustive):

- Production of different input raw materials,
- Electricity supply systems,
- Fuel supply systems and fuel combustion,
- Transportation.

Additional details on the datasets used to represent each of these upstream processes are provided in Chapter 5.

3.6.3. Data quality

Data quality is judged by its precision (measured, calculated or estimated), completeness (e.g. are there unreported emissions?), consistency (degree of uniformity of the methodology applied on a study serving as a data source) and representativeness (geographical, time period, technology). To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent, upstream LCA information from the EcoInvent 3.7.1 database were used.

Precision

The precision of each upstream dataset used is documented within the EcoInvent 3.7.1 database.

Technology coverage

The data presented in the report are representative of the currently used technologies in IMPOL GROUP (which is similar to technology of other competitors producing semi products from aluminium).

Geographic coverage

For manufacturing of the extruded aluminium products, the electricity grid mix in the model represent Slovenian boundary conditions (national grid mix) and fuel datasets used represent EU boundary conditions. For the distribution all background datasets chosen are based on EU boundary conditions, expect ship transport where background datasets chosen are based on GLO boundary conditions.

Time coverage

The most recently available data were used to model production of the extruded aluminium products. The foreground data was collected at IMPOL GROUP during 2020 and current version of EcoInvent 3.7.1 was used for background data.

Completeness

As far as possible, before any decision of excluding data, IMPOL GROUP has been contacted and outliers have been possibly corrected according to the company feedback.

Consistency

To ensure consistency only primary data of the same level of detail and upstream data from the EcoInvent 3.7.1 database are used. While building up the model cross-checks concerning the plausibility of mass and energy flows are continuously conducted. Data consolidation, averaging and modelling have been done College of Industrial Engineering. No inconsistency was found. The data collection procedures, the various questionnaires and the consolidated data are part of report.

Reproducibility

The study results are reproducible as the report provided the details necessary to model the primary technology used in this study. The presented results would allow an independent practitioner to reproduce the results reported in the study.

Uncertainty of the information (e.g. data, models, assumptions):

Uncertainty quantification in LCA has two dimensions: uncertainty on flow level, and uncertainty on process level. The uncertainty at the process level is about appropriateness of the dataset for the intended application and representativeness of data sets. The quantification of the overall uncertainty is not currently possible in a reliable, scientifically defendable, and reproducible manner. Databases that quantify uncertainty base the figures on a mixture of semi-quantitative approaches and guess work.

3.6.4. Focus on specific datasets, processes and production steps

Raw materials (including ancillary materials)

LCI data for all upstream raw materials were obtained from the EcoInvent 3.7.1 database. Primary ingots are imported into Europe from Mozambique and it is estimated that all ancillary materials are produced in Europe. The environmental impacts of the ancillary materials are considered from their arrivals on the production site.

Energy

Aluminium processes use fossil fuels (natural gas and diesel in our example) as 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 EcoInvent 3.7.1.

For the air emissions associated with the production process of the extruded aluminium products, the survey reported figures (i.e. particulates and NO_x) are then complemented with all the other air emissions which are associated with the extraction, preparation and the combustion of these fossil fuels. Precautions were taken to avoid double counting of the reported emissions.

The total air emissions from the production of the extruded aluminium products 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 processes in which fuel combustion takes place.

Electricity

Electricity production has been included in the system boundaries. The supplier of electrical energy provided data about Greenhouse Gas emission related to the supplied electricity (0,608kg CO_2-e/kWh). National average (national grid mix) for electricity grid mixes was obtained from the EcoInvent 3.7.1. databases and used for calculation of other impact categories.

Transportation

The Ecoinvent database for transportation vehicles and fuels were used to model the transportation associated with the extruded aluminium products. EU average fuels were used for all transportation within the EU. The transport of the primary ingots from Mozambique was modelled using a transport ship. All lorry transportation within the EU were modelled using the EcoInvent 3.7.1 EURO5 lorry transportation datasets.

Waste treatment

The treatment of the wastes have been modelled and integrated within the system boundaries. Material-specific EU EcoInvent 3.7.1 datasets are used throughout the model, since it was not possible to collect or model specific emission data. The landfill processes are used for the disposal of all inert wastes. Treatment of hazardous waste with incineration is used for other types of waste. Credits for electricity recovery from landfill methane emissions and incineration are not included in this model. More details on the End-of-Life model are presented in Section 5.

3.7. Allocation procedure

A process, sub-system or system may produce co-products in excess of the specified functional unit. Such co-products leave the system to be used in other systems yet should carry a portion of the burden of their production system. In some cases materials leaving the system are considered “free of burden.” To allocate burden in a meaningful way between co-products, several procedures are possible (e.g. allocation by mass, market value, heating value, etc.). Whenever allocation was necessary, the method was chosen based upon the original intent of the process in need of allocation. For instance, in the case of mining precious metals where the desired object (e.g. gold) is only a small fraction of the total mass of products produced (e.g. gravel), it is illogical to allocate the burdens of mining based upon mass. However, for transportation processes where the amount of cargo carried per trip is determined by weight limits, mass allocation is appropriate.

As much as possible, allocation has been avoided for the foreground data by expanding the system boundaries (see section 4). The by-products skimmings was also included inside the system boundaries and assumed to be treated and recycled. Therefore that the only valuable material exiting the system are the extruded aluminium products. All recycling and disposal of scrap materials associated with the production of the extruded aluminium products is included in the model. As far the background datasets, the allocation rules used in EcoInvent 3.7.1 database are conserved.

3.8. Cut-off criteria

The cut-off criteria applied in this study for including or excluding materials, energy and emissions data is as follows:

- Mass – If a material flow is less than 1% of the cumulative mass flow of the model it may be excluded, providing its environmental relevance is not a concern.
- Energy – If a flow is less than 1% of the cumulative energy flow of the model it may be excluded, providing its environmental relevance is not a concern.
- Environmental relevance – If a flow meets the above criteria for exclusion, yet is thought to potentially have a significant environmental impact, it will be included. Material flows which leave the system (emissions) and whose environmental impact is greater than 2% of the whole impact of an impact category that has been considered in the assessment must be covered. This judgment will be done based on experience.

The sum of the excluded material flows must not exceed 5% of mass, energy or environmental relevance.

In presented study some available inputs and outputs, even below the 1% threshold, have been considered for the LCI calculation (see details in Chapter 4.3).

