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Life Cycle Inventories of Air Transport Services

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Abbreviations

a	year (annum)
BAK	Swiss Federal Office of Culture
CH	Switzerland
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
FOCA	Federal Office of Civil Aviation
GLO	global average
gt	gross ton
h	hour
HC	hydrocarbons
ICAO	International Civil Aviation Organization
KBOB	Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren
kg	kilogram
km	kilometre
kWh	kilowatt hour
LCA	life cycle assessment
LCI	life cycle inventory analysis
LTO	landing and take off
min	minute
NMVOC	non-methane volatile organic compounds
N_2O	nitrous oxide / dinitrogen monoxide
NOx	nitrogen oxides
p	passenger
pkm	passenger kilometre (transport unit)
PM	particulate matter (index gives size range in μm)
RER	Europe
SO_2	sulphur dioxide
t	ton
tkm	ton kilometre (transport unit)
UBP	eco-points (German: Umweltbelastungspunkte)
VIP	very important persons
vkm	vehicle kilometre (transport unit)

Content

1 Introduction and Overview

Within the project “Update of mobitool life cycle assessment (LCA) data” life cycle inventory (LCI) data on transport processes of KBOB life cycle inventory data v2.2:2016 (based on ecoinvent data v2.2) were updated and life cycle inventory data on further transport modes and vehicles were compiled (KBOB et al. 2016). In this report the update and extension of the life cycle inventory data of air transport services are described and presented.

On one hand the existing data on aircraft and helicopter transport in KBOB LCI database v2.2:2016 are updated with current data on fuel consumption, emission factors, transport performance, vehicle travel distance and load factors. The passenger air transport activities are further distinguished between the three ticket classes “economy”, “business” and “first”. The structure of the existing datasets in KBOB life cycle inventory data v2.2:2016 was aligned with the structure of ecoinvent data v3.1 (no differentiation of operation anymore). On the other hand new life cycle inventories were compiled for freight helicopter and cable car transport services. Data describing the manufacturing and maintenance of the aircrafts and helicopters and construction of the airport infrastructure are not updated.

1.1 Overview

1.1.1 Aircraft Transport Services

The update of the aircraft transport described in Chapter 2 starts from the existing datasets available in KBOB life cycle inventory data v2.2:2016 (KBOB et al. 2016), which are based on ecoinvent data v2.2. The following updates have been performed:

- Update of the datasets on “aircraft operation” and “aircraft transport” using current primary data from airlines;
- Distinction of the three main ticket classes “economy”, “business”, “first” within the aircraft passenger transport process.

1.1.2 Helicopter Transport Services

The current dataset of helicopter transport in KBOB LCI database v2.2:2016 is based on a small helicopter suited for observation flights only (KBOB et al. 2016). The update and extension of helicopter transport data covers helicopter freight transport (single engine helicopter) and the helicopter transport for VIP passenger transport and government flights (twin engine helicopter). The life cycle inventories are described in Chapter 3.

1.1.3 Cable Car Transport Services

New LCI data are compiled describing construction, manufacture and operation of an average cable car in Switzerland. The new LCI data are described in Chapter 4.

2 Aircraft Transport Services

2.1 Goal and Scope

2.1.1 Functional Unit

The functional unit of freight transport is one ton kilometre (tkm), which corresponds to the transportation of one ton over a distance of one kilometre.

The functional unit of passenger transport is one passenger kilometre (pkm), which corresponds to the transportation of one passenger over a distance of one kilometre.

2.1.2 System Boundaries

The life cycle inventories of aircraft transport services refer to flights starting and/or landing in Europe.

The life cycle inventories of aircraft transport services include the following processes:

- Aircraft manufacturing and maintenance (according to LCI data described in Spielmann et al. (2007))
- Airport manufacturing, operation and maintenance and disposal (according to LCI data described in Spielmann et al. (2007))
- Aircraft operation (including fuel consumption and exhaust emission, described in Subchapter 2.3)
- Fuel supply (according to LCI data described in Jungbluth (2007)).

Disposal of aircrafts is not included in the life cycle inventories of air transport services. The effort of disposal is of minor importance compared to the operation and manufacture of aircrafts and the operation of airports. In the KBOB life cycle inventory data v2.2:2016 (KBOB et al. 2016) no life cycle inventory of aircraft disposal is available and compiling new life cycle inventories for means of transportation and infrastructures such as airplanes, airports or disposal of aircrafts was not part of the project.

2.1.3 Data Source and Quality

Transport performance, fuel consumption, load factors and emission factors are quantified using current data provided by a leading European airline (Lufthansa 2015) and complemented with data provided from FOCA[1]. According to FOCA the fuel consumption for flights starting and landing in Switzerland is slightly lower compared to the data published by the Lufthansa Group.

2.2 Key characteristics of the airplanes

Lufthansa Group uses different long- and short-haul aircrafts for intra- and intercontinental freight and passenger transport. In Tab. 2.1 technical characteristics of the average long- and short-haul aircraft are presented.

Tab. 2.1 Technical characteristics of the average short- and long-haul passenger aircraft of the Lufthansa Group operated in 2014 (Lufthansa 2015)

		Intracontinental	Intercontinental
Distance	km	819	6906
Number of seats	p	148	326
Occupation factors	%	75.7%	82.3%
Average number of passengers	p	112	268
Average freight	t	0.7	10

2.3 Allocation parameters and factors

The allocation of fuel consumption and emissions between passenger and freight transport was revisited and based on new adjusted parameters. In the existing datasets the weight per passenger was assumed to be 100 kg (70 kg for the passenger and 30 kg for the baggage). To determine a more appropriate weight attributable to a passenger (including the facilities in the aircraft required for passenger transport) the method used in the ICAO Carbon Emissions Calculator Methodology (ICAO 2016) was applied. This method assumes an average weight per passenger (incl. baggage) of 100 kg, plus a 50 kg add-on per seat to account for the on-board equipment and infrastructure associated with the passenger transport. Using the average number of passengers of intracontinental and intercontinental flights (122 and 268 passengers, respectively) and the average number of available seats (148 and 326 seats, respectively) the average weight per passenger is 166 and 160 kg for intracontinental and intercontinental flights, respectively.

Tab. 2.2 presents the resulting mass based allocation factors applied on the fuel consumption for freight and passengers transported with a passenger aircraft.

[1] Pers. Communication with T. Rindlisbacher and A. Suri, per Mail September 2016

Tab. 2.2 The mass allocation between passenger and freight of the operation of a passenger aircraft

	Allocation Freight	Allocation Passenger
Short haul aircraft (intracontinental flights)	4%	96%
Long haul aircraft (intercontinental flights)	19%	81%

The differentiation between the three cabin classes "economy", "business" and "first" requires an additional allocation step. The allocation of fuel consumption and emissions of the aircraft between these classes is based on the number of seats per class and the area required per seat of the respective class. In Tab. 2.3 the number of seats and the resulting allocation factors of the different classes are presented. The allocation factor applied on the fuel consumption etc. is calculated based on the area required per seat of the certain class divided by the area per average seat in the aircraft.

Tab. 2.3 Number of seats, area per seat in the different cabin classes in short haul and long haul aircrafts and resulting allocation factors, see also Tab. 2.1.

		Seats total	Seats first-class	Seats business-class	Seats economy-class
Short haul aircraft (intracontinental flights)	#	148		26	122
Area per seat[1)]	m^2			0.5	0.3
Allocation factor				1.40	0.90
Long haul aircraft (intercontinental flights)	#	326	8	61	257
Area per seat[1)]	m^2		1.2	0.8	0.4
Allocation factor			2.55	1.65	0.79

[1)] www.seatguru.com, last visit 26. April 2016

2.4 Aircraft Operation

2.4.1 Fuel Consumption

The fuel consumption of an average long- and short distance flight per km (l/km) is determined based on information of the Lufthansa Group and the allocation factors as outlined in Subchapter 2.3.

The calculation of the fuel consumption per pkm and tkm was performed according to the following four steps:

1) Calculation of the specific fuel consumption of passenger transport for long- and short distance flights.

2) Calculation of the specific fuel consumption of a pure freight transport for long- and short distance flights.

3) Calculation of the specific fuel consumption of belly freight transport for long- and short distance flights.

4) Calculation of the total fuel consumption of the average passenger aircraft (including belly freight transport) as specified in Tab. 2.1.
5) Calculation of the specific fuel consumption of passengers (per pkm) and freight (per tkm) applying the allocation factors as described in Subchapter 2.3.

Below the four steps are described in more detail including the source of the data used.

The first step includes the calculation of the specific fuel consumption of the passenger transport for inter- and intracontinental flights (short- and long distance) based on the data of the Lufthansa Group as presented in Tab. 2.4. For the calculation of the fuel consumption per pkm of intercontinental passenger transport a ratio of medium/long distance flights of 0.3/0.7[2] is applied.

Tab. 2.4 Fuel consumption per 100 pkm of short, medium and long distance flights of the Lufthansa (Lufthansa 2015)

		average	short distance	medium distance	long distance
Fuel consumption passenger transport	l/100 pkm	3.84	6.32	3.99	3.45
		average	intracontinental		intercontinental
Calculated fuel consumption passenger transport	l/100 pkm	3.84	6.32		3.61

The second step includes the calculation of the average specific fuel consumption (l/tkm) of an average pure freight aircraft (cargo) of the Lufthansa Group. Information about the fuel consumption of the freight aircrafts of the type MD11F (0.194 l/tkm) and 777F (0.161 l/tkm) was provided by BDL (2014). To calculate an average fuel consumption of an average freight aircraft data of the Lufthansa cargo fleet[3] were used (16 MD11F and 4 777F aircrafts) for the calculation. The calculated specific fuel consumption of an average pure freight aircraft of the Lufthansa Group is 0.187 l/tkm. The specific fuel consumption for intra- and intercontinental pure freight transport was derived from the average using the ratio of specific fuel consumption of intra- and intercontinental passenger flights (for intracontinental the extrapolation factor is 1.65 and for intercontinental flights 0.94 of the average fuel consumption).

