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Life Cycle Inventories of Aluminium and Aluminium Profiles

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Abbreviations and Acronyms

a	year (annum)
BaP	benzo(a)pyrene
CF_4	tetrafluoromethane
C_2F_6	hexafluoroethane
CH	Switzerland
CO_2	carbon dioxide
EAA	European Aluminium Association
GLO	global average
GWP	global warming potential
CED	cumulative energy demand
LCA	life cycle assessment
LCI	life cycle inventory analysis
LCIA	life cycle impact assessment
MJ	megajoule
NMVOC	non-methane volatile organic compounds
NO_x	nitrogen oxides
PAH	polycyclic aromatic hydrocarbons
RER	Europe
SO_2	sulfur dioxide
SZFF	Schweizerische Zentrale für Fenster und Fassaden (Swiss centre for windows and facades)
tkm	tonne kilometre, unit for transportation
UBP	Umweltbelastungspunkte (eco-points)

Summary

In this study, updated life cycle inventories of the production of primary aluminium, secondary aluminium from process scrap and secondary aluminium from old scrap were compiled based on reports published by the European Aluminium Association. In addition, the aluminium mixes for wrought and cast alloys as well as for the overall production were adapted to the mass flows in Europe in 2013. Finally, a specific production mix for the supply of aluminum profiles was compiled based on information from the Swiss centre for windows and facades.

The life cycle inventories encompass the whole production process of aluminium and include the supply of energy and materials, transports and waste treatment. The functional unit of the life cycle assessment of primary and secondary aluminium and of the aluminium mixes is 1 kg of aluminium at the production plant. The functional unit of the life cycle assessment of aluminium profiles is 1 kg of uncoated aluminium profiles at the production plant. The environmental impacts were assessed with the ecological scarcity method 2013, the cumulative energy demand (total and non-renewable) and the greenhouse gas emissions.

The environmental indicator results are summarized in Tab. Z. 1. The update of the life cycle inventories of aluminium results in significant changes in the environmental indicator results. With the exception of the cumulative energy demand of primary aluminium, the environmental impacts of primary aluminium, secondary aluminium from process scrap and secondary aluminium from old scrap decreased according to the three indicators considered. The reduction is stronger in the case of secondary aluminium compared to primary aluminium.

The composition of the aluminium mixes exhibits significant changes compared to the previous datasets. The aluminium production mix and the mix used for wrought alloys have higher shares of secondary aluminium whereas more primary aluminium is used to produce cast alloys. Due to the higher environmental impacts of primary aluminium production compared to secondary aluminium, the environmental indicator results of the aluminium production mix and of wrought alloys decreased and the environmental impacts of cast alloys increased. Similar to wrought alloys, the higher share of secondary aluminium in the specific mix used for the prodcution of aluminium profiles supplied to the Swiss market leads to reduced environmental impacts according to the three indicators considered.

Tab. Z. 1 Environmental indicator results of the aluminium products analysed in this study.

	Ecological Scarcity 2013 UBP / kg	Total Primary Energy MJoil-eq / kg	Non-renewable Primary Energy MJoil-eq / kg	Greenhouse Gas Emissions kgCO_2-eq / kg
Primary Aluminium	11’300	194	159	9.31
Secondary Aluminium Old Scrap	4’050	12.7	11.2	0.849
Secondary Aluminium Process Scrap	338	6.33	6.16	0.358
Aluminium Production Mix	6’600	103	85.4	5.03
Aluminium Wrought Alloys	6’520	107	88.6	5.20
Aluminium Cast Alloys	6’820	91.8	75.9	4.53
Aluminium Profiles, uncoated	6’930	117	97.9	5.68

Content

1 Introduction

Aluminium is an important resource due to its ubiquitous use in the technosphere. The life cycle inventories (LCI) of the European aluminium production contained in the ecoinvent database v2.2+ are mainly based on data from the European Aluminium Association (EAA) and represent the situation in 1998 (Classen et al. 2007; EAA 2000). Since then, the aluminium production data have been updated several times (EAA 2005; EAA 2008; EAA 2013) and an additional life cycle inventory was published, which models the worldwide aluminium production (WorldAluminium 2013).

In this study, the life cycle inventories of primary and secondary aluminium production were updated in order to account for changes in the production processes and better represent the current situation. In addition, the aluminium mixes for wrought and cast alloys as well as for the overall production were adapted to the mass flows in Europe in 2013. Finally, a specific production mix for the supply of aluminum profiles was compiled based on information from the Swiss centre for windows and facades (SZFF; German: Schweizerische Zentrale für Fenster und Fassaden).

The scope of the study is described in Chapter 2 and the updated and newly created life cycle inventories are presented in Chapter 3. The results according to three selected environmental indicators are briefly shown in Chapter 4. Some conclusions are drawn and an oultook is given in Chapter 5.

2 Scope

2.1 Functional Unit

The functional unit of the life cycle assessment of primary and secondary aluminium and of the aluminium mixes is 1 kg of aluminium at the production plant. The production process represents the European situation.

The functional unit of the life cycle assessment of aluminium profiles is 1 kg of uncoated aluminium profiles at the production plant. The production of aluminium profile is specific for the Swiss market.

2.2 System Boundaries

The life cycle inventory of primary aluminium includes the following processes:

- bauxite mining,
- production of aluminium oxide,
- electrolysis of aluminium oxide, and
- production of primary aluminium.

The life cycle assessment of secondary aluminium includes the following processes:

- collection and preparation of aluminium scrap, and
- production of secondary aluminium.

Production losses in the different processes are accounted for. The treatment of wastes, transports as well as the supply of materials and energy are included in the life cycle inventories.

2.3 Data Sources

The ecoinvent v2.2+ datasets for the production of primary and secondary aluminium served as a basis for the actualisation of the life cycle inventories. Data from EAA (2013) were used to update the inventories of the production of primary aluminium and of secondary aluminium from new scrap. These datasets represent the situation in the year 2010. The most recent data on the production of secondary aluminium from old scrap were published by EAA (2008) for the year 2005. The update of the life cycle inventory of the production of secondary aluminium from old scrap was therefore based on these data. Infrastructure processes were not updated due to the lack of new data. The datasets from ecoinvent v2.2+ were used to model these processes (Classen et al. 2007).

The life cycle inventories of the aluminium mixes were compiled based on data from a European mass flow model provided by World Aluminium.

The composition of the aluminium mix used to produce aluminium profiles for the Swiss market was derived with a survey among aluminium processing companies. This survey was carried out by the SZFF for the year 2014. The extrusion process to produce aluminium profiles was not updated based on specific data for the Swiss market. This process was modelled by the respective dataset in ecoinvent v2.2+.

Generic data from ecoinvent v2.2+ were used to model processes for which specific data were not available.

2.4 Life Cycle Impact Assessment

The environmental impacts of the aluminium products analysed in this study are assessed by the three different methods:

- Ecological scarcity method 2013 according to Frischknecht and Buesser Knoepfel (2013), expressed in eco-points (UBP),
- Cumulative energy demand (CED), which is further separated into total and non-renewable CED and expressed in MJ, according to Frischknecht (2007),
- Greenhouse gas (GHG) emissions, expressed in kgCO_2-eq, according to the 100 year global warming potentials (GWPs) reported by IPCC (2013).

The environmental indicator results according to these three methods are required for products to be listed in the KBOB recommendation (Frischknecht 2015).

3 Life Cycle Inventories

3.1 Overview

The updated life cycle inventories of primary aluminium as well as secondary aluminium from old and new scrap are described in Subchapters 3.2 to 3.4. The process chains and data sources are shortly explained and major differences to the previous life cycle inventories contained in ecoinvent v2.2+ (Classen et al. 2007) are emphasized. The life cycle inventories of the updated aluminium mixes for the overall aluminium production as well as for wrought and cast alloys are presented in Subchapter 3.5. The aluminium mix used to produce profiles supplied to the Swiss market is described in Subchapter 3.6.