3.9. Critical Review by independent experts

The applicable ISO standards require a critical review in cases where a comparative assertion is being made and communicated publicly. The primary goals of a critical review are to provide an independent evaluation of the LCA study and to provide input to the study proponents on how to improve the quality and transparency of the study. Critical Review was not performed since the study is not intended for comparative assertions intended to be disclosed to the public.

3.10. 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 LCA 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 LCA 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 not made publicly available.

4. LIFE CYCLE INVENTORY (LCI)

Inputs and outputs data have been collected through detailed questionnaire in company IMPOL GROUP with full reference to ISO standards 14040 and 14044 on Life Cycle Assessment. The various datasets have been collected at unit process within the system boundaries. The report contains:

- A process description,
- A material flow modelling,
- Table(s) with the inputs and outputs data and elementary flows.

4.1. Data collection for production process

The main input raw materials are primary ingots, Al scraps from suppliers and waste Al from processes 1 and 2. The production of the extruded aluminium products consists of 2 main processes (see Figure 2). Process 1 consists of melting, holding, casting and homogenisation. The intermediate product from process 1 is billet and there is by-product skimming that is sold to the recycling companies. The billet produced in process 1 and additional purchased billet then together enter process 2 that consist of turning, extrusion, drawing and straightening, cutting and packing. According to alloy grade and customer's requirements, a thermal treatment of homogenisation may also be applied. Processes 1 and 2 generate aluminium scrap. These scraps are recycled on-site. This internal recycling of process scrap is part of the LCI dataset for the production of the extruded aluminium products as illustrated in Figure 2. The product that exits the production process are the extruded aluminium products.

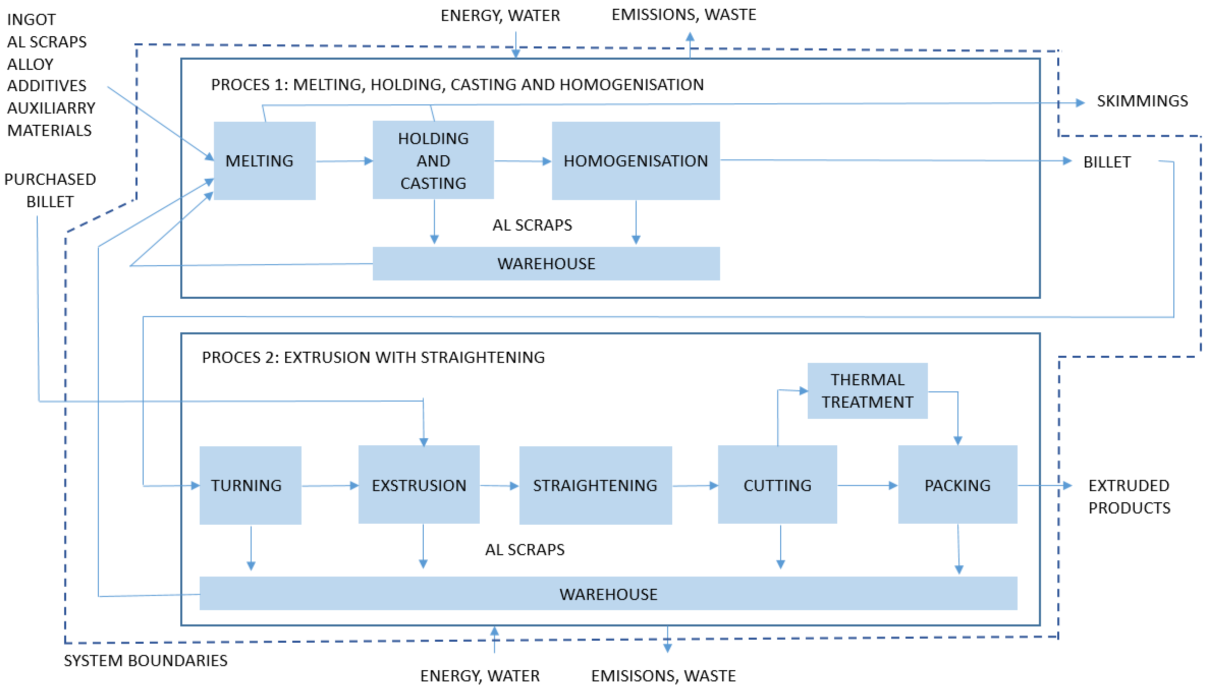

Figure 2: Simplified flow diagram for production of extruded aluminium products

The yearly input and output data were collected through questionnaires covering the year 2020 (1.1.2020-31.12.2020) and are presented in Tables 4 and 5. Besides the data presented in Tables 4 and 5, INPOL GROUP submitted data of numerous other waste materials (e.g. waste cartridges in the quantity of 1kg/year, alkaline batteries from electronic equipment in the amount of 2 kg/year etc.), which can be neglected and are not shown due to better transparency of the report.

These inputs and outputs are normalised to 1 ton of the finished extruded aluminium products. The data reported are representative of the average extruded aluminium product. Thus, the results for precise type of the extruded aluminium products may wary to some extent.

Table 4: Inputs and outputs at process 1 »Melting, holding, casting and homogenisation« for production of 1 tonne of the extruded aluminium *products at IMPOL GROUP*

Nr.	Relative figure per tonne of the extruded aluminium products	Unit	Quantity	Source
	Inputs			
	Input raw materials and auxiliary materials			
1	Primary ingot	kg/t	222,00	Weighting
2	Al scraps (from processes 1 and 2)*	kg/t	516,13	Weighting
3	Al scraps	kg/t	428,36	Weighting
4	Alloy additives	kg/t	22,603	Weighting
5	Hydraulic oil	kg/t	0,076	Consumption records
6	Argon	kg/t	3,25	Tender documentation
7	Nitrogen	kg/t	0,27	Tender documentation
8	Chlorine	kg/t	0,004	Tender documentation
9	Biocid Akiphos 670	kg/t	0,176	Tender documentation
10	Additive Basidin	kg/t	0,003	Tender documentation
11	Additive Ferikol	kg/t	0,081	Tender documentation
12	Nevtralizator	kg/t	0,025	Tender documentation
13	Bicid Preventol D7	kg/t	0,018	Tender documentation
14	Additive Desomix	kg/t	0,459	Tender documentation
	Water			
15	Fresh water (industrial quality, not drinkable)	m3/t	0,916	Measured
	Energy			
16	Natural gas	m3/t	97,359	Measured by provider
17	Electricity	kWh/t	379,585	Measured by provider
18	Diesel	litres/t	1,339	Measured by provider
	Outputs			
	Intermediates, by-products			
19	Billets (intermediate for process 2)**	kg/t	1000,00	Weighting
20	Skimmings (sold)	kg/t	39,622	Weighting
21	Al scraps (returning as input raw material)*	kg/t	152,136	Weighting
	Air emissions			
22	Particulates	kg/t	0,0013	Emission monitoring
23	NOx (as NO2)	kg/t	0,1230	Emission monitoring
24	Manganese compounds (as Mn)	kg/t	0,0001	Emission monitoring
25	HCl (Hydrogen Chloride)	kg/t	0,0332	Emission monitoring
26	Organic compounds (as TOC)	kg/t	0,0915	Emission monitoring
27	Water steam	m3/t	0,4021	Emission monitoring
	Water emissions			