Tab. 2.5 Specific fuel consumption of intra- and intercontinental freight transport

		average	intracontinental	intercontinental
Fuel consumption freight transport (cargo)	l/tkm	0.187[1)]	0.308	0.176
Fuel consumption freight transport (belly and cargo)	l/tkm	0.276[2)]	0.454	0.260
Fuel consumption freight transport (belly)	l/tkm	0.377[3)]	0.499	0.351
Extrapolation factors for intra-and intercontinental flights			1.65	0.94

[1)] Calculated based on information of the report 2014 Energy efficiency and climat protection, Bundesverband der Deutschen Luftverkehrswirtschaft and the Lufthansa fleet 2014

[2)] Average fuel consumption of freight transport published by Lufthansa (Balance 2015)

[3)] Calculated value

[2] This ratio is calculated based on the share of long distance (59 %) and medium distance (26 %) flights of the Lufthansa Group (Lufthansa 2015).

[3] Webpage: https://www.lufthansagroup.com/de/unternehmen/flotte/lufthansa-cargo.html, last visited 21.9.2016

In the third step the fuel consumption of belly freight transport was calculated. The calculation is based on the fuel consumption published by Lufthansa including belly and cargo freight transport (0.276 l/tkm, Lufthansa 2015) and the average specific fuel consumption of cargo transport (0.187 l/tkm). According to information of Lufthansa 48 % of the intercontinental and 76 % of the intracontinental freight is transported in the belly of passenger aircrafts (the shares are expressed in transport performance (tkm))[4]. To calculate the fuel consumption of the intra- and intercontinental belly freight transport (0.50 l/tkm and 0.35 l/tkm) The share of fuel used for pure freight transport (e.g. 0.52 * 0.176 l/tkm = 0.092 l/tkm) was subtracted from the fuel consumption of the average freight transport (including belly and cargo, e.g. 0.260 l/tkm - 0.092 l/tkm = 0.167 l/tkm) to get the share of fuel used for belly freight transport. The specific fuel consumption of belly was calculated by dividing the share of fuel used for belly freight transport by the share of belly transport (48 % and 76 % for intercontinental and domestic flights, respectively (0.167 l/tkm/0.48 = 0.35 l/tkm).

In the fourth step the total specific fuel consumption (l/km) of the average short- and long-distance passenger aircraft, specified as shown in Tab. 2.1 (including belly freight transport) was calculated.

The calculated fuel consumption per 100 pkm and 1 tkm was multiplied by the number of passengers and the freight in the aircraft (shown in Tab. 2.1) to obtain the total fuel consumption per km (see Tab. 2.6).

Tab. 2.6 Calculated specific fuel consumption for passenger and freight transported in the average passenger aircraft and the total specific fuel consumption per km of the average short and long-haul aircraft.

		intracontinental	intercontinental
Specific fuel consumption passenger transport	l/100pkm	6.32	3.61
Specific fuel consumption freight transport (belly)	l/tkm	0.50	0.35
Total fuel consumption	l/km	7.42	13.21

2.4.2 LTO and cruise fuel consumption

The share of the fuel consumption during take-off and landing (LTO) was provided for short, medium and long distance flights by FOCA5 (Tab. 2.7). With the share of long and medium distance flights (0.7/0.3)[6] an average share of the fuel consumption during LTO for intercontinental flights was calculated. The shares of the fuel consumption are presented in Tab. 2.8.

4 Personal communication: Katrin Brodowski, Lufthansa,per Mail, 20.8. 2015

5 Personal communication, FOCA, Theo Rindlisbacher, per Mail, 29. September 2016

6 This ratio is calculated based on the share of long distance (59 %) and medium distance (26 %) flights of the Lufthansa Group (Lufthansa 2015a).

Tab. 2.7 The share of the fuel consumption during take-off and landing (LTO) for short, medium and long distance flights provided by FOCA5

Fuel consumption	**short distance**	**medium distanc**	**long distance**
LTO	14%	7%	3%
Cruise	86%	93%	97%
Upper troposphere / lower stratosphere	*50%*	*75%*	*80%*
Troposphere	*50%*	*25%*	*20%*
Total	*100%*	*100%*	*100%*

Tab. 2.8 The share of fuel consumption of LTO and cruise of intra- and intercontinental flights.

Fuel consumption	**intracontinental**	**intercontinental**
LTO	14%	4%
Cruise	86%	96%
Upper troposphere / lower stratosphere	*50%*	*79%*
Troposphere	*50%*	*22%*
Total	*100%*	*100%*

The altitude of the emission is important since aircraft emissions in the upper troposphere and lower stratosphere have a higher effect on climate change compared to the release of the same pollutants on the ground (see e.g. Fuglestvedt et al. 2010). During the cruise emissions occur partly in the upper troposphere/lower stratosphere and in the troposphere. According to information provided by FOCA[7] 50 % and 79 % of the cruise emissions of intracontinental and intercontinental flights, respectively are emitted in the upper troposphere/lower stratosphere. The shares of cruise emissions occurring in the troposphere are therefore 50 % and 21 % for intracontinental and intercontinental flights, respectively. For intercontinental flights about 75% of the total fuel is used during the cruise in the stratosphere and the emissions are accounted as stratospheric emissions and for intracontinental flights it is about 43%.

2.4.3 Aircraft Emissions

The emissions of the operation of aircrafts are quantified with emission factor data provided by BAFU (2016) and FOCA[8] (see Tab. 2.9). During LTO substantially higher CO and NMVOC emission factors are reported.

[7] Personal communication, FOCA, Theo Rindlisbacher, per Mail 29.September 2016

[8] Personal communication with Theo Rindlisbacher, FOCA, per Mail 27.September 2016

Tab. 2.9 Emission factors for the main pollutants and CO_2 when burning 1 kg kerosene during aircraft LTO and cruising (BAFU 2016 and FOCA[8])

	Cruise (g/kg fuel)	LTO (g/kg fuel)
CO_2	3'150.00	3'150.00
CO	1.90	13.23
SO_x	1.00	1.00
NO_x	12.93	12.44
NMVOC	0.32	1.34
H_2O	1'240.00	1'240.00
$PM_{2.5}$	0.02	0.10

No up to date information was available on the NMVOC species profile. That is why data presented in the ecoinvent report 14 (Spielmann et al. 2007, page 153) were adopted.

The emissions of LTO and of cruise are accounted separately as they occur in different environments (close to the ground versus troposphere). The emissions during the cruise are additionally split into a share emitted in the troposphere and the share emitted in the lower stratosphere/upper troposphere (see Section 2.4.2). This allows for an individual environmental impact assessment of stratospheric emissions of $PM_{2.5}$ and NO_X and of their enhanced climate change effects).

Additionally to the emission of the cruise also the emission of LTO was accounted separately as the emission factors are different for LTO emission (see Tab. 2.9). The emissions of the LTO are assumed to occur in low population density areas and the closeness to the airport and cities was taken into account even though the differentiation between the compartments has not an impact on the impact assessment yet.

Additional to the exhaust emissions also particle emissions of the abrasion during the LTO are included in the life cycle inventory. According to information of FOCA[9] are the particle emissions $PM_{2.5}$ of the abrasion 0.08 g/LTO for intracontinental flights and 0.27 g/LTO for intercontinental flights, respectively.

Noise emissions were accounted for as recommended by Frischknecht and Büsser (2013) in paragraph 15.1.5 (page 201). Noise impacts are only accounted for in the ecological scarcity method 2013.

2.4.4 Aircraft Manufacture

The manufacture of the average intra- and intercontinental aircraft is modelled with the aircraft manufacture datasets published in KBOB life cycle inventory data v2.2:2016 (based on ecoinvent data v2.2) for medium and long haul aircraft, respectively (KBOB

9 Personal communication, FOCA, Theo Rindlisbacher, per Email, 29. September 2016

et al. 2016). Background information about aircraft manufacturing can be found in the ecoinvent report 14 (Spielmann et al. 2007).

2.4.5 Airport Infrastructure

Construction, operation and disposal of the airport is modelled with the airport construction, operation and disposal datasets provided by KBOB life cycle inventory data v2.2:2016 (KBOB et al. 2016). Background information about data and modelling of the airport infrastructure can be found in the ecoinvent report 14 (Spielmann et al. 2007).

2.5 Air Transport

2.5.1 Aircraft Demand

The life time of an aircraft is more dependent on the number of so called LTO cycles (take-off/landing cycles) than on the distances travelled or the years in charge. The material of an aircraft is highly stressed during the take-off and landing and thus the numbers of possible LTO cycles of an aircraft is limited. In Tab. 2.10 the designed numbers of a short and long haul aircraft is 50’000 and 25’000 respectively (FAA 2010).

The life time transport distance of an aircraft is determined with the designed number of LTO cycles and the average flight distance of the intracontinental and the intercontinental flight respectively. The allocation factors to attribute the appropriate share of the airplane manufacture to passengers and freight is based on the total mass shipped using a weight of 160 kg and 166 kg per passenger for inter- and intracontinental flights, respectively. Hence, 96 % of the short haul aircraft and 81 % of the long haul aircraft is allocated to the passengers transported. Dividing 0.95 airplanes by the total transport performance (transport distance times average load) results in the share of aircraft manufacture attributable to each pkm provided by the aircraft.

Tab. 2.10 presents the key figures to calculate the aircraft manufacture demand for passenger and freight transport in intra- and intercontinental flights.

Tab. 2.10 The reference figures of the aircraft demand for passenger and freight transport

		short haul aircraft				long haul aircraft				
		passenger transport	business	ecomomy	freight transport	passenger transport	first	business	ecomomy	freight transport
Number of cycles (LTO) in a lifetime of an aircraft	#	50000	50000	50000	50000	25000	25000	25000	25000	25000
Average distance of a flight	km	819	819	819	819	6906	6906	6906	6906	6906
Kilometric performance per vehicle	km	40'934'069	40'934'069	40'934'069	40'934'069	172'657'701	172'657'701	172'657'701	172'657'701	172'657'701
Average load	p/vehicle or t/vehicle	112	20	92	0.7	268	7	50	212	10.0
Vehicle demand per kilometer	vehicle/km	2.44E-08	2.44E-08	2.44E-08	2.44E-08	5.79E-09	5.79E-09	5.79E-09	5.79E-09	5.79E-09
Allocation freight, passenger (classes)		0.96	0.25	0.75	0.04	0.81	0.06	0.31	0.63	0.19
Vehicle demand per transport unit	vehicle/ tkm or vehicle/pkm	2.1.E-10	3.0.E-10	1.9.E-10	1.3.E-09	1.8.E-11	5.5.E-11	3.6.E-11	1.7.E-11	1.1.E-10

The maintenance of the aircraft is approximated by increasing the aircraft manufacture efforts by 5 %.