3.2 Production of Primary Aluminium

3.2.1 Description of the Process Chain

Primary aluminium is produced in several process steps. First, the mineral bauxite is mined, which is used to produce aluminium oxide. Aluminium oxide is then electrolysed to yield liquid aluminium. This process requires the production of anodes and is operated with a specific electricity mix. Finally, liquid aluminium is used to produce primary aluminium. The life cycle inventories of the individual process steps are described in Sections 3.2.2 to 3.2.5.

3.2.2 Bauxite

The life cycle inventory of bauxite mining was updated to the year 2010 with information on the use of diesel, heavy fuel oil, electricity and water (EAA 2013). The consumptive water use was calculated as the difference of water withdrawal and water discharge and was modelled as an evaporation process, which results in the emission of water to the atmosphere. The emissions of particles were adapted according to EAA (2013), which are substantially above the levels in 1998. Since no information is given on the size distribution of the particles, the relative shares of the different size categories were taken from ecoinvent v2.2+ (Classen et al. 2007). The life cycle inventory of bauxite is shown in Tab. 3.1.

Tab. 3.1 Life cycle inventory data of the production of 1 kg bauxite.

	Name	Location	InfrastructureProcess	Unit	bauxite, at mine	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				GLO			
	InfrastructureProcess				0			
	Unit				kg			
product	bauxite, at mine	GLO	0	kg	1			
technosphere	blasting	RER	0	kg	1.56E-4	1	1.06	(1,2,2,1,1,1); ecoinvent
	diesel, burned in building machine	GLO	0	MJ	1.28E-2	1	2.00	(1,1,2,1,1,1); EAA 2013
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	9.00E-4	1	1.06	(1,1,2,1,1,1); EAA 2013
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	8.24E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
	mine, bauxite	GLO	1	unit	8.33E-13	1	3.00	(1,2,2,1,1,1); ecoinvent
	recultivation, bauxite mine	GLO	0	m2	1.67E-4	1	2.00	(1,2,2,1,1,1); ecoinvent
emission resource, in ground	Aluminium, 24% in bauxite, 11% in crude ore, in ground	-	-	kg	2.81E-1	1	1.06	(1,2,2,1,1,1); ecoinvent
emission resource, land	Occupation, mineral extraction site	-	-	m2a	3.35E-4	1	1.50	(1,1,2,1,1,1); EAA 2008
	Transformation, from arable	-	-	m2	1.07E-4	1	2.00	(1,1,2,1,1,1); EAA 2008
	Transformation, from arable, non-irrigated, fallow	-	-	m2	3.41E-5	1	2.00	(1,1,2,1,1,1); EAA 2008
	Transformation, from forest, extensive	-	-	m2	2.67E-5	1	2.00	(1,1,2,1,1,1); EAA 2008
	Transformation, to mineral extraction site	-	-	m2	1.67E-4	1	2.00	(1,1,2,1,1,1); EAA 2008
emission resource, in water	Water, salt, ocean	-	-	m3	7.00E-4	1	1.06	(1,1,2,1,1,1); EAA 2013
	Water, cooling, unspecified natural origin	-	-	m3	5.00E-4	1	1.06	(1,1,2,1,1,1); EAA 2013
technosphere	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	7.50E-4	1	1.08	(2,1,2,1,1,1); EAA 2013
emission air, unspecified	Heat, waste	-	-	MJ	3.24E-3	1	1.08	(1,1,2,1,1,1); EAA 2013
	Particulates, < 2.5 um	-	-	kg	8.50E-6	1	3.01	(2,1,2,1,1,1); EAA 2013; size split according to ecoinvent
	Particulates, > 2.5 um, and < 10um	-	-	kg	7.65E-5	1	2.01	(2,1,2,1,1,1); EAA 2013; size split according to ecoinvent
	Particulates, > 10 um	-	-	kg	8.50E-5	1	1.51	(2,1,2,1,1,1); EAA 2013; size split according to ecoinvent
	Water, Europe	-	-	kg	4.50E-1	1	1.51	(2,1,2,1,1,1); EAA 2013

3.2.3 Aluminium Oxide

In ecoinvent v2.2+, the production of aluminium oxide from bauxite was modelled under consideration of aluminium hydroxide as the intermediate product (Classen et al. 2007). However, this step was omitted in the life cycle inventories compiled by EAA (2013). The direct production of aluminium oxide from bauxite was adopted in the actualisation of the life cycle inventories of primary aluminium in the present study.

The resource use and the pollutant emissions were updated according to EAA (2013). It was assumed that the steam (2 % of total energy demand of this process), which is used as an input of thermal energy, originates from another process as a by-product. The use of the steam therefore causes no additional environmental impacts and is not taken into account in the life cycle inventory. The emissions of particles, nitrogen oxides (NO_x), sulfur dioxide (SO_2) and mercury into air were newly included in the inventory. The size distribution of the particles was assumed to be identical to the distribution of the bauxite mining process since no information was available. Furthermore, the assumption was made that the bauxite residues are recycled, which are consequently not included in the life cycle inventory.

The unit process data of the production of aluminium oxide from bauxite in the year 2010 are compiled in Tab. 3.2. The demand of bauxite and fossil fuels in the production of aluminium oxide increased in comparison to the previous life cycle inventory.

Tab. 3.2 Life cycle inventory data of the production of 1 kg aluminium oxide.

	Name	Location	InfrastructureProcess	Unit	aluminium oxide, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
product	aluminium oxide, at plant	RER	0	kg	1			
technosphere	aluminium hydroxide, plant	RER	1	unit	2.51E-11	1	3.23	(5,na,na,na,na,na); ecoinvent
	aluminium oxide, plant	RER	1	unit	2.50E-11	1	3.23	(5,na,na,na,na,na); ecoinvent
	bauxite, at mine	GLO	0	kg	2.25E+0	1	1.06	(1,1,2,1,1,1); EAA 2013
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	1.06E-1	1	1.06	(1,1,2,1,1,1); EAA 2013
	quicklime, milled, loose, at plant	CH	0	kg	4.20E-2	1	1.06	(1,1,2,1,1,1); EAA 2013
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	5.82E+0	1	1.06	(1,1,2,1,1,1); EAA 2013
	diesel, burned in building machine	GLO	0	MJ	1.00E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
	natural gas, burned in industrial furnace >100kW	RER	0	MJ	4.30E+0	1	1.06	(1,1,2,1,1,1); EAA 2013
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	1.81E-1	1	1.06	(1,1,2,1,1,1); EAA 2013
	transport, freight, rail	RER	0	tkm	1.28E-1	1	2.09	(4,5,na,na,na,na); EAA 2013
	transport, lorry >16t, fleet average	RER	0	tkm	9.00E-3	1	2.09	(4,5,na,na,na,na); EAA 2013
	transport, transoceanic freight ship	OCE	0	tkm	1.37E+1	1	2.09	(4,5,na,na,na,na); EAA 2013
resource, in water	Water, well, in ground	-	-	m3	3.60E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
technosphere	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	4.09E-2	1	1.06	(1,1,2,1,1,1); EAA 2013
	disposal, redmud from bauxite digestion, 0% water, to residual material landfill	CH	0	kg	6.71E-1	1	1.06	(1,1,2,1,1,1); EAA 2013
	disposal, inert material, 0% water, to sanitary landfill	CH	0	kg	6.90E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
	disposal, hazardous waste, 0% water, to underground deposit	DE	0	kg	2.00E-4	1	1.08	(1,1,2,1,1,3); EAA 2013
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	3.10E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
emission air, unspecified	Heat, waste	-	-	MJ	6.52E-1	1	1.06	(1,1,2,1,1,1); EAA 2013
	Mercury	-	-	kg	6.00E-8	1	5.01	(2,1,2,1,1,1); EAA 2013
	Nitrogen oxides	-	-	kg	1.11E-3	1	1.51	(2,1,2,1,1,1); EAA 2013
	Sulfur dioxide	-	-	kg	2.68E-3	1	1.08	(2,1,2,1,1,1); EAA 2013
	Particulates, < 2.5 um	-	-	kg	7.00E-6	1	3.00	(1,1,2,1,1,1); EAA 2013
	Particulates, > 2.5 um, and < 10um	-	-	kg	6.30E-5	1	2.00	(1,1,2,1,1,1); EAA 2013
	Particulates, > 10 um	-	-	kg	7.00E-5	1	1.50	(1,1,2,1,1,1); EAA 2013
	Water, Europe	-	-	kg	5.00E-1	1	1.50	(1,1,2,1,1,1); EAA 2013
emission water, unspecified	Suspended solids, unspecified	-	-	kg	2.30E-4	1	1.50	(1,1,2,1,1,1); EAA 2013
	Mercury	-	-	kg	1.26E-10	1	5.00	(1,1,2,1,1,1); EAA 2013
	COD, Chemical Oxygen Demand	-	-	kg	2.46E-4	1	1.51	(2,1,2,1,1,1); EAA 2008 and ecoinvent, assumption for oil/grease
	BOD5, Biological Oxygen Demand	-	-	kg	2.46E-4	1	1.51	(2,1,2,1,1,1); EAA 2008 and ecoinvent, assumption for oil/grease
	DOC, Dissolved Organic Carbon	-	-	kg	6.75E-5	1	1.51	(2,1,2,1,1,1); EAA 2008 and ecoinvent, assumption for oil/grease
	TOC, Total Organic Carbon	-	-	kg	6.75E-5	1	1.51	(2,1,2,1,1,1); EAA 2008 and ecoinvent, assumption for oil/grease