28	Waste water	m3/t	0,1585	Measured
	Solid waste			
29	Filter dust	kg/t	0,4493	Waste collection records
30	Metal sludge containing oil	kg/t	0,0027	Waste collection records
31	Mixed packaging	kg/t	0,0414	Waste collection records
32	Absorbents,filter mater.(hazardous)	kg/t	0,0114	Waste collection records
33	Other linings	kg/t	0,2285	Waste collection records
34	Sludges containing dangerous substances	kg/t	0,0037	Waste collection records
35	Solid waste- prim.filtrat.and screen.	kg/t	0,0475	Waste collection records
36	Metals	kg/t	0,4505	Waste collection records
	Other			
37	Fresh water leakage to soil	m3/t	0,0647	Calculated estimation

Main input raw materials are primary ingot and aluminium scraps. Al scraps from processes 1 and 2 are also listed in the table but this quantity stays inside system boundaries. Additional alloying elements are added to aluminium. During the process small quantity of hydraulic oil is used. Finally some additives and gases are listed that are: 1) added into water as auxiliary materials in 2) used in cleaning devices and 3) used in automatic in fire prevention system (used during weekly testing procedure).

Fresh water (industrial quality that is not treated for drinking) is entering into the process mainly for cooling. Natural gas and electricity are used as main energy sources. Minor quantities of diesel are needed for powering the equipment for internal transport. Main by-products of the process are: 1) Al scraps that is stored and returned as input raw material into process 1 and 2) skimmings that are sold to the recycling companies. Air emissions are measured at treatment facility located in IMPOL GROUP Waters steam is emitted from cooling system. Waste water is treated in municipal waste water treatment facility. Solid waste is gathered and send to companies specialized to treatment of different types of solid waste. Finally, it is calculated that certain amount of fresh water runs into soil due to leakage of water supply system.

Table 5: Inputs and outputs at process 2 »Extrusion with straightening« for production of 1 tonne of the extruded aluminium products *at IMPOL GROUP*

Nr.	Relative figure per tonne of the extruded aluminium products	Unit	Quantity	Source
	Inputs			
	Input raw materials and auxiliary materials			
1	Billets (intermediate from process 1)**	kg/t	1000,00	Enterprise resource planning system
2	Billets (purchased)	kg/t	364,00	Enterprise resource planning system
3	Nitrogen	kg/t	41,01	Tender documentation

4	Casting soap (40% NaOH)	kg/t	3,67	Tender documentation
5	Ammonia	kg	0,09	Tender documentation
6	Lubricant (mineral oil)	kg	0,61	Consumption records
	Water			
7	Fresh water (industrial quality, not drinkable)	m3/t	0,532	Measured
	Energy			
8	Natural gas	m3/t	44,435	Measured by provider
9	Electricity	kWh/t	426,70	Measured by provider
10	Diesel	litres/t	0,97	Measured by provider
	Outputs			
	By products			
11	Al scraps (returning as input raw material)*	kg/t	364,00	Weighting
	Air emissions			
12	NOx (as NO2)	kg/t	0,0820	Emission monitoring
13	Carbon monoxide	kg/t	0,3479	Emission monitoring
14	Organic compounds (as TOC)	kg/t	0,0540	Emission monitoring
15	NH3	kg/t	0,0134	Emission monitoring
16	Water steam	m3/t	0,2956	Emission monitoring
	Water emissions			
17	Waste water	m3/t	0,1435	Measured
	Solid waste			
18	Other bases	kg/t	8,9986	Waste collection records
19	Aqueo.rinsing liquids cont.dang.sub.	kg/t	0,0058	Waste collection records
20	Ferrous metal dust and particles	kg/t	0,0000	Waste collection records
21	Plastics shavings and turnings	kg/t	0,0177	Waste collection records
22	Machining emulsions free of halogens	kg/t	1,0527	Waste collection records
23	Metal sludge containing oil	kg/t	0,0150	Waste collection records
24	Mineral-based non-chlor.engine,gear	kg/t	0,4118	Waste collection records
25	Sludges from oil/water separators	kg/t	0,0000	Waste collection records
26	Mixed packaging	kg/t	0,1179	Waste collection records
27	Packaging contaminated by dang.subs.	kg/t	0,0071	Waste collection records
28	Filter dust	kg/t	0,0000	Waste collection records
29	Oil filters	kg/t	0,0106	Waste collection records
30	Other linings	kg/t	0,0000	Waste collection records

31	Linings from non-metallurgical proc.	kg/t	0,0054	Waste collection records
32	Iron and steel	kg/t	0,0206	Waste collection records
33	Metals	kg/t	0,8150	Waste collection records
34	Municipal solid waste	kg/t	0,0000	Waste collection records
	Other			
35	Fresh water leakage to soil	m3/t	0,0931	Calculated estimation

Main input raw materials are the billets from process 1 and from the market. During the process smaller quantity of mineral oil is used for lubrication during drawing process. Fresh water (industrial quality that is not treated for drinking) is entering into the process mainly for cooling. Natural gas and electricity are used as main energy sources. Minor quantities of diesel are needed for powering the equipment for internal transport. Main by-products of the process is Al scraps that is stored and returned as input raw material into process 1. Air emissions are measured at treatment facility located in IMPOL GROUP. Waters steam is emitted from cooling system. Waste water is treated in municipal waste water treatment facility. Solid waste is gathered and send to companies specialized to treatment of different types of solid waste. Finally, it is calculated that certain amount of fresh water runs into soil due to leakage of water supply system.

4.2. Data collection for transport process

Average transport distances and types for main input raw material for production of 1 tonne of the extruded aluminium products are gathered in Table 6.