2.5.2 Demand of Airport construction and Operation

The data of the numbers of passengers and amount of freight transit the airport were taken from the yearly report of the airport Zürich (Flughafen Zürich AG 2014). To calculate the gross tonnage passing the Zürich airport per year for passenger a weight of 160 kg and 166 kg is assumed for inter- and intracontinental passengers respectively. The gross tonnage passing the airport per year (inclusive the passenger) is 4368775 Gt/year. To calculate the allocation factors for freight and passengers as well as for inter- and intracontinental flights the Gt/a is divided by the specific tonnage. To calculate specific airport demand two times the allocation factor was divided by the average transport performance (pkm or tkm) and the lifetime of the airport.

To determine the demand of airport operation and maintenance per year the demand of airport per tkm and pkm was multiplied by the life time of the airport (100 a).

Data about the average flight distances as well as the allocation between passenger and freight transport were updated using information provided by Lufthansa (2015).

Tab. 2.11 Reference figures of the calculation of the demand of airport construction and operation

		intracontinental		intercontinental	
		passenger transport	freight transport	passenger transport	freight transport
Load and passenger at the airport	p/a or t/a	19'561'630	40'283	5'865'254	260'191
Transported gross ton (passenger and freight)*	t/a	3'248'500	40'283	942'679	260'191
Allocation		72%	1%	21%	6%
Distance	km	819	819	6906	6906
Transport performance	pkm/a	1.60E+10	3.30E+07	4.05E+10	1.80E+09
Lifetime of an airport	a	100	100	100	100
Demand of an airport	airport/tkm or airport/pkm	8.97E-13	5.40E-12	1.06E-13	6.60E-13

*) For intercontinental flights: 160 kg per passenger, for intracontinental flights: 166 kg per passenger

2.5.3 Unit process life Cycle Inventory data

Tab. 2.12 Life cycle inventory data of intercontinental aircraft transport services

	Name	Location	InfrastructureProcess	Unit	transport, aircraft, passenger, intercontinental	transport, aircraft, passenger, intercontinental, economy-class	transport, aircraft, passenger, intercontinental, business-class	transport, aircraft, passenger, intercontinental, first-class	transport, aircraft, freight, intercontinental	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0	0			
	Unit				pkm	pkm	pkm	pkm	tkm			
product	transport, aircraft, passenger, intercontinental	RER	0	pkm	1	0	0	0	0			
product	transport, aircraft, passenger, intercontinental, economy-class	RER	0	pkm	0	1	0	0	0			
product	transport, aircraft, passenger, intercontinental, business-class	RER	0	pkm	0	0	1	0	0			
product	transport, aircraft, passenger, intercontinental, first-class	RER	0	pkm	0	0	0	1	0			
product	transport, aircraft, freight, intercontinental	RER	0	tkm	0	0	0	0	1			
technosphere	aircraft, long haul	RER	1	unit	1.84E-11	5.79E-11	3.75E-11	1.80E-11	1.14E-10	1	3.06	(2,4,1,3,1,5,BU:3); Calculated based on the assumed numbers of LTOs in the life time of an aircraft of 25000LTO/airplane, an average load of 268 passengers or 10 tons of freight and an average distance of a flight of 6906km; For the effort of the maintenance 5% of the production is added; FAA (2010) Aging Airplane Program; Lufthansa Balance 2015
	airport	RER	1	unit	1.06E-13	1.06E-13	1.06E-13	1.06E-13	6.60E-13	1	3.06	(2,4,1,3,1,5,BU:3); assumed yearly throughput airport: passenger 3143997 p and freight 942679t; Airport Zürich, yearly report 2014
	operation, maintenance, airport	RER	0	unit	1.06E-11	1.06E-11	1.06E-11	1.06E-11	6.60E-11	1	2.06	(2,4,1,3,1,5,BU:2); same as airport multipied by the lifetime of the airport of 100 years;
	disposal, airport	RER	1	unit	1.06E-13	1.06E-13	1.06E-13	1.06E-13	6.60E-13	1	3.06	(2,4,1,3,1,5,BU:3); same as airport;
	kerosene, at regional storage	RER	0	kg	3.16E-2	2.52E-2	5.24E-2	8.08432E-2	1.97E-1	1	1.24	(2,4,1,3,1,5,BU:1.05); ; Lufthansa Balance 2015, BLD 2014, pers. communication Lufthasa, Mail 20.8.2015
emission air, lower stratosphere + upper troposphere	Carbon dioxide, fossil	-	-	kg	7.50E-2	5.97E-2	1.24E-1	1.92E-1	4.66E-1	1	1.33	(2,5,2,5,1,5,BU:1.05); assumption: a share of 0.785 of the crusie emission take place in the upper troposphere and lower stratosphere (this corresponds to a share of 0.75203 of the total emissions); BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Carbon monoxide, fossil	-	-	kg	4.52E-5	3.60E-5	7.47E-5	1.15E-4	2.81E-4	1	5.12	(2,5,2,5,1,5,BU:5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Sulfur dioxide	-	-	kg	2.38E-5	1.89E-5	3.94E-5	6.08E-5	1.48E-4	1	1.33	(2,5,2,5,1,5,BU:1.05); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Nitrogen oxides	-	-	kg	3.08E-4	2.45E-4	5.09E-4	7.86E-4	1.91E-3	1	1.64	(2,5,2,5,1,5,BU:1.5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	7.57E-6	6.03E-6	1.25E-5	1.93E-5	4.71E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Water	-	-	kg	2.95E-2	2.35E-2	4.88E-2	7.54E-2	1.84E-1	1	1.64	(2,5,2,5,1,5,BU:1.5); ; Ecoinvent Report 14
	Benzene	-	-	kg	2.25E-7	1.79E-7	3.73E-7	5.75E-7	1.40E-6	1	3.11	(2,5,2,5,1,5,BU:3); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Formaldehyde	-	-	kg	1.78E-6	1.42E-6	2.94E-6	4.54E-6	1.11E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Butadiene	-	-	kg	2.13E-7	1.70E-7	3.53E-7	5.45E-7	1.33E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Ethene	-	-	kg	2.06E-6	1.64E-6	3.41E-6	5.27E-6	1.28E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Particulates, < 2.5 um	-	-	kg	5.71E-7	4.55E-7	9.45E-7	1.46E-6	3.55E-6	1	3.11	(2,5,2,5,1,5,BU:3); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Heat, waste	-	-	MJ	1.09E-3	8.64E-4	1.80E-3	2.77E-3	6.75E-3	1	1.33	(2,5,2,5,1,5,BU:1.05); default value;
emission air, unspecified	Carbon dioxide, fossil	-	-	kg	2.05E-2	1.63E-2	3.40E-2	5.25E-2	1.28E-1	1	1.33	(2,5,2,5,1,5,BU:1.05); assumption: a share of 0.215 of the cruise emissione take place in the troposphere (this corresponds to a share of 0.20597 of the total emissions); BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Carbon monoxide, fossil	-	-	kg	1.24E-5	9.85E-6	2.05E-5	3.16E-5	7.70E-5	1	5.12	(2,5,2,5,1,5,BU:5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Sulfur dioxide	-	-	kg	6.52E-6	5.19E-6	1.08E-5	1.66E-5	4.05E-5	1	1.33	(2,5,2,5,1,5,BU:1.05); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Nitrogen oxides	-	-	kg	8.43E-5	6.71E-5	1.39E-4	2.15E-4	5.24E-4	1	1.64	(2,5,2,5,1,5,BU:1.5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	2.07E-6	1.65E-6	3.43E-6	5.30E-6	1.29E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Water	-	-	kg	8.08E-3	6.44E-3	1.34E-2	2.06E-2	5.03E-2	1	1.64	(2,5,2,5,1,5,BU:1.5); ; Ecoinvent Report 14
	Benzene	-	-	kg	6.17E-8	4.91E-8	1.02E-7	1.58E-7	3.84E-7	1	3.11	(2,5,2,5,1,5,BU:3); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Formaldehyde	-	-	kg	4.87E-7	3.88E-7	8.06E-7	1.24E-6	3.03E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Butadiene	-	-	kg	5.84E-8	4.65E-8	9.67E-8	1.49E-7	3.64E-7	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Ethene	-	-	kg	5.65E-7	4.50E-7	9.35E-7	1.44E-6	3.51E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Particulates, < 2.5 um	-	-	kg	1.56E-7	1.25E-7	2.59E-7	4.00E-7	9.73E-7	1	3.11	(2,5,2,5,1,5,BU:3); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Heat, waste	-	-	MJ	2.97E-4	2.37E-4	4.92E-4	7.59E-4	1.85E-3	1	1.33	(2,5,2,5,1,5,BU:1.05); default value;
emission air, low population density	Carbon dioxide, fossil	-	-	kg	4.19E-3	3.33E-3	6.93E-3	1.07E-2	2.61E-2	1	1.33	(2,5,2,5,1,5,BU:1.05); assumption: a share of 0.042 of the total emission occure during the LTO; for LTO emissions different emission factors are used than for cruise; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Carbon monoxide, fossil	-	-	kg	1.76E-5	1.40E-5	2.91E-5	4.49E-5	1.09E-4	1	5.12	(2,5,2,5,1,5,BU:5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Sulfur dioxide	-	-	kg	1.33E-6	1.06E-6	2.20E-6	3.40E-6	8.28E-6	1	1.33	(2,5,2,5,1,5,BU:1.05); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Nitrogen oxides	-	-	kg	1.65E-5	1.32E-5	2.74E-5	4.22E-5	1.03E-4	1	1.64	(2,5,2,5,1,5,BU:1.5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	1.78E-6	1.42E-6	2.95E-6	4.55E-6	1.11E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Water	-	-	kg	1.65E-3	1.31E-3	2.73E-3	4.21E-3	1.03E-2	1	1.64	(2,5,2,5,1,5,BU:1.5); ; Ecoinvent Report 14
	Benzene	-	-	kg	5.30E-8	4.22E-8	8.77E-8	1.35E-7	3.30E-7	1	3.11	(2,5,2,5,1,5,BU:3); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Formaldehyde	-	-	kg	4.18E-7	3.33E-7	6.92E-7	1.07E-6	2.60E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Butadiene	-	-	kg	5.02E-8	4.00E-8	8.30E-8	1.28E-7	3.12E-7	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Ethene	-	-	kg	4.85E-7	3.86E-7	8.03E-7	1.24E-6	3.02E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Particulates, < 2.5 um	-	-	kg	1.33E-7	1.06E-7	2.20E-7	3.40E-7	8.27E-7	1	3.11	(2,5,2,5,1,5,BU:3); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Heat, waste	-	-	MJ	6.06E-5	4.83E-5	1.00E-4	1.55E-4	3.77E-4	1	1.33	(2,5,2,5,1,5,BU:1.05); default value;
	Particulates, < 2.5 um	-	-	kg	8.17E-7	6.50E-7	1.35E-6	2.09E-6	5.08E-6	1	3.11	(2,5,2,5,1,5,BU:3); PM2.5 Emission of the abrasion during LTO ; pers. correspondence BAZL, 27.9.2016
emission Non materi	Noise, aircraft, freight	-	-	tkm					1.00E+0	1	1.50	(1,1,1,1,1,1,BU:1.5); ; Ecological Scarcity method 2013; Frischknecht & Büsser Knöpfel 2013
	Noise, aircraft, passenger	-	-	pkm	1.00E+0	7.96E-1	1.65E+0	2.55E+0		1	1.50	(1,1,1,1,1,1,BU:1.5); ; Ecological Scarcity method 2013; Frischknecht & Büsser Knöpfel 2013