3.2.4 Electrolysis of Aluminium Oxide

The electrolysis of aluminium oxide yields liquid primary aluminium. In addition to the electrolysis process, the production of anodes as well as the electricity mix of the European aluminium industry were adapted to represent the situation in the year 2010.

The life cycle inventory of the production of anodes was updated based on data on the use of petroleum coke, bitumen, fossil fuels and electricity (EAA 2013). It was assumed that the anode butts are recycled after their use and therefore no additional environmental impacts are caused by the disposal. Emissions of suspended solids and polycyclic aromatic hydrocarbons (PAH) into water were newly included in the inventory and the emitted amounts of various air pollutants were updated (EAA 2013). The size distribution of the particles emitted to the atmosphere was taken from Classen et al. (2007).

The life cycle inventory of the production of 1 kg anode is shown in Tab. 3.3. The amount of petroleum coke increased, whereas less bitumen, fossil fuels and electricity were used in comparison to the year 1998. A strong increase in NO_x emissions was observed.

Tab. 3.3 Life cycle inventory data of the production of 1 kg anode used for the electrolysis of aluminium oxide.

	Name	Location	InfrastructureProcess	Unit	anode, aluminium electrolysis	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
product	anode, aluminium electrolysis	RER	0	kg	1			
technosphere	anode plant	RER	1	unit	2.50E-10	1	3.20	(5,na,na,na,na,na); ecoinvent
	bitumen, at refinery	RER	0	kg	1.52E-1	1	1.10	(1,1,2,1,1,3); EAA 2013
	cast iron, at plant	RER	0	kg	4.10E-3	1	1.10	(1,1,2,1,1,1); EAA 2013
	refractory, fireclay, packed, at plant	DE	0	kg	5.90E-3	1	1.10	(1,1,2,1,1,1); EAA 2013
	petroleum coke, at refinery	RER	0	kg	7.20E-1	1	1.10	(1,1,2,1,1,1); EAA 2013
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	1.08E-1	1	1.10	(1,1,2,1,1,1); EAA 2013
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	5.20E-1	1	1.10	(1,1,2,1,1,1); EAA 2013
	natural gas, burned in industrial furnace >100kW	RER	0	MJ	2.23E+0	1	1.10	(1,1,2,1,1,1); EAA 2013
	diesel, burned in building machine	GLO	0	MJ	1.55E-2	1	1.06	(1,1,2,1,1,1); EAA 2013
	transport, freight, rail	RER	0	tkm	1.66E-1	1	2.09	(4,5,na,na,na,na); ecoinvent, standard distances for all sub-processes
	transport, lorry >16t, fleet average	RER	0	tkm	8.31E-2	1	2.09	(4,5,na,na,na,na); ecoinvent, standard distances for all sub-processes
resource, in water	Water, cooling, unspecified natural origin	-	-	m3	5.60E-3	1	1.10	(1,1,2,1,1,1); EAA 2013
technosphere	disposal, asphalt, 0.1% water, to sanitary landfill	CH	0	kg	9.60E-3	1	1.10	(1,1,2,1,1,1); EAA 2013
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	3.30E-3	1	1.10	(1,1,2,1,1,1); EAA 2013
	disposal, refractory SPL, Al elec.lysis, 0% water, to residual material landfill	CH	0	kg	3.00E-3	1	1.10	(1,1,2,1,1,1); EAA 2013
	disposal, hazardous waste, 0% water, to underground deposit	DE	0	kg	1.40E-3	1	6.00	(1,1,2,1,1,3); EAA 2013
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	2.20E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
emission air, unspecified	Water, Europe	-	-	kg	3.40E+0	1	1.50	(1,1,2,1,1,1); EAA 2013
	Benzo(a)pyrene	-	-	kg	6.00E-8	1	3.00	(1,1,2,1,1,1); EAA 2013
	Carbon monoxide, fossil	-	-	kg	1.04E-3	1	5.00	(1,1,2,1,1,3); ecoinvent v2.0
	Heat, waste	-	-	MJ	3.89E-1	1	1.10	(1,1,2,1,1,1); EAA 2013
	Hydrogen fluoride	-	-	kg	1.23E-5	1	1.50	(1,1,2,1,1,1); EAA 2013
	Nitrogen oxides	-	-	kg	4.50E-4	1	1.50	(1,1,2,1,1,1); EAA 2013
	PAH, polycyclic aromatic hydrocarbons	-	-	kg	6.00E-5	1	3.00	(1,1,2,1,1,1); EAA 2013
	Particulates, < 2.5 um	-	-	kg	6.03E-05	1	3.00	(1,1,2,1,1,1); EAA 2013; size split according to ecoinvent
	Particulates, > 2.5 um, and < 10um	-	-	kg	9.94E-05	1	2.00	(1,1,2,1,1,1); EAA 2013; size split according to ecoinvent
	Particulates, > 10 um	-	-	kg	9.03E-05	1	1.50	(1,1,2,1,1,1); EAA 2013; size split according to ecoinvent
	Sulfur dioxide	-	-	kg	7.70E-4	1	1.10	(1,1,2,1,1,1); EAA 2013
emission water, unspecified	PAH, polycyclic aromatic hydrocarbons	-	-	kg	9.60E-7	1	3.00	(1,1,2,1,1,1); EAA 2013
	Suspended solids, unspecified	-	-	kg	1.40E-4	1	1.50	(1,1,2,1,1,1); EAA 2013

The electricity mix used to operate the electrolysis of aluminium oxide was determined by EAA (2013) with a European electricity model. The composition of the electricity mix in the year 2010 is listed in Tab. 3.4. The electricity mix is dominated by hydropower (54 %), but fossil (28 %) and nuclear (18 %) energy carriers are also important.

Tab. 3.4 Life cycle inventory data of the generation of 1 kWh electricity used for the electrolysis of aluminium oxide.