Table 6: Transport distances and types for production of 1 tonne of the extruded aluminium products at IMPOL GROUP

Material	Distance (km)	Type of transport	Mass (ton)	Remarks
Process 1 - input				
Primary ingot	10130	Ship	0,2488	
Primary ingot	190	Lorry, capacity 22 tons	0,2488	EURO 5
Alloy additives	1200	Lorry, capacity 22 tons	0,0251	EURO 6
Al scraps	1180	Lorry, capacity 22 tons	0,4259	EURO 5
Desomix	1200	Lorry, capacity 22 tons	0,0004	EURO 6
Nitrogen	38	Lorry with cistern, capacity 21 tons	0,0003	EURO 5
Argon	33	Lorry with cistern, capacity 21 tons	0,0078	EURO 5
Process 2 - input				
Billet (purchased)	5800	Ship	0,2931	EURO 5
Billet (purchased)	190	Lorry, capacity 22 tons	0,2931	EURO 5
Billet (purchased)	24	Lorry, capacity 22 tons	0,0314	EURO 5
Billet (purchased)	1180	Lorry, capacity 22 tons	0,0314	EURO 5

Casting soap (40% NaOH)	116	Lorry with cistern, capacity 21 tons	0,0034	EURO 5
Nitrogen	38	Lorry with cistern, capacity 21 tons	0,0337	EURO 6
Lubricant (mineral oil)	100	Lorry, capacity 22 tons	0,0005	EURO 5
Process 1 - output				
Iron and steel	120	Lorry, capacity 22 tons	0,0002	EURO 5
Metals	20	Lorry, capacity 22 tons	0,0012	EURO 5
Other linings	24	Lorry, capacity 22 tons	0,0011	EURO 5
Filter dust	24	Lorry, capacity 22 tons	0,0004	EURO 6
Skimmings	465	Lorry, capacity 22 tons	0,0396	EURO 5
Process 2 - output				
Other basis	127	Lorry, capacity 13 tons	0,0084	EURO 5
Iron and steel	120	Lorry, capacity 22 tons	0,0005	EURO 6
Metals	24	Lorry, capacity 22 tons	0,0009	EURO 6
Mineral-based oils	80	Lorry, capacity 22 tons	0,0004	EURO 6

Primary ingots are imported from Mozambique and transported from mainly by ship and to lesser extend by lorry. Purchased billets are imported from Dubai and transported from mainly by ship and to lesser extend by lorry. All other input and output materials are purchased locally and transported by lorry.

4.3. Modelling

Data reported in Tables 4, 5 and 6 are used to model the production route for the extruded aluminium products. In the model, all energy inputs and all material input and output flows of quantities higher than 1 kg per tonne of the extruded aluminium products (which represents less than 0,2% of total material flow) have been taken into account. In accordance with Chapter 2.2.1.3. the following main simplifications and hypothesis were used:

- Aluminium input is composed not only of aluminium but also alloying elements. In the material flow model alloying elements are substituted by primary aluminium.
- Primary ingot was modelled with dataset "Aluminium ingot, import from Africa" from EcoInvent 3.7.1 which is in good correlation with Environmental profile report, published by European Aluminium.
- Aluminium scrap entering the process 1 was modelled with dataset "Aluminuim scrap prepared for melting" from EcoInvent 3.7.1.
- Purchased billets from suppliers that did not provide environmental data (Environmental Product Declaration) were replaced with intermediate material billets from process 1 in the LCA model.

The LCA model was created using the Umberto software system for life cycle engineering, developed by ifu Hamburg GmbH. The EcoInvent 3.7.1. database provides the Life Cycle Inventory background data for some raw and process materials obtained from the upstream system. LCA model is presented in Figure 3.

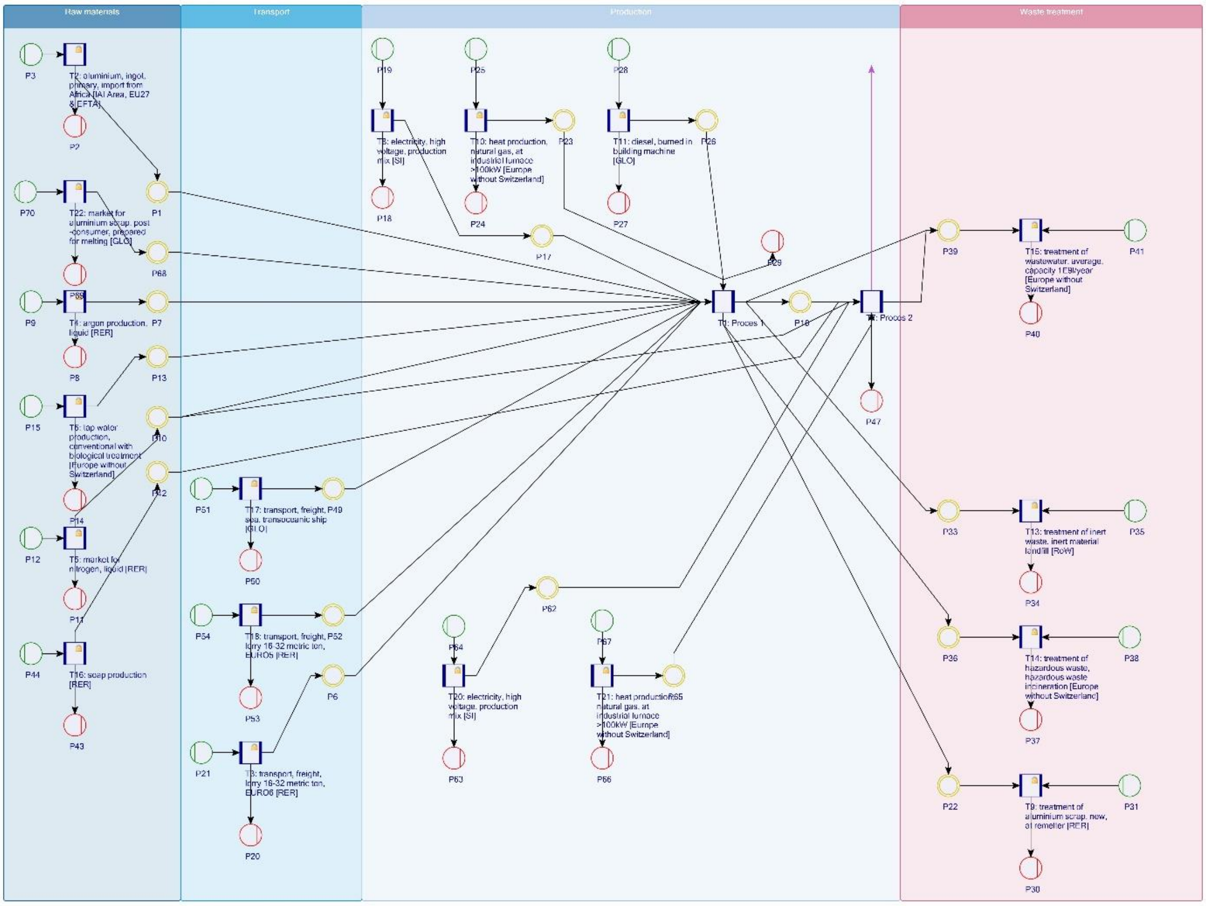

Figure 3: Modelling the production of extruded aluminium *products using Umberto software*