Tab. 2.13 Life cycle inventory data of intra Europe aircraft transport services

	Name	Location	InfrastructureProcess	Unit	transport, aircraft, passenger, Europe	transport, aircraft, passenger, Europe, economy-class	transport, aircraft, passenger, Europe, business-class	transport, aircraft, freight, Europe	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				pkm	pkm	pkm	tkm			
product	transport, aircraft, passenger, Europe	RER	0	pkm	1	0	0	0			
product	transport, aircraft, passenger, Europe, economy-class	RER	0	pkm	0	1	0	0			
product	transport, aircraft, passenger, Europe, business-class	RER	0	pkm	0	0	1	0			
product	transport, aircraft, freight, Europe	RER	0	tkm	0	0	0	1			
technosphere	aircraft, medium haul	RER	1	unit	2.21E-10	3.15E-10	2.01E-10	1.33E-9	1	3.06	(2,4,1,3,1,5,BU:3); Calculated based on the assumed numbers of LTOs in the life time of an aircraft of 50000LTO/airplane, an average load of 112 passengers or 10 tons of freight and an average distance of a flight of 819km. For the effort of the maintenance 5% of the aircraft manufacture is added; FAA (2010) Aging Airplane Program; Lufthansa Balance 2015
	airport	RER	1	unit	8.97E-13	8.97E-13	8.97E-13	5.40E-12	1	3.06	(2,4,1,3,1,5,BU:3); assumed yearly throughput at the airport: passengers 19561630 p and freight 40283t; Airport Zürich, yearly report, 2014
	operation, maintenance, airport	RER	0	unit	8.97E-11	8.97E-11	8.97E-11	5.40E-10	1	2.06	(2,4,1,3,1,5,BU:2); same as airport multipied by the lifetime of the airport of 100 years;
	disposal, airport	RER	1	unit	8.97E-13	8.97E-13	8.97E-13	5.40E-12	1	3.06	(2,4,1,3,1,5,BU:3); same as airport;
	kerosene, at regional storage	RER	0	kg	5.08E-2	4.62E-2	7.25E-2	3.06E-1	1	1.24	(2,4,1,3,1,5,BU:1.05); ; Lufthansa Balance 2015, BLD 2014, pers. communication Lufthasa, Mail 20.8.2015
emission air, lower stratosphere + upper troposphere	Carbon dioxide, fossil	-	-	kg	6.88E-2	6.26E-2	9.81E-2	4.14E-1	1	1.33	(2,5,2,5,1,5,BU:1.05); assumption: a share of 0.5 of the cruise emission take place in the upper troposphere and lower stratosphere (this corresponds to a share of 0.43 of the total emissions); BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Carbon monoxide, fossil	-	-	kg	4.15E-5	3.77E-5	5.91E-5	2.50E-4	1	5.12	(2,5,2,5,1,5,BU:5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Sulfur dioxide	-	-	kg	2.18E-5	1.99E-5	3.11E-5	1.32E-4	1	1.33	(2,5,2,5,1,5,BU:1.05); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Nitrogen oxides	-	-	kg	2.82E-4	2.57E-4	4.03E-4	1.70E-3	1	1.64	(2,5,2,5,1,5,BU:1.5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	6.95E-6	6.32E-6	9.91E-6	4.19E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Water	-	-	kg	2.71E-2	2.46E-2	3.86E-2	1.63E-1	1	1.64	(2,5,2,5,1,5,BU:1.5); ; Ecoinvent Report 14
	Benzene	-	-	kg	2.07E-7	1.88E-7	2.95E-7	1.24E-6	1	3.11	(2,5,2,5,1,5,BU:3); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Formaldehyde	-	-	kg	1.63E-6	1.48E-6	2.33E-6	9.83E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Butadiene	-	-	kg	1.96E-7	1.78E-7	2.79E-7	1.18E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Ethene	-	-	kg	1.89E-6	1.72E-6	2.70E-6	1.14E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Particulates, < 2.5 um	-	-	kg	5.24E-7	4.77E-7	7.48E-7	3.16E-6	1	3.11	(2,5,2,5,1,5,BU:3); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Heat, waste	-	-	MJ	9.96E-4	9.06E-4	1.42E-3	6.00E-3	1	1.33	(2,5,2,5,1,5,BU:1.05); ; default value
emission air, unspecified	Carbon dioxide, fossil	-	-	kg	6.88E-2	6.26E-2	9.81E-2	4.14E-1	1	1.33	(2,5,2,5,1,5,BU:1.05); assumption: a share of 0.5 of the cruise emission take place in the troposphere (this corresponds to a share of 0.43 of the total emissions) ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Carbon monoxide, fossil	-	-	kg	4.15E-5	3.77E-5	5.91E-5	2.50E-4	1	5.12	(2,5,2,5,1,5,BU:5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Sulfur dioxide	-	-	kg	2.18E-5	1.99E-5	3.11E-5	1.32E-4	1	1.33	(2,5,2,5,1,5,BU:1.05); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Nitrogen oxides	-	-	kg	2.82E-4	2.57E-4	4.03E-4	1.70E-3	1	1.64	(2,5,2,5,1,5,BU:1.5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	6.95E-6	6.32E-6	9.91E-6	4.19E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Water	-	-	kg	2.71E-2	2.46E-2	3.86E-2	1.63E-1	1	1.64	(2,5,2,5,1,5,BU:1.5); ; Ecoinvent Report 14
	Benzene	-	-	kg	2.07E-7	1.88E-7	2.95E-7	1.24E-6	1	3.11	(2,5,2,5,1,5,BU:3); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Formaldehyde	-	-	kg	1.63E-6	1.48E-6	2.33E-6	9.83E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Butadiene	-	-	kg	1.96E-7	1.78E-7	2.79E-7	1.18E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Ethene	-	-	kg	1.89E-6	1.72E-6	2.70E-6	1.14E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Particulates, < 2.5 um	-	-	kg	5.24E-7	4.77E-7	7.48E-7	3.16E-6	1	3.11	(2,5,2,5,1,5,BU:3); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Heat, waste	-	-	MJ	9.96E-4	9.06E-4	1.42E-3	6.00E-3	1	1.33	(2,5,2,5,1,5,BU:1.05); default value;
emission air, low population density	Carbon dioxide, fossil	-	-	kg	2.24E-2	2.04E-2	3.20E-2	1.35E-1	1	1.33	(2,5,2,5,1,5,BU:1.05); assumption: a share of 0.14 of the total emission occure during the LTO; for LTO emissions different emission factors are used than for cruise; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Carbon monoxide, fossil	-	-	kg	9.41E-5	8.56E-5	1.34E-4	5.67E-4	1	5.12	(2,5,2,5,1,5,BU:5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Sulfur dioxide	-	-	kg	7.12E-6	6.48E-6	1.02E-5	4.29E-5	1	1.33	(2,5,2,5,1,5,BU:1.05); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Nitrogen oxides	-	-	kg	8.85E-5	8.04E-5	1.26E-4	5.33E-4	1	1.64	(2,5,2,5,1,5,BU:1.5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	9.53E-6	8.67E-6	1.36E-5	5.74E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Water	-	-	kg	8.82E-3	8.02E-3	1.26E-2	5.31E-2	1	1.64	(2,5,2,5,1,5,BU:1.5); ; Ecoinvent Report 14

Tab. 2.13 Life cycle inventory data of intra Europe aircraft transport services (continued)

	Name	Location	InfrastructureProcess	Unit	transport, aircraft, passenger, Europe	transport, aircraft, passenger, Europe, economy-class	transport, aircraft, passenger, Europe, business-class	transport, aircraft, freight, Europe	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER	RER	RER			
	InfrastructureProcess				0	0	0	0			
	Unit				pkm	pkm	pkm	tkm			
product	transport, aircraft, passenger, Europe	RER	0	pkm	1	0	0	0			
product	transport, aircraft, passenger, Europe, economy-class	RER	0	pkm	0	1	0	0			
product	transport, aircraft, passenger, Europe, business-class	RER	0	pkm	0	0	1	0			
product	transport, aircraft, freight, Europe	RER	0	tkm	0	0	0	1			
	Benzene	-	-	kg	2.83E-7	2.58E-7	4.04E-7	1.71E-6	1	3.11	(2,5,2,5,1,5,BU:3); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Formaldehyde	-	-	kg	2.24E-6	2.03E-6	3.19E-6	1.35E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Butadiene	-	-	kg	2.69E-7	2.44E-7	3.83E-7	1.62E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Ethene	-	-	kg	2.60E-6	2.36E-6	3.70E-6	1.56E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ; VOC Profil wie ecoinvent 2.2, ecoinvent report 14
	Particulates, < 2.5 um	-	-	kg	7.11E-7	6.47E-7	1.01E-6	4.28E-6	1	3.11	(2,5,2,5,1,5,BU:3); ; BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR); pers. correspondence BAZL, 27.9.2016
	Heat, waste	-	-	MJ	3.24E-4	2.95E-4	4.63E-4	1.95E-3	1	1.33	(2,5,2,5,1,5,BU:1.05); default value;
	Particulates, < 2.5 um	-	-	kg	1.21E-6	1.10E-6	1.72E-6	7.26E-6	1	3.11	(2,5,2,5,1,5,BU:3); PM2.5 Emission of the abrasion during LTO ; pers. correspondence BAZL, 27.9.2016
emission Non material emissions, unspecified	Noise, aircraft, freight	-	-	tkm				1.00E+0	1	1.50	(1,1,1,1,1,1,BU:1.5); ; Ecological Scarcity method 2013; Frischknecht & Büsser Knöpfel 2013
	Noise, aircraft, passenger	-	-	pkm	1.00E+0	9.09E-1	1.43E+0		1	1.50	(1,1,1,1,1,1,BU:1.5); ; Ecological Scarcity method 2013; Frischknecht & Büsser Knöpfel 2013

2.6 Average Aircraft Transport

To calculate the average of intra- and intercontinental flights for the average aircraft transport of freight and passenger current data of the transport performance in Switzerland (BFS 2014a) are used. The number of passengers and freight transported to intercontinental and intracontinental destinations are multiplied by the average distance of intercontinental and intracontinental flights to get the transport performance. The share of each transport category is calculated by dividing the individual transport performances with the total transport performance. In Tab. 2.14 the numbers of passengers and freight transported in Switzerland and the shares are presented.