	Name	Location	InfrastructureProcess	Unit	electricity mix, aluminium industry	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				GLO			
	InfrastructureProcess				0			
	Unit				kWh			
product	electricity mix, aluminium industry	GLO	0	kWh	1			
technosphere	electricity, hydropower, at power plant	NO	0	kWh	5.40E-1	1	1.06	(1,1,2,1,1,1); EAA 2013
	electricity, natural gas, at power plant	IT	0	kWh	1.00E-1	1	1.06	(1,1,2,1,1,1); EAA 2013
	electricity, nuclear, at power plant	UCTE	0	kWh	1.80E-1	1	1.06	(1,1,2,1,1,1); EAA 2013
	electricity, hard coal, at power plant	UCTE	0	kWh	1.70E-1	1	1.06	(1,1,2,1,1,1); EAA 2013
	electricity, oil, at power plant	DE	0	kWh	1.00E-2	1	1.06	(1,1,2,1,1,1); EAA 2013

The electrolysis process used to produce liquid primary aluminium was modelled with data from EAA (2013) for the year 2010. Only electricity is used as an energy input in aluminium electrolysis according to EAA (2013). Cryolite is not inventoried as an input in EAA (2013) but is assumed to still be required in aluminium electrolysis. The consumption of cryolite is therefore taken from the ecoinvent v2.2+ inventory of the production of liquid aluminium. The use of refractory fireclay and water as well as the emissions of particles, oil, fluoride and PAH into water were newly considered in the inventory. The size distribution of particle emissions to air was assumed to be identical to the distribution reported in ecoinvent v2.2+.

The life cycle inventory of the production of liquid primary aluminium is compiled in Tab. 3.5. Compared with 1998, the use of anodes and electricity decreased slightly in the year 2010. The consumption of cathodes, which are modelled with data from ecoinvent v2.2+ due to the lack of more recent data, is significantly lower than in the previous life cycle inventory. The transport by transoceanic freight ship increased substantially. The emissions of NO_x rose, whereas less tetrafluoromethane (CF_4), hexafluoroethane (C_2F_6), benzo(a)pyrene (BaP) and (PAH) were emitted to air.

Tab. 3.5 Life cycle inventory data of the production 1 kg liquid primary aluminium.

	Name	Location	InfrastructureProcess	Unit	aluminium, primary, liquid, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
product	aluminium, primary, liquid, at plant	RER	0	kg	1			
technosphere	aluminium electrolysis, plant	RER	1	unit	1.54E-10	1	3.23	(5,na,na,na,na,na); ecoinvent
	aluminium oxide, at plant	RER	0	kg	1.92E+0	1	1.06	(1,1,2,1,1,1); EAA 2013
	aluminium fluoride, at plant	RER	0	kg	1.58E-2	1	1.06	(1,1,2,1,1,1); EAA 2013
	cryolite, at plant	RER	0	kg	1.60E-3	1	1.11	(1,1,3,1,1,1); ecoinvent
	anode, aluminium electrolysis	RER	0	kg	4.40E-1	1	1.06	(1,1,2,1,1,1); EAA 2013
	cathode, aluminium electrolysis	RER	0	kg	6.90E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
	refractory, fireclay, packed, at plant	DE	0	kg	8.00E-3	1	1.08	(1,1,2,1,1,3); EAA 2013
	reinforcing steel, at plant	RER	0	kg	3.80E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
	electricity, medium voltage, aluminium industry, at grid	GLO	0	kWh	1.49E+1	1	1.06	(1,1,2,1,1,1); EAA 2013
	transport, lorry >16t, fleet average	RER	0	tkm	4.76E-2	1	2.09	(4,5,na,na,na,na); EAA 2013
	transport, freight, rail	RER	0	tkm	9.52E-2	1	2.09	(4,5,na,na,na,na); EAA 2013
	transport, barge	RER	0	tkm	1.69E-1	1	2.09	(4,5,na,na,na,na); EAA 2013
	transport, transoceanic freight ship	OCE	0	tkm	4.67E+0	1	2.09	(4,5,na,na,na,na); EAA 2013
resource, in water	Water, salt, ocean	-	-	m3	4.85E-2	1	1.06	(1,1,2,1,1,1); EAA 2013
	Water, well, in ground	-	-	m3	1.69E-2	1	1.06	(1,1,2,1,1,1); EAA 2013
technosphere	disposal, filter dust Al electrolysis, 0% water, to residual material landfill	CH	0	kg	1.30E-3	1	1.12	(2,1,3,1,1,1); EAA 2008
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	7.00E+0	1	1.12	(2,1,3,1,1,1); EAA 2008
	disposal, asphalt, 0.1% water, to sanitary landfill	CH	0	kg	6.80E-3	1	1.12	(2,1,3,1,1,1); EAA 2008
	disposal, refractory SPL, Al elec.lysis, 0% water, to residual material landfill	CH	0	kg	1.10E-2	1	1.08	(2,1,2,1,1,1); EAA 2013
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	6.40E-2	1	1.08	(2,1,2,1,1,1); EAA 2013
emission air, unspecified	Carbon dioxide, fossil	-	-	kg	1.57E+0	1	1.06	(1,1,2,1,1,1); EAA 2013
	Benzo(a)pyrene	-	-	kg	2.60E-7	1	3.00	(1,1,2,1,1,1); EAA 2013
	PAH, polycyclic aromatic hydrocarbons	-	-	kg	1.27E-5	1	3.00	(1,1,2,1,1,1); EAA 2013
	Nitrogen oxides	-	-	kg	4.40E-4	1	1.50	(1,1,2,1,1,1); EAA 2013
	Sulfur dioxide	-	-	kg	7.40E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
	Particulates, < 2.5 um	-	-	kg	6.81E-4	1	3.00	(2,1,2,1,1,1); EAA 2013; size split according to ecoinvent
	Particulates, > 2.5 um, and < 10um	-	-	kg	1.59E-4	1	2.00	(2,1,2,1,1,1); EAA 2013; size split according to ecoinvent
	Hydrogen fluoride	-	-	kg	5.20E-4	1	1.50	(1,1,2,1,1,1); EAA 2013; Gaseous fluoride and fluoride particulates
	Methane, tetrafluoro-, R-14	-	-	kg	4.00E-5	1	1.50	(1,1,2,1,1,1); EAA 2013
	Ethane, hexafluoro-, HFC-116	-	-	kg	4.00E-6	1	1.50	(1,1,2,1,1,1); EAA 2013
	Water, Europe	-	-	kg	1.40E+0	1	1.50	(1,1,2,1,1,1); EAA 2013
	Heat, waste	-	-	MJ	5.36E+1	1	1.06	(1,1,2,1,1,1); EAA 2013
emission water, unspecified	Suspended solids, unspecified	-	-	kg	8.10E-4	1	1.52	(1,1,3,1,1,1); EAA 2008
	COD, Chemical Oxygen Demand	-	-	kg	2.58E-6	1	1.52	(2,1,3,1,1,1); EAA 2008; C-content oil: 0.86, COD = 3DOC
	PAH, polycyclic aromatic hydrocarbons	-	-	kg	3.32E-6	1	3.01	(1,1,3,1,1,1); EAA 2008
	Fluoride	-	-	kg	3.50E-4	1	1.50	(1,1,2,1,1,1); EAA 2013

3.2.5 Primary Aluminium

In line with the approach followed in ecoinvent v2.2+, primary aluminium is assumed to be produced exclusively from liquid primary aluminium without any use of secondary material. The inputs of various chemicals, fossil fuels, electricity and water were updated according to data from EAA (2013). The emissions of NO_x, SO_2 and hydrogen chloride were newly added to the inventory.

The life cycle inventory data of the production of primary aluminium are shown in Tab. 3.6. A slight increase in the input of liquid primary aluminium is registered between 1998 and 2010. The use of fossil fuels was substantially reduced.

Tab. 3.6 Life cycle inventory data of the production of 1 kg primary aluminium.