5. INTERPRETATION OF THE RESULTS

The results of the LCI and LCIA are interpreted with regards to the goal and purpose of the project. The interpretation addresses the following topics:

- Identification of significant findings, such as the primary materials and processes contributing to the overall results, and the potential contribution of emissions for main impact categories in the context of the whole life cycle.
- Evaluation of completeness, sensitivity, and consistency, to confirm the inclusion or exclusion of data from the system boundaries as well as the cut off criteria and data quality checks are described in Section 3.6.
- Conclusions, limitations and recommendations including stating the appropriateness of the definitions of the system functions, the functional unit and system boundary.

The functional unit has been defined as "1 tonne of the extruded aluminium products (mix of products) ready for delivery to the user at the gate (i.e. out) of the system boundary". This functional unit is generic, i.e. not specific to one extruded aluminium product. Thus, in case of the specific extruded aluminium product, a specific assessment should be performed.

The various environmental data have been considered as robust and representative. Majority of input and output data are based on a direct reporting of company IMPOL GROUP. For energy consumption national grid mix of Slovenia, where IMPOL is located, was used. As much as possible, allocation has been avoided for the foreground data by expanding the system boundaries as explained in chapters 3 and 4. As far the background datasets, the allocation rules used in EcoInvent 3.7.1. database are conserved.

5.1. Environmental indicators

Associated environmental indicators for the predefined impact categories are reported in Table 7. These sets of environmental indicators are purely informative and should not be used 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 7: Main environmental indicators (per tonne of the extruded aluminium *products*

Impact categories	Value	Unit	Share (%)			
			Raw materials	Transport	Manufacturing	Waste treatment
Depletion of Abiotic Resources elements (ADP)	40,12	kg antimony-Eq	79,70	3,78	15,81	0,71
Acidification Potential (AP)	56,90	kg SO2-Eq	83,97	3,31	12,34	0,38
Eutrophication Potential (EP)	13,78	kg PO4-Eq	78,66	1,77	18,27	1,30
Greenhouse Gas emission (GWP 100 years)	6.368,4	kg CO2-Eq	83,02	3,37	12,76	0,85

Ozone Layer Depletion Potential (ODP, steady state)	0,00026	kg CFC-11-Eq	60,48	14,21	23,15	2,16
Photo-oxidant Creation Potential (POCP)	1,51	kg ethylene-Eq	96,29	1,46	2,01	0,24
Total Primary energy *(from renewable and non-renewable resources)*	82.853,3	MJ-Eq	73,55	4,16	21,50	0,79
- Primary energy from renewable resources	11.729,7	MJ-Eq	89,17	0,46	9,74	0,63
- Primary energy from non-renewable resources	71.123,6	MJ-Eq	70,97	4,77	23,44	0,81

Most of the environmental impacts are related to the production of raw materials. Production of primary aluminium ingot creates the greatest impact. Environmental impacts of other raw materials used are significantly lower. The second most import is the manufacturing phase where the use of natural gas and electricity have the greatest impacts. The contribution of transport and waste treatment process are much lower.

5.2. Main Elementary Flows

For each environmental indicators presented in the tables above, the main contributing elementary flows and related processes are presented in Figures 4 to 8.