Tab. 2.14 Passengers and freight transported in Switzerland in 2014, average distance, the calculated transport performances and the shares of intercontinental and intracontinental transports on the average transport of passengers and freight

		intracontinental	intercontinental	total
Transported passengers	p	18'842'808	5'105'280	23'948'088
Transported freight	t	110'373	300'260	410'633
Average distance	km	819	6'906	
Transport performance passenger	pkm	15'432'259'752	35'257'063'680	50'689'323'432
Transport performacne freight	tkm	90'395'487	2'073'595'560	2'163'991'047
Share of average passenger transport	%	30.4%	69.6%	
Share of average freight transport	%	4.2%	95.8%	

2.6.1 Unit process life cycle inventory data

Tab. 2.15 Life cycle inventory data of average aircraft passenger and freight transport service

	Name	Location	InfrastructureProcess	Unit	transport, aircraft, passenger	transport, aircraft, freight	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				RER	RER			
	InfrastructureProcess				0	0			
	Unit				pkm	tkm			
product	transport, aircraft, passenger	RER	0	pkm	1	0			
product	transport, aircraft, freight	RER	0	tkm	0	1			
technosphere	aircraft, passenger	RER	1	unit	8.00E-11		1	3.06	(2,4,1,3,1,5,BU:3); Passenger: share Europe flights: 0.30, share intercontinental flights0.70; 2014 BFS
technosphere	aircraft, freight	RER	1	unit		1.65E-10	1	3.06	(2,4,1,3,1,5,BU:3); Freight: share Europe flights 0.04, share intercontinental flights 0.96; 2014 BFS
	airport	RER	1	unit	3.47E-13	8.58E-13	1	3.06	(2,4,1,3,1,5,BU:3); ;
	operation, maintenance, airport	RER	0	unit	3.47E-11	8.58E-11	1	2.06	(2,4,1,3,1,5,BU:2); ;
	disposal, airport	RER	1	unit	3.47E-13	8.58E-13	1	3.06	(2,4,1,3,1,5,BU:3); ;
	kerosene, at regional storage	RER	0	kg	3.7478E-2	2.01E-1	1	1.24	(2,4,1,3,1,5,BU:1.05); ;
emission air, lower stratosphere + upper troposphere	Carbon dioxide, fossil	-	-	kg	7.31E-2	4.64E-1	1	1.33	(2,5,2,5,1,5,BU:1.05); ;
	Carbon monoxide, fossil	-	-	kg	4.40E-5	2.80E-4	1	5.12	(2,5,2,5,1,5,BU:5); ;
	Sulfur dioxide	-	-	kg	2.32E-5	1.47E-4	1	1.33	(2,5,2,5,1,5,BU:1.05); ;
	Nitrogen oxides	-	-	kg	3.00E-4	1.91E-3	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	7.38E-6	4.69E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Water	-	-	kg	2.88E-2	1.83E-1	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Benzene	-	-	kg	2.20E-7	1.39E-6	1	3.11	(2,5,2,5,1,5,BU:3); ;
	Formaldehyde	-	-	kg	1.73E-6	1.10E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Butadiene	-	-	kg	2.08E-7	1.32E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Ethene	-	-	kg	2.01E-6	1.28E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Particulates, < 2.5 um	-	-	kg	5.57E-7	3.54E-6	1	3.11	(2,5,2,5,1,5,BU:3); ;
	Heat, waste	-	-	MJ	1.06E-3	6.72E-3	1	1.33	(2,5,2,5,1,5,BU:1.05); ;
emission air, unspecified	Carbon dioxide, fossil	-	-	kg	3.52E-2	1.40E-1	1	1.33	(2,5,2,5,1,5,BU:1.05); ;
	Carbon monoxide, fossil	-	-	kg	2.12E-5	8.42E-5	1	5.12	(2,5,2,5,1,5,BU:5); ;
	Sulfur dioxide	-	-	kg	1.12E-5	4.43E-5	1	1.33	(2,5,2,5,1,5,BU:1.05); ;
	Nitrogen oxides	-	-	kg	1.45E-4	5.73E-4	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	3.56E-6	1.41E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Water	-	-	kg	1.39E-2	5.50E-2	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Benzene	-	-	kg	1.06E-7	4.20E-7	1	3.11	(2,5,2,5,1,5,BU:3); ;
	Formaldehyde	-	-	kg	8.35E-7	3.31E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Butadiene	-	-	kg	1.00E-7	3.98E-7	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Ethene	-	-	kg	9.69E-7	3.84E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Particulates, < 2.5 um	-	-	kg	2.68E-7	1.06E-6	1	3.11	(2,5,2,5,1,5,BU:3); ;
	Heat, waste	-	-	MJ	5.10E-4	2.02E-3	1	1.33	(2,5,2,5,1,5,BU:1.05); ;
emission air, low population density	Carbon dioxide, fossil	-	-	kg	9.73E-3	3.06E-2	1	1.33	(2,5,2,5,1,5,BU:1.05); ;
	Carbon monoxide, fossil	-	-	kg	4.09E-5	1.29E-4	1	5.12	(2,5,2,5,1,5,BU:5); ;
	Sulfur dioxide	-	-	kg	3.09E-6	9.73E-6	1	1.33	(2,5,2,5,1,5,BU:1.05); ;
	Nitrogen oxides	-	-	kg	3.84E-5	1.21E-4	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	4.14E-6	1.30E-5	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Water	-	-	kg	3.83E-3	1.20E-2	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Benzene	-	-	kg	1.23E-7	3.87E-7	1	3.11	(2,5,2,5,1,5,BU:3); ;
	Formaldehyde	-	-	kg	9.72E-7	3.06E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Butadiene	-	-	kg	1.17E-7	3.67E-7	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
	Ethene	-	-	kg	1.13E-6	3.55E-6	1	1.64	(2,5,2,5,1,5,BU:1.5); ;
emission ,									
emission air, low population density	Heat, waste	-	-	MJ	1.41E-4	4.43E-4	1	1.33	(2,5,2,5,1,5,BU:1.05); ;
	Particulates, < 2.5 um	-	-	kg	9.35E-7	5.17E-6	1	3.11	(2,5,2,5,1,5,BU:3); ;
emission Non material emissions, unspecified	Noise, aircraft, freight	-	-	tkm	0	1.00E+0	1	1.50	(1,1,1,1,1,1,BU:1.5); ; Ecological Scarcity method 2013; Frischknecht & Büsser Knöpfel 2013
	Noise, aircraft, passenger	-	-	pkm	1.00E+0	0	1	1.50	(1,1,1,1,1,1,BU:1.5); ; Ecological Scarcity method 2013; Frischknecht & Büsser Knöpfel 2013

3 Helicopter Transport Services

3.1 Overview

The update and extension of helicopter transport data covers helicopter transport of passenger flights and helicopter freight transport (single engine helicopter) as well as VIPs and government flights (twin engine helicopter). The life cycle inventory data of the twin engine helicopter is based on the Airbus Helicopters EC 135 and life cycle inventory data of the single engine helicopter is based on the Ecureuil AS 350 B3. Data from webpages [10,11] and FOCA (2016) are used to update and extend the helicopter transport life cycle inventories.

3.2 Functional unit

The functional unit of helicopter transport is one hour operation. For freight transport the operation is described as a rotation and no additional LTO cycle has to be added to the one hour flight mode. For the passenger transport the average flight duration is 20 min in the air and 13.5 min of LTO. The one hour operation therefore includes 36 min cruise and 1.8 LTO cycles.

3.3 System Boundaries

The size and power of helicopters varies considerably. Within this project data representing two different types of helicopters are compiled, namely a single and a twin engine helicopter. Single engine helicopters are usually used for freight transport as well as for passenger and observation flights. The twin engine helicopters are mainly used for VIP passenger transport and government flight services.

The life cycle inventory of helicopter transport services includes the following unit processes:

- Helicopter manufacturing
- Helicopter operation
- Helicopter maintenance (approximated by increasing the aircraft manufacture efforts by 5 %)

Disposal of the helicopter is not included in the life cycle inventories. The effort of the disposal is usually of minor importance compared to the helicopter operation. No life cycle inventories are available in the KBOB LCI database v2.2:2016 (KBOB et al. 2016) for the disposal of helicopters and compiling new life cycle inventories for infrastructure such as the disposal of helicopters was not part of the project.

[10] www.swisshelicopters.ch, last visit 27. April 2016

[11] www.flugzeuginfo.net, last visit 25. May 2016

3.4 Data Sources and Quality

The process of helicopter transport services is linked to background datasets available in KOBO life cycle inventory data v2.2:2016 (KBOB et al. 2016), which are based on eocinvent data v2.2. Specific data on fuel consumption and emission factors of different helicopter types, provided in FOCA (2016) are used to model helicopter operation.