	Name	Location	InfrastructureProcess	Unit	aluminium, primary, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
product	aluminium, primary, at plant	RER	0	kg	1			
technosphere	aluminium casting, plant	RER	1	unit	1.54E-10	1	3.23	(5,na,na,na,na,na); ecoinvent
	aluminium, primary, liquid, at plant	RER	0	kg	1.02E+0	1	1.06	(1,1,2,1,1,1); EAA 2013
	cryolite, at plant	RER	0	kg	4.00E-4	1	1.08	(1,1,2,1,1,3); ecoinvent
	nitrogen, liquid, at plant	RER	0	kg	2.20E-4	1	1.08	(1,1,2,1,1,3); EAA 2013
	chlorine, liquid, production mix, at plant	RER	0	kg	5.00E-5	1	1.06	(1,1,2,1,1,1); EAA 2013
	argon, liquid, at plant	RER	0	kg	2.11E-3	1	1.08	(2,1,2,1,1,1); EAA 2013
	palm oil, at oil mill	MY	0	kg	8.00E-5	1	1.08	(1,1,2,1,1,3); ecoinvent
	corrugated board, mixed fibre, single wall, at plant	RER	0	kg	1.80E-3	1	1.08	(1,1,2,1,1,3); ecoinvent
	rock wool, at plant	CH	0	kg	1.10E-4	1	1.08	(1,1,2,1,1,3); ecoinvent
	electricity, medium voltage, aluminium industry, at grid	GLO	0	kWh	9.80E-2	1	1.06	(1,1,2,1,1,1); EAA 2013
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	1.90E-1	1	1.06	(1,1,2,1,1,1); EAA 2013
	diesel, burned in building machine	GLO	0	MJ	4.60E-2	1	1.06	(1,1,2,1,1,1); EAA 2013
	natural gas, burned in industrial furnace >100kW	RER	0	MJ	1.35E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
emission resource, in water	Water, well, in ground	-	-	m3	8.30E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
	disposal, filter dust Al electrolysis, 0% water, to residual material landfill	CH	0	kg	5.00E-4	1	1.06	(1,1,2,1,1,1); EAA 2013, filter dust
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	1.10E-3	1	1.06	(1,1,2,1,1,1); EAA 2013, other landfill waste
	disposal, refractory SPL, Al elec.lysis, 0% water, to residual material landfill	CH	0	kg	6.00E-4	1	1.06	(1,1,2,1,1,1); EAA 2013, refractory material
	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	8.70E-3	1	1.08	(2,1,2,1,1,1); EAA 2013
emission air, unspecified	Nitrogen oxides	-	-	kg	2.10E-4	1	1.50	(1,1,2,1,1,1); EAA 2013
	Sulfur dioxide	-	-	kg	1.50E-4	1	1.50	(1,1,2,1,1,1); EAA 2013
	Particulates, > 2.5 um, and < 10um	-	-	kg	4.00E-05	1	1.50	(2,1,2,1,1,1); EAA 2013 and ecoinvent
emission air, unspecified	Hydrogen chloride	-	-	kg	2.00E-5	1	1.50	(1,1,2,1,1,1); EAA 2013
emission air, unspecified	Heat, waste	-	-	MJ	3.53E-1	1	1.50	(1,1,2,1,1,1); EAA 2013
emission water, unspecified	Suspended solids, unspecified	-	-	kg	3.40E-4	1	1.50	(1,1,2,1,1,1); EAA 2013

3.3 Production of Secondary Aluminium from Old Scrap

3.3.1 Description of the Process Chain

Old aluminium scrap (also termed product scrap) encompasses a wide range of aluminium products, which are collected after their use for recycling. Examples of old scrap include beverage cans, cylinder heads of motor vehicles, window frames and electrical conductor cables (EAA 2008).

The production of secondary aluminium from old scrap requires first the collection of used aluminium products and the separation from foreign elements or contaminants (scrap preparation). The old aluminium scrap is then molten into casting alloys (scrap refining) (EAA 2008). The life cycle inventories of these two processes for the situation in the year 2005 are described in Sections 3.3.2 and 3.3.3.

3.3.2 Collection and Preparation of Old Scrap

The life cycle inventory data of the collection and preparation of old aluminium scrap were updated to the year 2005 by using the resource use and pollutant emissions published in EAA (2008). The use of water was newly added. The input of additives was modelled as a consumption of copper, which is in line with the previous life cycle inventory in ecoinvent v2.2+ (Classen et al. 2007). The size distribution of the particle emissions to air is not described in EAA (2008). The relative shares of the three size categories was therefore taken from the corresponding dataset in ecoinvent v2.2+ (Classen et al. 2007).

The life cycle inventory of the collection and preparation of old aluminium scrap is listed in Tab. 3.7. Compared to 1998, the consumption of fossil fuels is clearly lower in 2005. In contrast, the particle emissions strongly increased in this time period.

Tab. 3.7 Life cycle inventory data of the collection and preparation 1 kg old aluminium scrap.

	Name	Location	InfrastructureProcess	Unit	aluminium scrap, old, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
product	aluminium scrap, old, at plant	RER	0	kg	1			
technosphere	scrap preparation plant	RER	1	unit	2.00E-9	1	3.23	(5,na,na,na,na,na); ecoinvent
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	6.30E-2	1	1.06	(1,1,2,1,1,1); EAA 2008
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	6.07E-2	1	1.06	(1,1,2,1,1,1); EAA 2008
	natural gas, burned in industrial furnace >100kW	RER	0	MJ	6.13E-1	1	1.06	(1,1,2,1,1,1); EAA 2008
	chemicals organic, at plant	GLO	0	kg	1.20E-4	1	1.06	(1,1,2,1,1,1); EAA 2008
	lubricating oil, at plant	RER	0	kg	1.00E-5	1	1.06	(1,1,2,1,1,1); EAA 2008
	light fuel oil, at regional storage	RER	0	kg	1.70E-4	1	1.06	(1,1,2,1,1,1); EAA 2008
	copper, at regional storage	RER	0	kg	4.60E-4	1	1.06	(1,1,2,1,1,1); EAA 2008
	MG-silicon, at plant	NO	0	kg	1.20E-3	1	1.06	(1,1,2,1,1,1); EAA 2008
	lime, hydrated, packed, at plant	CH	0	kg	1.40E-4	1	1.06	(1,1,2,1,1,1); EAA 2008
	transport, lorry >16t, fleet average	RER	0	tkm	1.55E-1	1	2.09	(4,5,na,na,na,na); ecoinvent standard distances
	transport, freight, rail	RER	0	tkm	2.51E-1	1	2.09	(4,5,na,na,na,na); ecoinvent standard distances
	disposal, hazardous waste, 0% water, to underground deposit	DE	0	kg	5.73E-2	1	1.08	(1,1,2,1,1,3); EAA 2008
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	1.60E-2	1	1.06	(1,1,2,1,1,1); EAA 2008
	disposal, filter dust Al electrolysis, 0% water, to residual material landfill	CH	0	kg	3.52E-3	1	1.06	(1,1,2,1,1,1); EAA 2008
	disposal, rubber, unspecified, 0% water, to municipal incineration	CH	0	kg	4.70E-2	1	1.06	(1,1,2,1,1,1); EAA 2008
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	1.61E-3	1	1.06	(1,1,2,1,1,1); EAA 2008
resource, in water	Water, unspecified natural origin	-	-	m3	4.50E-2	1	1.06	(1,1,2,1,1,1); EAA 2008
emission air,	Particulates, < 2.5 um	-	-	kg	2.00E-5	1	3.00	(1,1,2,1,1,1); EAA 2008
	Particulates, > 2.5 um, and < 10um	-	-	kg	4.80E-5	1	2.00	(1,1,2,1,1,1); EAA 2008
	Particulates, > 10 um	-	-	kg	3.20E-5	1	1.50	(1,1,2,1,1,1); EAA 2008
	Hydrogen chloride	-	-	kg	1.10E-5	1	1.50	(1,1,2,1,1,1); EAA 2008
	Heat, waste	-	-	MJ	2.27E-1	1	1.06	(1,1,2,1,1,1); EAA 2008
	Water, Europe	-	-	kg	4.50E+1	1	1.50	(1,1,2,1,1,1); EAA 2008

3.3.3 Secondary Aluminium from Old Scrap

Data from EAA (2008) was used to compile an updated life cycle inventory of the production of secondary aluminium from old srap for the year 2005. Analogously to the assumption made in ecoinvent v2.2+, the input of alloys was modelled by a mixture of zinc, MG-silicon and copper. The shares of these materials were taken from Classen et al. (2007). The same procedure was applied to the size distribution of particle emissions to air.