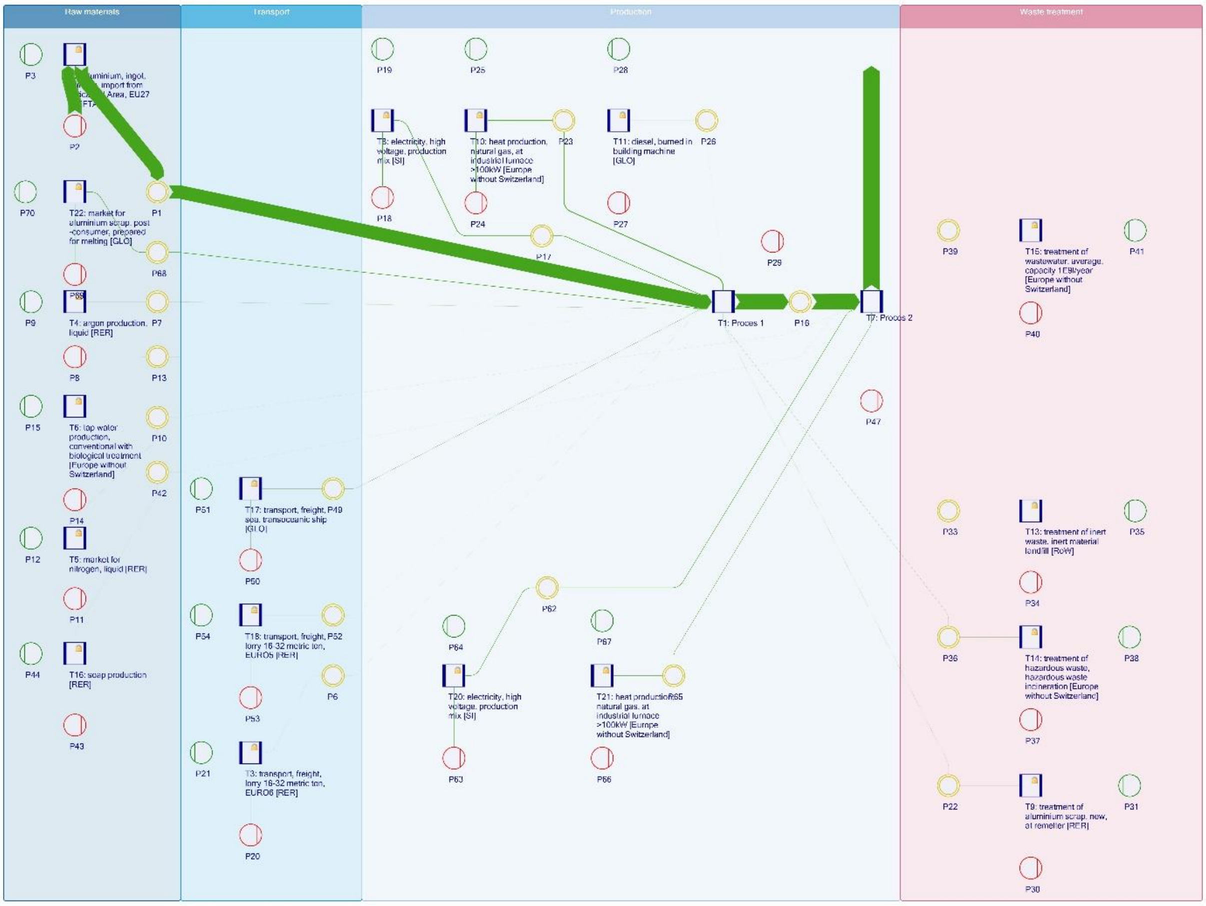

Figure 4: Main flows and related processes contributing to Global warming potential (GWP)

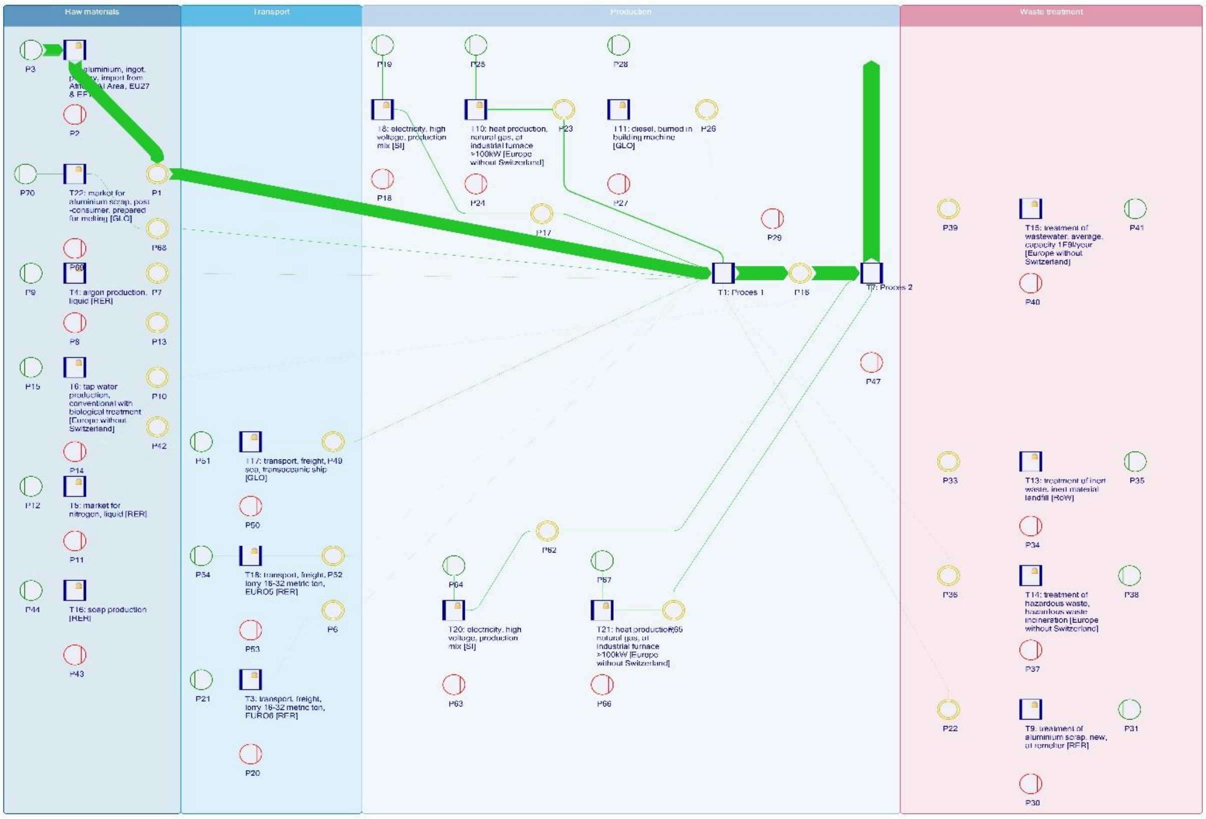

Figure 5: Main flows and related processes contributing to Depletion of Abiotic Resources elements (ADP)