3.5 Life Cycle Inventories

3.5.1 Key characteristics of helicopters

In Tab. 3.1 some key figures of helicopter passenger transport services are presented. The weight is representative for a typical single and twin engine helicopter used in Switzerland. The data on fuel consumption per hour (flight mode) and LTO cycle are based on information provided in the statistic of FOCA (2016). The duration of an average helicopter flight (flight mode and LTO) is assumed to be 33.5 min including 20 min[12] for the flight mode and 13.5 min for the LTO cycle (FOCA 2016). Thus an operation of one hour includes 36 min flight mode and 1.8 LTO (24 min). The life span of the helicopter of 10’000 h flight hours is adopted from Faist Emmenegger et al. (2007).

Tab. 3.1 Key characteristics of single and twin engine helicopters used for passenger transports as modelled in this study

	Unit	single engine helicopter (passenger transport)	twin engine helicopter (passenger transport)
Helicopter weight[1]	t	1'280	1'490
Fuel consumption	kg/h	182.6	259.3
Fuel consumption per LTO	kg/LTO	27.6	41.2
Duration of LTO	min	13.5	13.5
Duration of cruise[2]	min	20	20
Duration average flight	min	33.5	33.5
Number of LTO per hour	#	1.8	1.8
Life span	h	10'000	10'000
Tank volume[3]	l	540	560

[1] from webpage http://www.swisshelicopter.ch, last visited 17.12.2015

[2] personal communication, Adrian Gloor, Helibernina, 9.6.2016

[3] from webpage http://www.wucher-helicopter.at/de/wucher/flotte/, last visited 4. 5.2016

In Tab. 3.2 some key figures of the helicopter freight transport service are presented. The weight is representative for a typical single engine helicopter used in Switzerland

[12] Personal communication, Adrian Gloor, Helibernina, 9.6.2016

for freight transportation. Freight transport with helicopters can be described as rotations. The data on fuel consumption of the rotations per hour are based on information provided in the statistic of FOCA (2016).

Tab. 3.2 Key characteristics of a single engine helicopter used for freight transport as modelled in this study

	Unit	single engine helicopter (freight)
Helicopter weight[1]	t	1'280
Fuel consumption	kg/h	182.6
Life span	h	10'000
Tank volume[2]	l	540

[1] from webpage http://www.swisshelicopter.ch, last visited 17.12.2015

[2] from webpage http://www.wucher-helicopter.at/de/wucher/flotte/, last visited 4. 5.2016

3.5.2 Helicopter Manufacturing

No specific data were available representing helicopter manufacturing. Therefore the manufacturing of a helicopter was approximated using manufacturing data of a medium haul aircraft adjusted by the ratio of the weight of the aircraft and the helicopter, respectively.

Tab. 3.3 Ratio of the weight between the aircraft and the helicopters

	Weight (t)	Ratio helicopter/aircraft
Medium haul aircraft	61	
Helicoper two engine	1.5	2.4%
Helicopter single engine	1.3	2.1%

3.5.3 Helicopter Demand and Maintenance

The helicopter demand per hour operation is 0.0001. Using the weight ratio between medium haul aircraft and helicopters, the operation of 1 hour single and twin engine helicopter requires 2.1E-6 units and 2.4E-6 units, respectively, of medium haul aircraft manufacture.

The maintenance of the helicopter is approximated by increasing the aircraft manufacture efforts by 5 %.

3.5.4 Airborne Emissions

Specific emission factors for cruise or rotation and the LTO cycle of different engines and types of helicopters are provided in the excel file with statistic data of FOCA (2016).

The Sulphur- and Carbon-contents of Kerosene burned in helicopters are assumed to be the same as those of Kerosene used in aircrafts. Therefore the same emission factors are applied, namely 3.15 kg CO_2/kg and 1 g SO_2/kg (Winther & Rypdal 2013).

In Tab. 3.4 the emission factors of the combustion dependent pollutants of the single and twin engine helicopter are presented. For CH_4, NMVOC, N_2O, heavy metals and individual HC no specific data were available. Therefore the emission factors of aircrafts are applied.

Tab. 3.4 Emission factors of combustion dependent pollutants (FOCA 2016)

	Unit	single engine helicopter	twin engine helicopter	Source
NO_x	kg/h	1.57	1.66	FOCA (2016)
CO	kg/h	0.75	1.84	FOCA (2016)
PM non vol.	kg/h	0.04	0.05	FOCA (2016)
HC	kg/h	0.61	1.49	FOCA (2016)
CH_4	kg/h	0.32	0.79	Share of HC emission adapted from emission of aircrafts
NMVOC	kg/h	0.18	0.45	Share of HC emission adapted from emission of aircrafts
Benzene	kg/h	0.01	0.01	Share of HC emission adapted from emission of aircrafts
Formaldehyde	kg/h	0.04	0.11	Share of HC emission adapted from emission of aircrafts
Butadiene	kg/h	0.01	0.01	Share of HC emission adapted from emission of aircrafts
Ethylene	kg/h	0.05	0.12	Share of HC emission adapted from emission of aircrafts
N_2O	kg/h	0.02	0.03	Emission factor of aircafts
Cadmium	kg/h	1.83E-06	2.59E-06	Emission factor of aircarfts
Copper	kg/h	3.10E-04	4.41E-04	Emission factor of aircarfts
Chromium	kg/h	9.13E-06	1.30E-05	Emission factor of aircarfts
Nickel	kg/h	1.28E-05	1.82E-05	Emission factor of aircarfts
Selenium	kg/h	1.83E-06	2.59E-06	Emission factor of aircarfts
Zinc	kg/h	1.83E-04	2.59E-04	Emission factor of aircarfts
Lead	kg/h	3.65E-06	5.19E-06	Emission factor of aircarfts
Mercury	kg/h	1.28E-08	1.82E-08	Emission factor of aircarfts
NO_x	kg/LTO	0.181	0.207	FOCA (2016)
CO	kg/LTO	0.313	1.000	FOCA (2016)
PM non vol.	kg/LTO	0.006	0.007	FOCA (2016)
HC	kg/LTO	0.248	0.769	FOCA (2016)
CH_4	kg/LTO	0.131	0.408	Share of HC emission adapted from emission of aircrafts
NMVOC	kg/LTO	0.074	0.231	Share of HC emission adapted from emission of aircrafts
Benzene	kg/LTO	0.002	0.007	Share of HC emission adapted from emission of aircrafts
Formaldehyde	kg/LTO	0.017	0.054	Share of HC emission adapted from emission of aircrafts
Butadiene	kg/LTO	0.002	0.007	Share of HC emission adapted from emission of aircrafts
Ethylene	kg/LTO	0.020	0.063	Share of HC emission adapted from emission of aircrafts
N_2O	kg/LTO	0.003	0.005	Emission factor of aircafts
Cadmium	kg/LTO	2.76E-07	4.12E-07	Emission factor of aircarfts
Copper	kg/LTO	4.69E-05	7.00E-05	Emission factor of aircarfts
Chromium	kg/LTO	1.38E-06	2.06E-06	Emission factor of aircarfts
Nickel	kg/LTO	1.93E-06	2.88E-06	Emission factor of aircarfts
Selenium	kg/LTO	2.76E-07	4.12E-07	Emission factor of aircarfts
Zinc	kg/LTO	2.76E-05	4.12E-05	Emission factor of aircarfts
Lead	kg/LTO	5.52E-07	8.24E-07	Emission factor of aircarfts
Mercury	kg/LTO	1.93E-09	2.88E-09	Emission factor of aircarfts

For helicopter no specific noise emissions are recommended by Frischknecht & Büsser Knöpfel (2013). Helicopter transport noise emissions are approximated with the noise emissions of aircrafts. The noise emissions of aircrafts are expressed as "noise pkm" and "noise tkm". The maximum transport service of the helicopter is 4 passengers or 1.2 t of freight (single engine helicopter) and 5 passengers (twin engine helicopter). With an average travel speed of 230 km/h (twin engine, passengers) and 225 km/h (single engine freight or passenger)[13], respectively, the transport service is 920 pkm, 270 tkm and 1'125 pkm per hour. The noise emissions of aircrafts were multiplied by the calculated transport services of single and twin engine helicopters.