The life cycle inventory of the production of secondary aluminium from old scrap is shown in Tab. 3.8. The input of old aluminium scrap slightly increased between 1998 and 2005. The use of energy decreased substantially in this time period.

Tab. 3.8 Life cycle inventory data of the production of 1 kg secondary aluminium from old aluminium scrap.

	Name	Location	InfrastructureProcess	Unit	aluminium, secondary, from old scrap, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
product	aluminium, secondary, from old scrap, at plant	RER	0	kg	1			
technosphere	aluminium casting, plant	RER	1	unit	1.54E-10	1	3.23	(5,na,na,na,na,na); ecoinvent
	aluminium melting furnace	RER	1	unit	2.00E-9	1	3.23	(5,na,na,na,na,na); ecoinvent
	aluminium scrap, old, at plant	RER	0	kg	1.05E+0	1	1.06	(1,1,2,1,1,1); EAA 2008
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	6.08E-2	1	1.06	(1,1,2,1,1,1); EAA 2008
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	1.16E-1	1	1.06	(1,1,2,1,1,1); EAA 2008
	natural gas, burned in industrial furnace >100kW	RER	0	MJ	3.80E+0	1	1.06	(1,1,2,1,1,1); EAA 2008
	nitrogen, liquid, at plant	RER	0	kg	3.20E-3	1	1.06	(1,1,2,1,1,1); EAA 2008
	chlorine, liquid, production mix, at plant	RER	0	kg	2.50E-4	1	1.06	(1,1,2,1,1,1); EAA 2008
	argon, liquid, at plant	RER	0	kg	9.70E-4	1	1.06	(1,1,2,1,1,1); EAA 2008
	MG-silicon, at plant	NO	0	kg	1.01E-2	1	1.06	(1,1,2,1,1,1); EAA 2008
	copper, at regional storage	RER	0	kg	6.15E-4	1	1.06	(1,1,2,1,1,1); EAA 2008
	zinc, primary, at regional storage	RER	0	kg	5.33E-2	1	1.06	(1,1,2,1,1,1); EAA 2008
	lime, hydrated, packed, at plant	CH	0	kg	3.94E-3	1	1.06	(1,1,2,1,1,1); EAA 2008
	sodium chloride, powder, at plant	RER	0	kg	1.13E-2	1	1.06	(1,1,2,1,1,1); EAA 2008
	aluminium fluoride, at plant	RER	0	kg	7.20E-4	1	1.06	(1,1,2,1,1,1); EAA 2008
	lubricating oil, at plant	RER	0	kg	1.10E-4	1	1.06	(1,1,2,1,1,1); EAA 2008
	refractory, fireclay, packed, at plant	DE	0	kg	2.40E-3	1	1.08	(1,1,2,1,1,3); EAA 2008
resource, in water	Water, cooling, unspecified natural origin	-	-	m3	1.78E-2	1	1.06	(1,1,2,1,1,1); EAA 2008
emission air,	Chlorine	-	-	kg	2.00E-6	1	1.50	(1,1,2,1,1,1); EAA 2008
	Particulates, < 2.5 um	-	-	kg	4.20E-6	1	3.00	(1,1,2,1,1,1); EAA 2008
	Particulates, > 2.5 um, and < 10um	-	-	kg	1.01E-5	1	2.00	(1,1,2,1,1,1); EAA 2008
	Particulates, > 10 um	-	-	kg	6.73E-6	1	1.50	(1,1,2,1,1,1); EAA 2008
	Hydrogen chloride	-	-	kg	3.80E-5	1	1.50	(1,1,2,1,1,1); EAA 2008
	Hydrogen fluoride	-	-	kg	2.00E-6	1	1.50	(1,1,2,1,1,1); EAA 2008
	Heat, waste	-	-	MJ	2.19E-1	1	1.06	(1,1,2,1,1,1); EAA 2008
	Water, Europe	-	-	kg	9.00E+0	1	1.50	(1,1,2,1,1,1); EAA 2008
technosphere	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	8.80E-3	1	1.06	(1,1,2,1,1,1); EAA 2008
	disposal, hazardous waste, 0% water, to underground deposit	DE	0	kg	8.50E-4	1	1.08	(1,1,2,1,1,3); EAA 2008
	disposal, filter dust Al electrolysis, 0% water, to residual material landfill	CH	0	kg	1.74E-2	1	1.06	(1,1,2,1,1,1); EAA 2008
	transport, lorry >16t, fleet average	RER	0	tkm	9.98E-3	1	2.09	(4,5,na,na,na,na); ecoinvent standard distances
	transport, freight, rail	RER	0	tkm	2.27E-2	1	2.09	(4,5,na,na,na,na); ecoinvent standard distances

3.4 Production of Secondary Aluminium from Process Scrap

3.4.1 Description of the Process Chain

Aluminium process scrap, which is also termed new aluminium scrap, arises as discard in the production and fabrication of aluminium products. Process scrap includes, for instance, extrusion wastes, sheet edge trim, millings and turnings (EAA 2013).

The production of secondary aluminium from process scrap occurs in two steps. First, new aluminium scrap is collected and prepared. Remelting of this material then yields new wrought aluminium alloys (EAA 2013). Updated data on the collection of process scrap is lacking. For this process step, the data published in ecoinvent v2.2+ were still used (Classen et al. 2007). The remelting process of new scrap in the aluminium plant was modelled with data from EAA (2013) for the situation in the year 2010 and is described in Section 3.4.2.

3.4.2 Secondary Aluminium from Process Scrap

In the environmental profile report, the EAA (2013) replaced the inputs of other aluminium products and alloying elements by new aluminium scrap. This modelling approach was adopted in the update of the inventory of secondary aluminium from process scrap. Inputs of MG-silicon and copper, which were included in the life cycle inventories of secondary aluminium production from process scrap in ecoinvent v2.2+ (Classen et al. 2007), are therefore no longer considered. The use of absorbent for exhaust gas treatment was modelled as a consumption of sodium hydroxide. Based on Classen et al. (2007), it was assumed that the input of other ancillary materials mainly encompasses refractory fireclay. The emissions of gaseous organic carbon were modelled as methane emissions since non-methane volatile organic compounds (NMVOC) are already taken into account (EAA 2013). It was further assumed that dross and skimmings as well as hazardous and non-hazardous wastes for further processing are recycled and therefore do not cause any additional environmental impacts. The emissions of chlorine, NO_x, SO_2, NMVOC, methane and particles were newly considered in the life cycle inventory for the year 2010. The size distribution of the particles emitted was assumed to be identical to that of the production of secondary aluminium from old scrap. The emissions of water pollutants were modelled by applying the sum parameter of chemical oxygen demand (COD) (EAA 2013).

The life cycle inventory data of the production of secondary aluminium from process scrap in the year 2010 are compiled in Tab. 3.9. The use of fossil fuels increased, whereas the consumption of electricity decreased in comparison to 1998.

Tab. 3.9 Life cycle inventory data of the production of 1 kg secondary aluminium from process scrap.