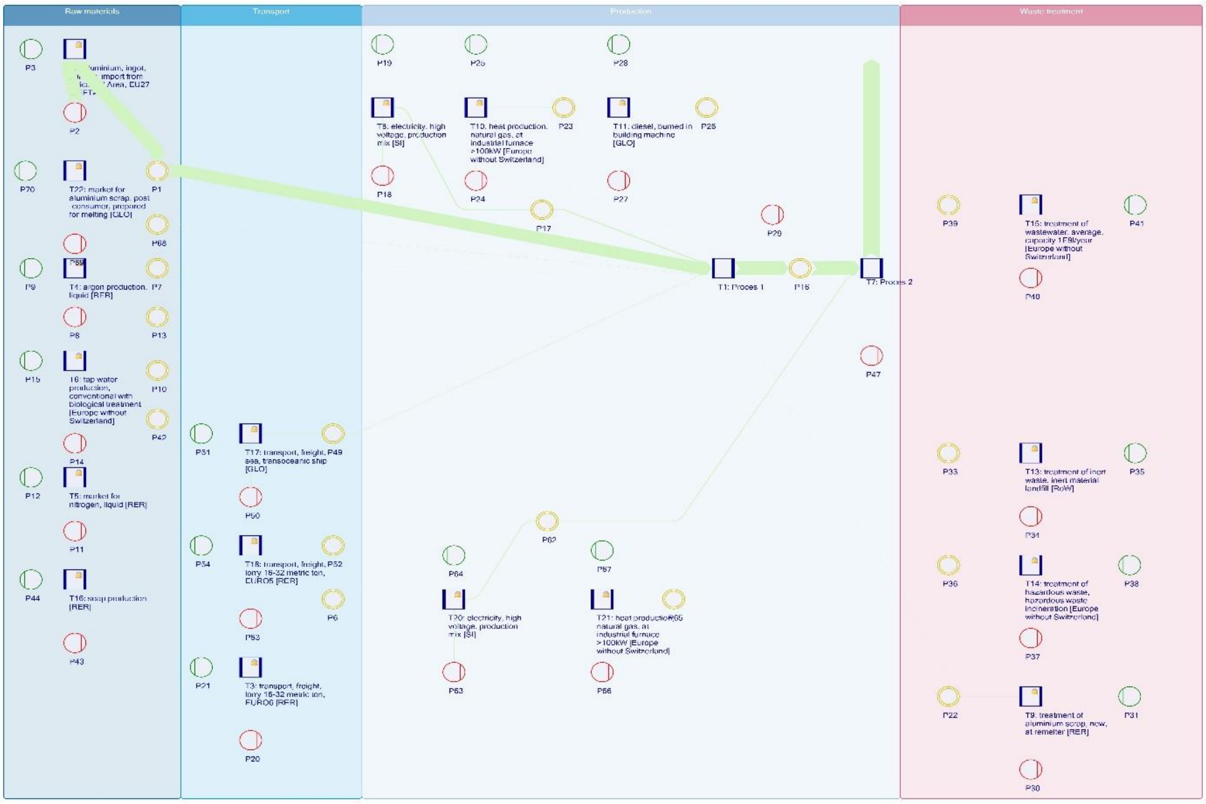

Figure 6: Main flows and related processes contributing to Acidification Potential (AP)

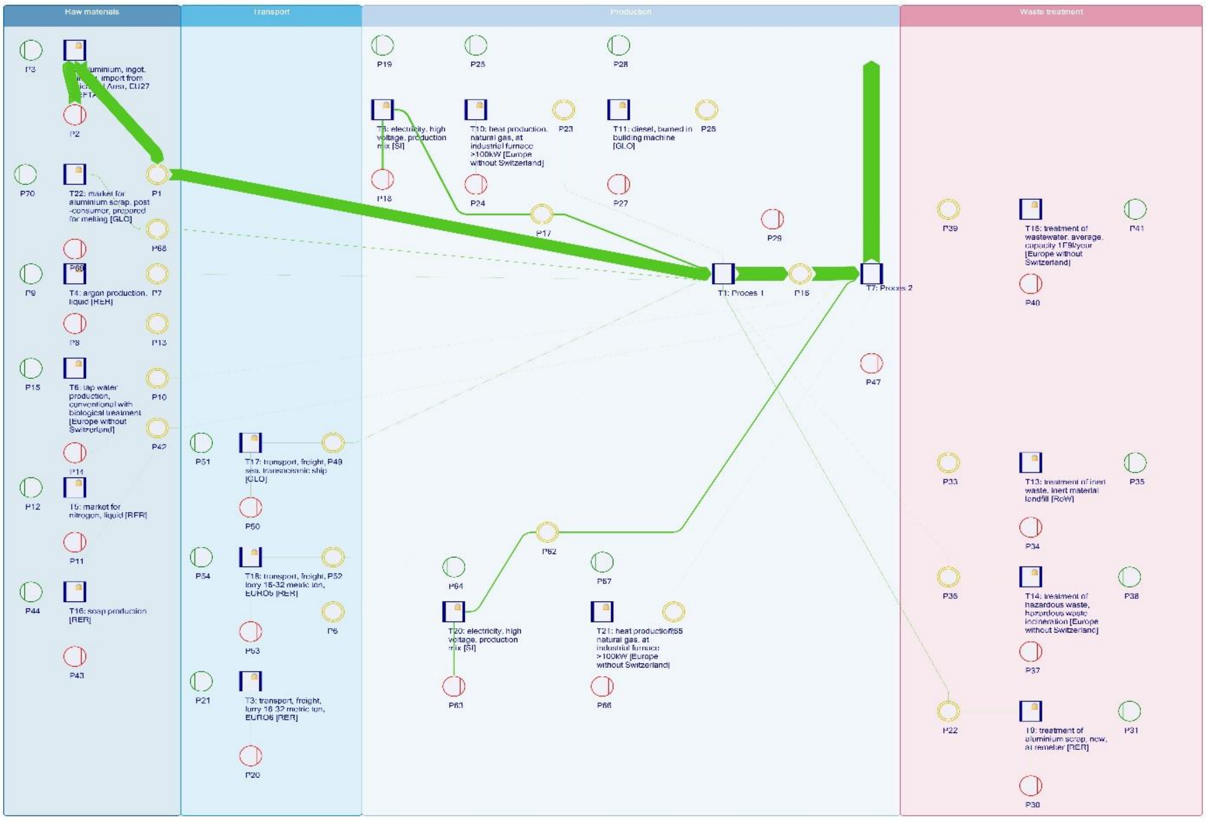

Figure 7: Main flows and related processes contributing to Eutrophication Potential (EP)