3.5.5 Life Cycle Inventory of Helicopter Transport

Tab. 3.5 Life cycle inventory of helicopter transport services

	Name	Location	InfrastructureProcess	Unit	transport, helicopter, twin-engine, LTO cycle	transport, passenger helicopter, twin-engine	transport, helicopter, single-engine, LTO cycle	transport, freight helicopter, single-engine	transport, passenger, helicopter, single-engine	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH	CH	CH	CH	CH			
	InfrastructureProcess				0	0	0	0	0			
	Unit				p	hr	p	hr	hr			
product	transport, helicopter, twin-engine, LTO cycle	CH	0	p	1	0	0	0	0			
product	transport, passenger helicopter, twin-engine	CH	0	hr	0	1	0	0	0			
product	transport, helicopter, single-engine, LTO cycle	CH	0	p	0	0	1	0	0			
product	transport, freight helicopter, single-engine	CH	0	hr	0	0	0	1	0			
product	transport, passenger, helicopter, single-engine	CH	0	hr	0	0	0	0	1			
technosphere	aircraft, medium haul	RER	1	unit		2.56E-6		2.20E-6	2.20E-6	1	4.25	(5,5,5,5,5,5,BU:3); extrapolated using a mediumhaul aircraft, weight of twin engine helicopter 1490.0 kg and weight of a single engin helicopter 1280.0kg. For the effort of the maintenence a surcharge of 5% of the production is added.; swisshelicopter.ch, last visit 17.12.2015"
technosphere	transport, helicopter, twin-engine, LTO cycle	CH	0	p		1.79E+0				1	2.38	(4,5,1,5,4,5,BU:2); an average fligth duration of 33.5min (13.5min for LTO and 20min for cruise) is assumed, this corresponds to 1.8 LTO per hour;
technosphere	transport, helicopter, single-engine, LTO cycle	CH	0	p				0	1.79E+0	1	2.38	(4,5,1,5,4,5,BU:2); an average fligth duration of 33.5min (13.5min for LTO and 20min for cruise) is assumed, this corresponds to 1.8 LTO
	kerosene, at regional storage	RER	0	kg	4.12E+1	2.59E+2	2.76E+1	1.83E+2	1.83E+2	1	1.24	(2,4,1,3,1,5,BU:1.05); ; Table with emission factors FOCA, 2016
emission air, low population density	Nitrogen oxides	-	-	kg	2.07E-1	1.66E+0	1.81E-1	1.57E+0	1.57E+0	1	1.63	(2,3,2,1,3,5,BU:1.5); ; Table with emission factors FOCA, 2016
	Methane, fossil	-	-	kg	4.08E-1	7.89E-1	1.31E-1	3.23E-1	3.23E-1	1	1.63	(2,3,2,1,3,5,BU:1.5); Calculated based on share of HC with value of ecoinvent2.2 process; Table with emission factors FOCA, 2016
	NMVOC, non-methane volatile organic compounds, unspecified origin	-	-	kg	2.31E-1	4.48E-1	7.44E-2	1.83E-1	1.83E-1	1	1.63	(2,3,2,1,3,5,BU:1.5); Calculated based on share of HC with value of ecoinvent 2.2 process; Table with emission factors FOCA, 2016
	Carbon monoxide, fossil	-	-	kg	1.00E+0	1.84E+0	3.13E-1	7.50E-1	7.50E-1	1	5.11	(2,3,2,1,3,5,BU:5); ; Table with emission factors FOCA, 2016
	Particulates, < 2.5 um	-	-	kg	7.00E-3	5.06E-2	5.50E-3	4.46E-2	4.46E-2	1	3.10	(2,3,2,1,3,5,BU:3); ; Table with emission factors FOCA, 2016
	Carbon dioxide, fossil	-	-	kg	1.30E+2	8.17E+2	8.69E+1	5.75E+2	5.75E+2	1	1.31	(2,3,2,1,3,5,BU:1.05); ; EEA, Trier 1, 2013, Flugtransport
	Sulfur dioxide	-	-	kg	4.00E-2	2.59E-1	2.68E-2	1.83E-1	1.83E-1	1	1.31	(2,3,2,1,3,5,BU:1.05); ; EEA, Trier 1, 2013, Flugtransport
	Water	-	-	kg	5.11E-2	3.22E-1	3.42E-2	2.26E-1	2.26E-1	1	2.13	(5,5,2,5,4,5,BU:1.5); ; ecoinvent report 14, air transport
	Dinitrogen monoxide	-	-	kg	4.99E-3	2.59E-2	3.35E-3	1.83E-2	1.83E-2	1	2.13	(5,5,2,5,4,5,BU:1.5); ; EEA, Trier 1, 2013, Flugtransport
	Benzene	-	-	kg	6.87E-3	1.33E-2	2.21E-3	5.45E-3	5.45E-3	1	3.56	(5,5,2,5,4,5,BU:3); ; VOC Profil of ecoinvent report 14, air transport
	Formaldehyde	-	-	kg	5.42E-2	1.05E-1	1.75E-2	4.30E-2	4.30E-2	1	2.13	(5,5,2,5,4,5,BU:1.5); ; VOC Profil of ecoinvent report 14, air transport
	Butadiene	-	-	kg	6.51E-3	1.26E-2	2.10E-3	5.17E-3	5.17E-3	1	2.13	(5,5,2,5,4,5,BU:1.5); ; VOC Profil of ecoinvent report 14, air transport
	Ethene	-	-	kg	6.29E-2	1.22E-1	2.03E-2	4.99E-2	4.99E-2	1	2.13	(5,5,2,5,4,5,BU:1.5); ; VOC Profil of ecoinvent report 14, air transport
	Cadmium	-	-	kg	4.12E-7	2.59E-6	2.76E-7	1.83E-6	1.83E-6	1	5.64	(5,5,2,5,4,5,BU:5); ; ecoinvent report 14, air transport
	Copper	-	-	kg	7.00E-5	4.41E-4	4.69E-5	3.10E-4	3.10E-4	1	5.64	(5,5,2,5,4,5,BU:5); ; ecoinvent report 14, air transport
	Chromium	-	-	kg	2.06E-6	1.30E-5	1.38E-6	9.13E-6	9.13E-6	1	5.64	(5,5,2,5,4,5,BU:5); ; ecoinvent report 14, air transport
	Nickel	-	-	kg	2.88E-6	1.82E-5	1.93E-6	1.28E-5	1.28E-5	1	5.64	(5,5,2,5,4,5,BU:5); ; ecoinvent report 14, air transport
	Selenium	-	-	kg	4.12E-7	2.59E-6	2.76E-7	1.83E-6	1.83E-6	1	5.64	(5,5,2,5,4,5,BU:5); ; ecoinvent report 14, air transport
	Zinc	-	-	kg	4.12E-5	2.59E-4	2.76E-5	1.83E-4	1.83E-4	1	5.64	(5,5,2,5,4,5,BU:5); ; ecoinvent report 14, air transport
	Lead	-	-	kg	8.24E-7	5.19E-6	5.52E-7	3.65E-6	3.65E-6	1	5.64	(5,5,2,5,4,5,BU:5); ; ecoinvent report 14, air transport
	Mercury	-	-	kg	2.88E-9	1.82E-8	1.93E-9	1.28E-8	1.28E-8	1	5.64	(5,5,2,5,4,5,BU:5); ; ecoinvent report 14, air transport
	Heat, waste	-	-	MJ	1.88E+3	1.18E+4	1.26E+3	8.33E+3	8.33E+3	1	1.89	(5,5,2,5,4,5,BU:1.05); ; default value
emission Non material emissions, unspecified	Noise, aircraft, passenger	-	-	pkm		920.00			1'125.00	1	1.74	(4,5,2,5,3,5,BU:1.5); own calculation, using the max. load and speed; Ecological Scarcity method 2013; Frischknecht & Büsser Knöpfel 2013
	Noise, aircraft, freight	-	-	tkm				270.00		1	1.74	(4,5,2,5,3,5,BU:1.5); own calculation, using the max. load and speed; Ecological Scarcity method 2013; Frischknecht & Büsser Knöpfel

13 www.swisshelicopter.ch, last visit 27.April 2016

4 Cable Car Transport Services

4.1 Overview

This chapter contains the description of the life cycle inventory of cable car transport services in Switzerland. The inventory is based on an average cable car installation in Switzerland with two cable cars with a maximum capacity of 35 passengers each and a distance of 2 km. The infrastructure modelled in the inventory consists of 4 masts, the supporting cable, two stations and the electric motor.

4.2 Goal and Scope

4.2.1 Functional Unit

The functional unit of cable car transport services is one passenger kilometre (pkm).

4.2.2 System Boundaries

The process “cable car transport” is structured into the following unit processes:

- Cable car operation
- Cable car manufacture and disposal,
- Cable car maintenance, and
- Cable car infrastructure (supporting cables, masts, stations and electric motors).

4.2.3 Data Sources and Quality

Data on transport performance, energy requirement, average load factor and the demand of infrastructure stem from national statistics (BFS 2015 and BAK 2011), Swiss cable car manufacturers and Swiss cable car operators.

4.3 Life Cycle Inventories

4.3.1 Key Characteristics of an average cable car operated in Switzerland

According to BFS (2015), about 240 cable cars are operated in Switzerland (see Tab. 4.1), with a cumulative transport performance of more than 50 Mio. pkm per year. The average capacity of one cable car is 35 persons and the average load factor is close to 50 %. The average transport performance of a single cable car is 222’785 pkm a year and it is calculated by dividing the kilometric performance of all cable cars in Switzerland by the number of cable cars and multiplying it with the average number of passengers.

Tab. 4.1 Annual transport performance of Swiss cable cars and key characteristics of an average cable car operated in Switzerland (BAK 2011, BFS 2014b)

Number of cable cars in CH	#	237
Total kilometric transport performance in CH	vkm	2'970'000
Total transported people per year in CH	p	26'222'000
Total transport performance in CH	pkm	52'800'000
Average capacity in one cable car	p	35
Average load factor	%	50.7
Transport performance of a single cable car	pkm	222'785
Life time of a cable car	a	25
Life time of the cable car infrastructure	a	50

4.3.2 Electricity consumption

The electricity consumption related to the traction of an average cable car was estimated by Garaventa for the very usual case that a fully loaded cable car is going up the hill and the other one is going down empty. According to Garaventa[14,15] the electricity consumption is 4.3 kWh/km or 0.123 kWh/pkm. The traction related electricity consumption of the cable cars is about 40 % of the total energy consumption of cable car operation.[16] Therefore the overall electricity consumption of cable car operation is 0.307 kWh/pkm.

4.3.3 Demand of cable car manufacture and infrastructure

The demand of the components “infrastructure construction”, “cable car manufacture”, “cable car maintenance” and “cable car disposal” is determined with the yearly transport performance (pkm/a) presented in Tab. 4.1 and the average lifetime of 25 years (duration of a concession for cable cars in Switzerland).

4.3.4 Unit process life cycle inventory data

Tab. 4.2 Life cycle inventory data of cable car transport services

	Name	Location	InfrastructureProcess	Unit	transport, passenger cable car	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				0			
	Unit				pkm			
product	transport, passenger cable car	CH	0	pkm	1			
technosphere	cable car, for passenger transport	CH	1	p	1.80E-7	1	3.06	(4,2,2,1,1,4,BU:3); ; BFS 2014
	cable car infrastructure	CH	1	p	4.4886E-8	1	3.06	(4,2,2,1,1,4,BU:3); ; own assumption, Luftseilbahninventar
	maintenance, passenger cable car	CH	1	p	1.80E-7	1	3.06	(4,2,2,1,1,4,BU:3); ; BFS 2014
	electricity, medium voltage, at grid	CH	0	kWh	3.09E-1	1	1.32	(3,5,1,1,1,5,BU:1.05); ; pers. communication Garventa 2015, energie.ch

14 Personal communication with Daniel Andermatten, Garaventa, 3.11.2015

15 Personal communication with Daniel Andermatten, Garaventa, 3.11.2015

16 Information published on www.energy.ch, last visit 2. May 2016

4.3.5 Manufacturing and Maintenance of the Cable Car

The average weight of a cable car in Switzerland is 2'876 kg (one single cabin, BAK 2011). It is assumed that cable cars are similar to train wagons with the exception of the furniture of the interior. The manufacture and maintenance of a cable car are therefore approximated with data on manufacture and maintenance of a regional train. The data on manufacture and maintenance of one regional train are scaled down to the weight of the average cable car. The manufacture of a regional train includes a battery, which is omitted in the cable car manufacture dataset.