	Name	Location	InfrastructureProcess	Unit	aluminium, secondary, from new scrap, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER			
	InfrastructureProcess				0			
	Unit				kg			
product	aluminium, secondary, from new scrap, at plant	RER	0	kg	1			
technosphere	aluminium casting, plant	RER	1	unit	1.54E-10	1	3.23	(5,na,na,na,na,na); ecoinvent
	aluminium melting furnace	RER	1	unit	2.00E-9	1	3.23	(5,na,na,na,na,na); ecoinvent
	aluminium scrap, new, at plant	RER	0	kg	1.04E+0	1	1.06	(1,1,2,1,1,1); EAA 2013
	electricity, medium voltage, production ENTSO, at grid	ENTSO	0	kWh	1.24E-1	1	1.06	(1,1,2,1,1,1); EAA 2013
	heavy fuel oil, burned in industrial furnace 1MW, non-modulating	RER	0	MJ	7.70E-2	1	1.06	(1,1,2,1,1,1); EAA 2013
	diesel, burned in building machine	GLO	0	MJ	6.70E-2	1	1.06	(1,1,2,1,1,1); EAA 2013
	natural gas, burned in industrial furnace >100kW	RER	0	MJ	3.68E+0	1	1.06	(1,1,2,1,1,1); EAA 2013; natural gas and propane/butane
	refractory, fireclay, packed, at plant	DE	0	kg	5.00E-4	1	1.08	(1,1,2,1,1,3); EAA 2013
	argon, liquid, at plant	RER	0	kg	1.70E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
	nitrogen, liquid, at plant	RER	0	kg	5.00E-4	1	1.06	(1,1,2,1,1,1); EAA 2013
	chlorine, liquid, production mix, at plant	RER	0	kg	3.00E-4	1	1.06	(1,1,2,1,1,1); EAA 2013
	sodium hydroxide, 50% in H2O, production mix, at plant	RER	0	kg	1.60E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
	transport, lorry >16t, fleet average	RER	0	tkm	8.12E-4	1	2.09	(4,5,na,na,na,na); ecoinvent standard distances
	transport, freight, rail	RER	0	tkm	1.12E-3	1	2.09	(4,5,na,na,na,na); ecoinvent standard distances
resource, in water	Water, unspecified natural origin	-	-	m3	9.00E-4	1	1.06	(1,1,2,1,1,1); EAA 2013
	Water, cooling, unspecified natural origin	-	-	m3	4.90E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
technosphere	treatment, sewage, to wastewater treatment, class 3	CH	0	m3	5.40E-3	1	1.06	(1,1,2,1,1,1); EAA 2013
	disposal, hazardous waste, 0% water, to underground deposit	DE	0	kg	8.00E-4	1	1.08	(1,1,2,1,1,3); EAA 2013
	disposal, inert waste, 5% water, to inert material landfill	CH	0	kg	1.00E-4	1	1.06	(1,1,2,1,1,1); EAA 2013
	disposal, municipal solid waste, 22.9% water, to municipal incineration	CH	0	kg	1.00E-4	1	1.06	(1,1,2,1,1,1); EAA 2013
emission air, unspecified	Chlorine	-	-	kg	1.30E-6	1	1.50	(1,1,2,1,1,1); EAA 2013
	Hydrogen chloride	-	-	kg	1.56E-5	1	1.50	(1,1,2,1,1,1); EAA 2013
	Nitrogen oxides	-	-	kg	3.53E-4	1	1.50	(1,1,2,1,1,1); EAA 2013
	Sulfur dioxide	-	-	kg	6.47E-5	1	1.06	(1,1,2,1,1,1); EAA 2013
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	4.40E-6	1	1.50	(1,1,2,1,1,1); EAA 2013
	Methane, fossil	-	-	kg	5.26E-5	1	1.50	(1,1,2,1,1,1); EAA 2013
	Particulates, < 2.5 um	-	-	kg	1.05E-5	1	3.00	(1,1,2,1,1,1); EAA 2013
	Particulates, > 2.5 um, and < 10um	-	-	kg	2.52E-5	1	2.00	(1,1,2,1,1,1); EAA 2013
	Particulates, > 10 um	-	-	kg	1.68E-5	1	1.50	(1,1,2,1,1,1); EAA 2013
	Heat, waste	-	-	MJ	4.46E-1	1	1.06	(1,1,2,1,1,1); EAA 2013
	Water, Europe	-	-	kg	4.00E-1	1	1.50	(1,1,2,1,1,1); EAA 2013
emission water, unspecified	COD, Chemical Oxygen Demand	-	-	kg	3.52E-5	1	1.50	(1,1,2,1,1,1); EAA 2013

3.5 Aluminium Mixes

The life cycle inventories of aluminium wrought and cast alloys as well as of the overall aluminium production mix were updated based on data obtained from World Aluminium[1]. The shares of primary aluminium and secondary aluminium from new and old scrap in the aluminium mixes were calculated with a mass flow model for Europe in 2013. The model data are listed in Tab. 3.10 and the life cycle inventories of the aluminium mixes are shown in Tab. 3.11.

The share of secondary aluminium increased significantly in the aluminium production mix (48.8 %) in comparison to ecoinvent v2.2+ (68.0 %) (Classen et al. 2007). This is due to an increase in both the input of secondary aluminium from process scrap and of product scrap. A similar but more pronounced development is observed in the

1 Personal communication, Marlen Bertram, World Aluminium, 06.04.2016.

aluminium mix for wrought alloys where the share of primary material decreased from 90.0 % to 53.6 %. Secondary aluminium from old scrap was not used in the production of wrought alloy according to ecoinvent v2.2+ but has a share of 8.3 % in the updated inventory. More primary aluminium is used in the production of cast alloys (44.1 %) compared to the respective dataset in ecoinvent v2.2+ (20 %). The main reason is probably a sharp decrease in the input of secondary aluminium from process scrap (10.5 % compared to 47.0 % in ecoinvent v2.2+).

Tab. 3.10 Inputs of different fractions in the aluminium production mix and in wrought and cast alloys in 1000 t. The net positive stock change of primary aluminium in the production mix represents an accumulation of this fraction and is therefore subtracted from the total primary aluminium input. Data have been calculated with a mass flow model for Europe in 2013 and provided by Marlen Bertram, World Aluminium[1].

Metal Intake in 1000 t	Production Mix	Wrought Alloy	Cast Alloy
Total Primary	**8'150**	**6'367**	**1'783**
Primary Ingots	4'170		
Net Imports	4'360		
Stock Change	380		
Total Secondary	**7'760**	**5'502**	**2'258**
Old Scrap	2'780	980	1800
Wrought Scrap	3'220	3'059	161
Traded New Scrap	1'760	1'463	297
Total	**15'910**	**11'869**	**4'041**

Tab. 3.11 Life cycle inventories of the overall aluminium production mix and of the mixes for wrought and cast alloys.

	Name	Location	InfrastructureProcess	Unit	aluminium, production mix, at plant	aluminium, production mix, cast alloy, at plant	aluminium, production mix, wrought alloy, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER			
	InfrastructureProcess				0	0	0			
	Unit				kg	kg	kg			
product	aluminium, production mix, at plant	RER	0	kg	1	0	0			
	aluminium, production mix, cast alloy, at plant	RER	0	kg	0	1	0			
	aluminium, production mix, wrought alloy, at plant	RER	0	kg	0	0	1			
technosphere	aluminium, primary, at plant	RER	0	kg	5.12E-1	4.41E-1	5.36E-1	1	1.09	(2,1,2,1,1,3,BU:1.05); Data from mass flow model for Europe in 2013; World
	aluminium, secondary, from old scrap, at plant	RER	0	kg	1.75E-1	4.45E-1	8.26E-2	1	1.09	(2,1,2,1,1,3,BU:1.05); Data from mass flow model for Europe in 2013; World
	aluminium, secondary, from new scrap, at plant	RER	0	kg	3.13E-1	1.13E-1	3.81E-1	1	1.09	(2,1,2,1,1,3,BU:1.05); Data from mass flow model for Europe in 2013; World

3.6 Aluminium Mix for Profile Production

The aluminium mix used to produce aluminium profiles supplied to the Swiss market was derived with a survey among the relevant aluminium processing companies carried out by the SZFF for the year 2014. The share of primary aluminium in the production of profiles amounts to 48.3 % on average. Since the fraction of secondary aluminium is not further divided into secondary aluminium from process and product scrap, their relative shares were assumed to be identical to the European mass flows in 2013 (see Subchapter 3.5). The life cycle inventory of the aluminium mix used for the production of aluminium profiles for the Swiss market is shown in Tab. 3.12.

Tab. 3.12 Life cycle inventories of the aluminium mix used for the production of aluminium profiles for the Swiss market based on the SZFF survey for the year 2014.