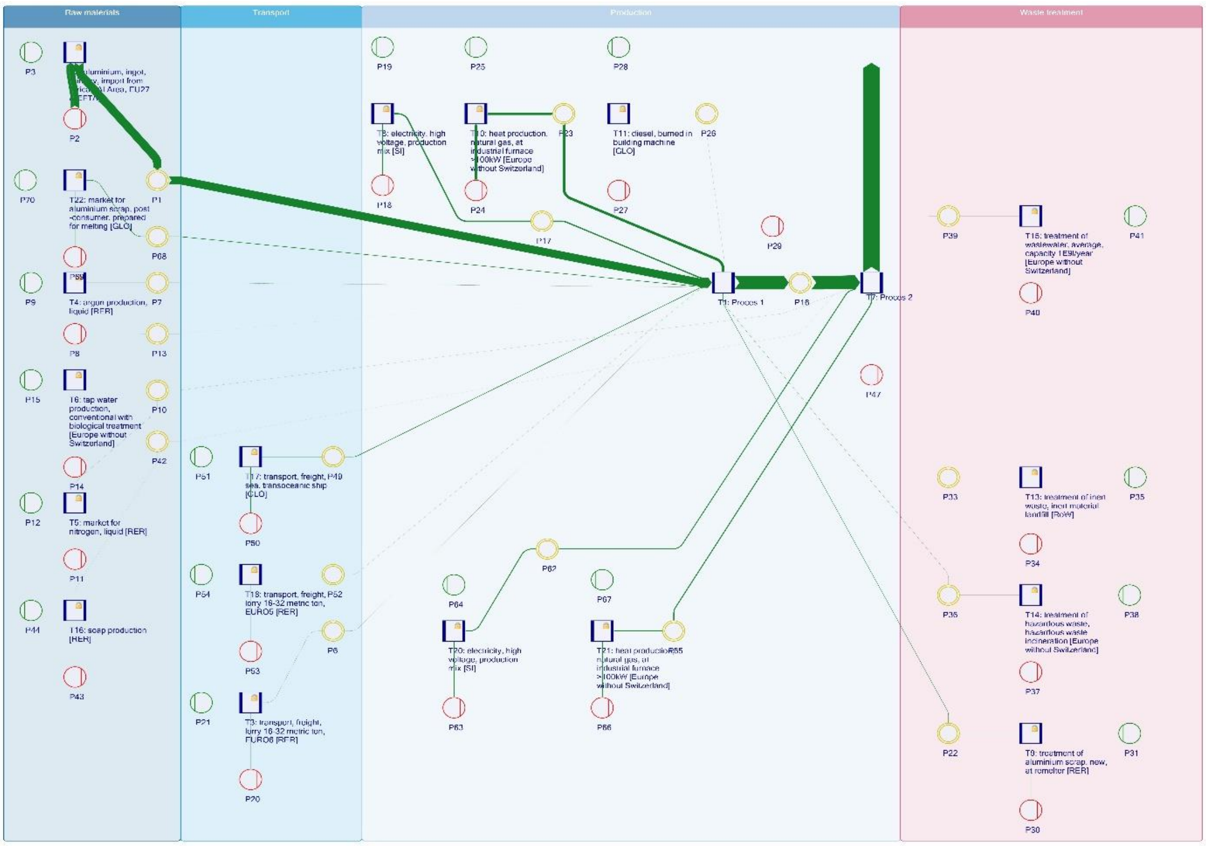

Figure 8: Main flows and related processes contributing to Ozone Layer Depletion Potential (ODP)

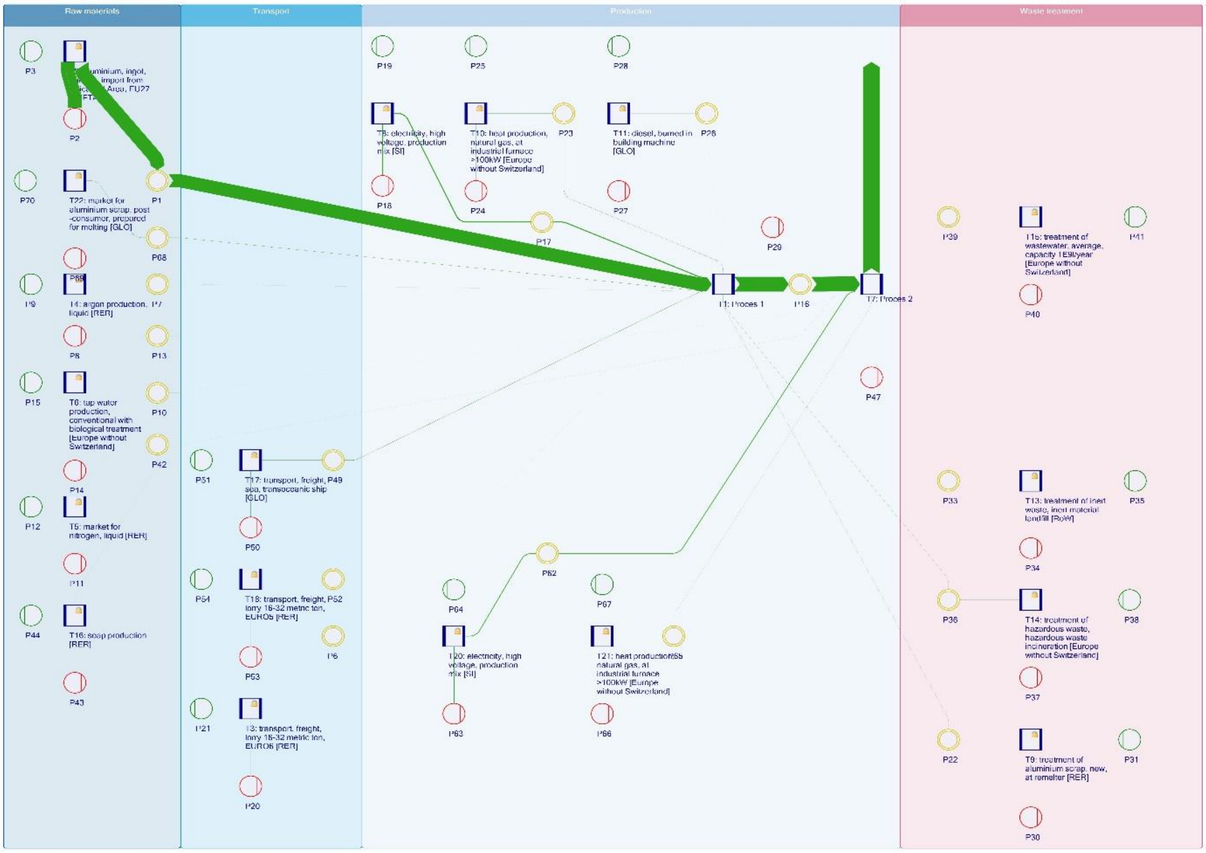

Figure 9: Main flows and related processes contributing to Photo-oxidant Creation Potential (POCP)

5.3. Sensitivity check

No significant sensitivity analysis was conducted in the framework of the report. The uncertainties in the data, allocations methods (should) have a limited effect on the reliability of the final results and on the conclusions.

6. SOURCES

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[2] ASI Performance Standard V2 –Guidance, Aluminium Stewardship Initiative (ASI), December 2017

[3] ISO 14040:2006 International Organization for Standardization (ISO). (2006). ISO 14040 Environmental Management – Life Cycle Assessment – Principles and Framework, 2006

[4] ISO 14044:2006 International Organization for Standardization (ISO). (2006).ISO 14044 Environmental Management – Life Cycle Assessment – Requirements and Guidelines, 2006

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[6] Life-Cycle inventory data for aluminium production and transformation processes in Europe, European Aluminium, February, 2018

[7] Umberto Software (https://www.ifu.com/en/umberto/)

[8] EcoInvent database, 2019 (https://www.ecoinvent.org/)

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