4.3.6 Unit Process Life Cycle Inventory data

Tab. 4.3 Life cycle inventory of cable car manufacture

	Name	Location	InfrastructureProcess	Unit	cable car, for passenger transport	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				1			
	Unit				p			
product	cable car, for passenger transport	CH	1	p	1			
technosphere	reinforcing steel, at plant	RER	0	kg	1.92E+3	1	1.84	(5,4,1,3,4,5,BU:1.05); approximated with data on manufacturing and maintenance of a regional train; ecoinvent 2.2
	aluminium, production mix, at plant	RER	0	kg	1.68E+2	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	copper, at regional storage	RER	0	kg	1.18E+2	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	polyethylene, HDPE, granulate, at plant	RER	0	kg	2.19E+2	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	flat glass, uncoated, at plant	RER	0	kg	1.22E+2	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	alkyd paint, white, 60% in solvent, at plant	RER	0	kg	2.15E+1	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	glued laminated timber, outdoor use, at plant	RER	0	m3	1.46E-1	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	rock wool, packed, at plant	CH	0	kg	2.15E+1	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	lead, at regional storage	RER	0	kg	2.44E+1	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	transport, lorry 20-28t, fleet average	CH	0	tkm	1.30E+2	1	2.52	(5,4,1,3,4,5,BU:2); ; ecoinvent
	transport, freight, rail	CH	0	tkm	5.18E+2	1	2.52	(5,4,1,3,4,5,BU:2); ; ecoinvent
	electricity, medium voltage, at grid	CH	0	kWh	2.15E+3	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	heat, light fuel oil, at industrial furnace 1MW	CH	0	MJ	3.03E+3	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
emission air, unspecified	Heat, waste	-	-	MJ	7.77E+3	1	1.84	(5,4,1,3,4,5,BU:1.05); ; ecoinvent 2.2
technosphere	disposal, emulsion paint, 0% water, to municipal incineration	CH	0	kg	9.37E-2	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	disposal, glass, 0% water, to municipal incineration	CH	0	kg	1.22E+2	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	disposal, plastics, mixture, 15.3% water, to sanitary landfill	CH	0	kg	2.19E+2	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	disposal, wood untreated, 20% water, to municipal incineration	CH	0	kg	1.04E+2	1	1.84	(5,4,1,3,4,5,BU:1.05); ;
	transport, lorry 20-28t, fleet average	CH	0	tkm	2.22E+1	1	2.52	(5,4,1,3,4,5,BU:2); ; ecoinvent

4.3.7 Cable Car Infrastructure

The infrastructure of the modelled cable car includes four masts[17] made of structural steel with concrete foundation, a suspension and a pull cable, a lower and a top cable car station as well as an electric engine with a power of 224 kW (BAK 2011). The weight of the pull cable is based on information of the Luftseilbahn Kandersteg-Sunnbühel (LKS 2007). The information about the weight of steel and concrete of a mast is adapted from electricity masts installed in Switzerland[18]. The stations are assumed to cover an area of 100 m^2 and have a height of 6 m, which results in 600 m^3 built space per station.. The fuel and electricity demand related to the construction of the stations and masts are disregarded due to lack of information. The key characteristics are presented in Tab. 4.4.

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[17] In Switzerland the length of the average cable car is 2 km (BAK 2011) and it has on average 2 masts per km.

[18] Information of the ewz about transmission networks, received 2. February 2012

Tab. 4.4 Key characteristics of the cable car infrastructure

	Unit	Value
Length of the cable car	km	2
Average number of mast per km	mast/km	2
Weight of the cable	kg/m	14.2
Weight of a mast (steel)	kg	30'200
Concrete foundation	kg	26'000
Cable car station	m^3	600
Electric engine	kg	2'000

4.3.8 Life Cycle Inventory data

Tab. 4.5 Life cycle inventory data of cable car infrastructure

	Name	Location	InfrastructureProcess	Unit	cable car infrastructure	UncertaintyType	StandardDeviation95%	GeneralComment
	Location				CH			
	InfrastructureProcess				1			
	Unit				p			
product	cable car infrastructure	CH	1	p	1			
technosphere	electric motor, electric vehicle, at plant	RER	0	kg	2.00E+3	1	1.34	(3,4,1,3,3,5,BU:1.05); ; Technische Daten Elektromotor Kemmerich
	reinforcing steel, at plant	RER	0	kg	5.71E+4	1	1.65	(4,4,1,5,4,5,BU:1.05); steel for rope of a length of 2km one way; Luftseilbahninventar, 2011
	building, multi-storey	RER	1	m3	1.20E+3	1	3.97	(5,4,1,5,5,5,BU:3); own assumption of a 100m2 and three storey
	reinforcing steel, at plant	RER	0	kg	1.22E+5	1	1.65	(4,4,1,5,4,5,BU:1.05); steel for mast with a weight 24.7t and the
	concrete, exacting, at plant	CH	0	m3	4.36E+1	1	1.65	(4,4,1,5,4,5,BU:1.05); concrete for the foundation of the 4 mast, 26t
resource, land	Transformation, from unknown	-	-	m2	2.00E+2	1	2.99	(5,5,2,5,5,5,BU:2); ;
	Transformation, to industrial area, built up	-	-	m2	2.00E+2	1	2.99	(5,5,2,5,5,5,BU:2); ;
	Occupation, industrial area, built up	-	-	m2a	1.00E+4	1	2.56	(5,5,2,5,5,5,BU:1.5); ;
	Occupation, construction site	-	-	m2a	1.00E+4	1	2.56	(5,5,2,5,5,5,BU:1.5); ;

References

BAFU 2016 BAFU (2016) Switzerland's Informative Inventory Report 2014 (IIR) - Submission under the UNECE Convention on Long-range Transboundary Air Pollution. INFRAS consulting group, Zurich & Federal Office for the Environment FOEN, Air Pollution Control and Non-Ionising Radiation Division, Berne. INFRAS consulting group, Zurich & Federal Office for the Environment FOEN, Air Pollution Control and Non-Ionising Radiation Division, Berne.

BAK 2011 BAK (2011) Schweizer Seilbahninventar. Bundesamt für Kultur.

BDL 2014 BDL (2014) report2014 Energy efficiency and climate protection. Bundesverband der Deutschen Luftverkehrswirtschaft.

BFS 2014a BFS (2014a) Fahrzeugbewegungen und Fahrleistungen im Personenverkehr. Bundesamt für Statistik, Neuchâtel, retrieved from: http://www.bfs.admin.ch/bfs/portal/de/index/themen/11/04/blank/01.Document.21295.xls.

BFS 2014b BFS (2014b) Öffentlicher Verkehr (inkl. Schienengüterverkehr) - Zeitreihen. Bundesamt für Statistik, Neuchâtel, retrieved from: http://www.bfs.admin.ch/bfs/portal/de/index/themen/11/07/blank/01.Document.126965.xls.

BFS 2015 BFS (2015) Verkehrsleistung im Personenverkehr. Bundesamt für Statistik, Neuchâtel, retrieved from: http://www.bfs.admin.ch/bfs/portal/de/index/infothek/lexikon/lex/0.Document.21297.xls.

ewz 2016 ewz (2016) Umweltdaten 2015, Umweltmanagementsystem (ed. Emch G.), Zürich.

FAA 2010 FAA (2010) Aging Airplane Program: Widespread Fatigue Damage. Federal Aviation Administration, retrieved from: https://www.federalregister.gov/articles/2010/11/15/2010-28363/aging-airplane-program-widespread-fatigue-damage#page-69769.

Faist Emmenegger et al. 2007 Faist Emmenegger M., Heck T., Jungbluth N. and Tuchschmid M. (2007) Erdgas. In: Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz, Vol. ecoinvent report No. 6-V, v2.0 (Ed. Dones R.). Paul Scherrer Institut Villigen, Swiss Centre for Life Cycle Inventories, Dübendorf, CH retrieved from: www.ecoinvent.org.

Flughafen Zürich AG 2014 Flughafen Zürich AG (2014) Statistikbericht 2014. Flughafen Zürich AG, Zürich.

FOCA 2016 FOCA (2016) Emission of Helicopters. Federal Office of Civil Aviation FOCA.

Frischknecht & Büsser Knöpfel 2013 Frischknecht R. and Büsser Knöpfel S. (2013) Ökofaktoren Schweiz 2013 gemäss der Methode der ökologischen Knappheit. Grundlagen und Anwendung auf die Schweiz. Umwelt-Wissen Nr. 1330. Bundesamt für Umwelt, Bern, retrieved from: http://www.bafu.admin.ch/publikationen/publikation/01750/index.html?lang=de.

Fuglestvedt et al. 2010 Fuglestvedt J. S., Shine K. P., Berntsen T., Cook J., Lee D. S., Stenke A., Skeie R. B., Velders G. J. M. and Waitz I. A. (2010) Transport impacts on atmosphere and climate: Metrics. In: Atmospheric Environment, 44(2010), pp. 4648–4677.

ICAO 2016 ICAO (2016) ICAO Carbon Emissions Calculator Methodology.

Jungbluth 2007 Jungbluth N. (2007) Erdöl. In: Sachbilanzen von Energiesystemen: Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz, Vol. ecoinvent report No. 6-IV, v2.0 (Ed. Dones R.). Paul Scherrer Institut Villigen, Swiss Centre for Life Cycle Inventories, Dübendorf, CH retrieved from: www.ecoinvent.org.

KBOB et al. 2016 KBOB, eco-bau and IPB (2016) KBOB Ökobilanzdatenbestand v2.2:2016; Grundlage für die KBOB-Empfehlung 2009/1:2016: Ökobilanzdaten im Baubereich, Stand 2016. Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren c/o BBL Bundesamt für Bauten und Logistik, retrieved from: www.lc-inventories.ch.

LKS 2007 LKS (2007) Technische Luftseilbahn Kandersteg-Sunnbühl. In, pp.

Lufthansa 2015 Lufthansa (2015) Balance, Das Wichtigste zum Thema Nachhaltigkeit in der Lufthansa Group. Lufthansa Group, Frankfurt am Main.

Spielmann et al. 2007 Spielmann M., Roberto Dones, Bauer C. and Tuchschmid M. (2007) Life Cycle Inventories of Transport Services. ecoinvent report No. 14, v2.0. Swiss Centre for Life Cycle Inventories, Dübendorf, CH, retrieved from: www.ecoinvent.org.

Winther & Rypdal 2013 Winther M. and Rypdal K. (2013) 1.A.3.a, 1.A.5.b Civil and military aviation. In: EMEP/EEA emission inventory guidebook 2013 - Technical guidance to prepare national emission inventories. Publications Office of the European Union, Luxemburg.