	Name	Location	Category	SubCategory	InfrastructureProcess	Unit	aluminium, production mix for aluminium profiles, SZFF 2014, at plant	UncertaintyType	StandardDeviation95%	GeneralComment
	Location						CH			
	InfrastructureProcess						0			
	Unit						kg			
product	aluminium, production mix for aluminium profiles, SZFF 2014, at plant	CH	-	-	0	kg	1			
technosphere	aluminium, primary, at plant	RER	-	-	0	kg	4.83E-1	1	1.09	(2,1,2,1,1,3,BU:1.05); Data for producers supplying the Swiss market
	aluminium, secondary, from old scrap, at plant	RER	-	-	0	kg	9.20E-2	1	1.09	(2,1,2,1,1,3,BU:1.05); Data for producers supplying the Swiss market
	aluminium, secondary, from new scrap, at plant	RER	-	-	0	kg	4.25E-1	1	1.09	(2,1,2,1,1,3,BU:1.05); Data for producers supplying the Swiss market

4 Life Cycle Impact Assessment

4.1 Overview

The environmental impacts of the production of primary and secondary aluminium are presented in Subchapter 4.2. The results of the aluminium mixes and the aluminium profiles supplied to the Swiss market are shown in Subchapters 4.3 and 4.4, respectively.

4.2 Primary and Secondary Aluminium

The environmental indicator results for the production of primary and secondary aluminium are listed in Tab. 4.1. The total environmental impacts according to the ecological scarcity method 2013 of primary aluminium production decreased by -10 % due to a reduction in the emissions of greenhouse gases and air pollutants. The cumulative energy demand increased (total: +4 %, non-renewable: +7 %) because of a higher share of fossil and nuclear technologies in the electricity mix used for the electrolysis of aluminium oxide. The reduction in greenhouse gas emissions (-15 %) is caused by much lower emissions of CF_4 and C_2F_6 in the electrolysis.

The environmental impacts of secondary aluminium production from old scrap decreased according to all indicators analysed (total environmental impacts: -20 %, non-renewable cumulative energy demand: -47 %). The main reason for the reduction is the significantly lower energy demand of remelting.

The total environmental impacts of secondary aluminium from process scrap decreased by -59 %. The reduction in the cumulative energy demand (total: -21 %, non-renewable: -12 %) and the greenhouse gas emissions (-13 %) is less pronounced. This change is caused to a large extent by the new modelling of alloying elements (MG-silicon and copper), which were substituted by aluminium scrap in the updated life cycle inventory (see Section 3.4.2). The reduction in the total environmental impacts is higher compared to the other indicators because of much lower heavy metal emissions to air.

Tab. 4.1 Environmental indicator results for primary and secondary aluminium production. The more recent values were calculated based on the updated life cycle inventories presented in this study, whereas the previous results are based on ecoinvent v2.2+ data (KBOB et al. 2014).

		Ecological Scarcity 2013 UBP / kg	Total Primary Energy MJoil-eq / kg	Non-renewable Primary Energy MJoil-eq / kg	Greenhouse Gas Emissions kgCO_2-eq / kg
Primary Aluminium	**New**	**11’300**	**194**	**159**	**9.31**
	Prev.	12’600	187	148	11.0
Secondary Aluminium Old Scrap	**New**	**4’050**	**12.7**	**11.2**	**0.849**
	Prev.	5’050	23.0	21.0	1.35
Secondary Aluminium Process Scrap	**New**	**338**	**6.33**	**6.16**	**0.358**
	Prev.	838	8.01	6.97	0.411

4.3 Aluminium Mixes

The environmental impacts of the aluminium mixes analysed are presented in Tab. 4.2. A comparison to the results of the former mixes included in ecoinvent v2.2+ shows significant changes in all three indicators for each of the aluminium mixes. These changes are caused by both differences in the environmental intensity of aluminium production and the composition of the aluminium mixes.

The environmental impacts of the aluminium production mix and the aluminium mix for wrought alloys decreased substantially due to the higher share of secondary aluminium. In contrast, more primary aluminium is used for the production of aluminium cast alloy which leads to a strong increase in the environmental impacts of between +49 % in the total environmental impacts and +90 % in the non-renewable cumulative energy demand.

Tab. 4.2 Environmental indicator results for the aluminium production mix and for the mixes for wrought and cast alloys. The more recent values were calculated based on the updated aluminium mixes presented in this study, whereas the previous results are based on ecoinvent v2.2+ data (KBOB et al. 2014).

		Ecological Scarcity 2013 UBP / kg	Total Primary Energy MJoil-eq / kg	Non-renewable Primary Energy MJoil-eq / kg	Greenhouse Gas Emissions $kgCO_2$-eq / kg
Production Mix	**New**	**6'600**	**103**	**85.4**	**5.03**
	Prev.	10'200	151	122	8.65
Wrought Alloys	**New**	**6'520**	**107**	**88.6**	**5.20**
	Prev.	11'400	169	134	9.90
Cast Alloys	**New**	**6'820**	**91.8**	**75.9**	**4.53**
	Prev.	4'580	48.8	39.9	2.83

4.4 Aluminium Profiles

Tab. 4.3 lists the environmental indicator results for aluminium profiles supplied to the Swiss market. According to all indicators considered, the environmental impacts decreased significantly compared to the previous values based on ecoinvent v2.2+ data. This change is caused by both differences in the environmental intensity of aluminium production and the composition of the aluminium mix used for the production of aluminium profiles.

Tab. 4.3 Environmental indicator results for aluminium profiles produced for the Swiss market. The more recent values were calculated based on the updated aluminium mix presented in this study, whereas the previous results are based on ecoinvent v2.2+ data (KBOB et al. 2014).

		Ecological Scarcity 2013 UBP / kg	Total Primary Energy MJoil-eq / kg	Non-renewable Primary Energy MJoil-eq / kg	Greenhouse Gas Emissions $kgCO_2$-eq / kg
Aluminium Profiles, uncoated	**New**	**6'930**	**117**	**97.9**	**5.68**
	Prev.	10'200	151	122	8.65

5 Conclusions and Outlook

The update of the life cycle inventories of aluminium, which were compiled more than ten years ago for the ecoinvent v2.0 database, results in significant changes in the environmental indicator results. With the exception of the cumulative energy demand of primary aluminium, the environmental impacts of primary aluminium, secondary aluminium from process scrap and secondary aluminium from old scrap decreased according to the three indicators considered. The reduction is stronger in the case of secondary aluminium compared to primary aluminium. The results also show that the environmental impacts are particularly sensitive to the energy demand and the energy mix used for electrolysis (primary aluminium) or remelting (secondary aluminium). Fossil and nuclear technologies have higher shares in the specific electricity mix of the aluminium industry used for the electrolysis of aluminium oxide compared to the previous life cycle inventories. This is the main reason for increase in the cumulative energy demand of primary aluminium production.

In addition to the life cycle inventories of aluminium production, also those of aluminium mixes were updated in this study. The composition of the aluminium mixes exhibits significant changes compared to the previous datasets. The aluminium production mix and the mix used for wrought alloys have higher shares of secondary aluminium whereas more primary aluminium is used to produce cast alloys. Due to the higher environmental impacts of primary aluminium production compared to secondary aluminium, the environmental indicator results of the aluminium production mix and of wrought alloys decreased and the environmental impacts of cast alloys increased. Consequently, some convergence is observed in the environmental impacts of wrought and cast alloys.

A new life cycle inventory was compiled, which accounts for the specific aluminium mix used in the production of aluminium profiles supplied to the Swiss market. Similar to wrought alloys, the higher share of secondary aluminium in the mix leads to reduced environmental impacts according to the three indicators considered.

The life cycle inventory of the section bar extrusion process was not updated since more recent data were lacking. It is recommended to update this process in the future in order to better represent the current situation. In addition, it might also be desirable to collect data on the specific aluminium mix used for the production of sheets supplied to the Swiss market and to update the existing sheet rolling process in the ecoinvent database.

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