Life cycle inventories of global air freight - Global

for the SRI project

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Name of associations

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Background

The creation of reliable, consistent and transparent regionalised Life Cycle Inventories (LCI) represents a core purpose of the SRI programme. The LCI component of the SRI project provides a basis for informed decision-making on the sustainability of products and developments in other components of SRI project. The main goal is to establish and provide regional LCIs for the use in Life Cycle Assessment (LCA) studies, environmental product declarations, carbon foot-printing and similar assessment tools. The ecoinvent Association, as the leading global supplier of transparent LCI data, is in charge of developing the basis for national LCI data in South America (Brazil, Colombia, Peru), South Africa, and India.

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Data provider details

Data Provider is here defined as the association/s that created and submitted datasets to the ecoinvent Database in the context of the SRI project. The Data Provider are the authors of this report in collaboration of the ecoinvent Association.

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This report has been prepared by the author in close collaboration with the ecoinvent Association. Nevertheless, ownership of the contents, data and conclusions in this report ("Content") remains with the authors of this report.

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1 Background and overarching data

1.1.1 Introduction to global air freight

Global air freight accounts for 170,508 million tonne.kms of freight movement annually (ICAO, 2016), accounting for approximately 2% of global freight transport (UNCTAD, 2017, Szakonyi, 2014). Although this is a small percentage of global freight, the freight typically consists of high-value items (Freightos, 2018, Szakonyi, 2014), which allows air freight to move more than 30-35% of total cargo value annually (Szakonyi, 2014, Shepard et al., 2016). The volume of goods moved by air freight also continues to grow, with the industry having experienced a 5.4% and 9% increase in freight tonne.kms during 2016 and 2017 respectively (IATA, 2017).

Air transport can be seen to occur in three segments, namely (OAG, 2016):

- Passenger transport: Passengers transported in aircraft operated purely for the transport of passengers (these flights are typically operated by low-cost operators, such as easyJet, who only transport passengers as part of their operating policy) and passengers transported in aircraft also carrying freight. These flights carrying both passengers and freight simultaneously are named belly-freight flights.
- Belly-freight transport: Freight transport in belly-freight aircraft. This freight is transported in the hold, along with passenger luggage. The freight loading is therefore relatively small (2-7 tonnes per flight).
- Dedicated freight transport: Freight transport in aircraft used exclusively for freight movements. The freight loading is therefore much greater (42-51 tonnes) than in belly-freight aircraft.

Air transport can also be disaggregated depending on the haulage distance over which freight and passengers are moved. Although no clear boundaries exist on which to separate haulage distance, for the purposes of this project the haulage distances classes were chosen based on typical ranges of different aircraft types (typically small narrow body aircraft have a flight distance of below 4,000 km (Cox et al., 2018)). A further category was also added due to the fact that for distances below 800 km air transport can easily be substituted by other means of transport, while for longer distances there is often no viable alternative to air transport. Therefore, 800 km was seen as an interesting boundary for many LCA applications. As such, the four haulage distances for this project were defined as:

- Very short haul: Under 800 km
- Short haul: Between 800 km and 1,500 km
- Medium haul: Between 1,500 km and 4,000 km
- Long haul: Over 4,000 km

As discussed in further detail below (see Sections 1.1.2 and 2.1.2), the various transport segments and haulage distances have significantly different transport volumes, splits between the transport segments, aircraft demands (and associated production demands) and operational demands. Therefore, this project disaggregated global air transport into 15 different categories. The modelling focussed on the production of the aircraft needed to meet transport demand (production datasets) and the operation of these aircraft (transport datasets).

1.1.2 Overarching air freight data

Air transport data was taken from OAG (2016) global flight plan data, which included the carrier name, plane type, airport of departure, airport of arrival and the freight weight for every scheduled flight in 2016. This ensures that the data was representative of the global average for both passenger and freight movements.

The distances of 99.5% of all flights was calculated as the Great Circle Distance (GCD) using coordinates of the destination airports and corrected using a distance dependent factor (74 km for distances below 926 km and 139 for distances above 926 km). For the 0.044% of the flights for which no coordinates for one of the destinations was available, flight distance of 1,000 km was assumed.

In order to calculate the weights of individual flights in the yearly averages, the number of executions of each flight needed to be known. Unfortunately, data on this was unavailable. Therefore, a number was estimated using the total global aircraft.kms for 2015 from ICAO (2016) (46,218 million aircraft.kms) for the calibration.

The number of passenger.kms was calculated using the typical number of seats per plane type from EcoTransIT (2016) and an average passenger load factor of 0.80 (ICAO, 2016). The calculated total yearly passenger.kms value is 91% of the value given by ICAO (2016) and this is shown for the various transport segments and haulage categories in Table 1.

The number of tonne.kms was calculated from the aircraft.kms and the freight weight form (OAG, 2016) and calibrated to the total freight transport (170,508 million tonne.kms) reported in ICAO (2016). The total tonne.kms for the various transport segments and haulage categories are presented in Table 1.

For passenger planes, allocation factors for passengers and belly-freight were calculated according to EN 16'058, using the weight of the passengers and luggage (105 kg / passenger according to EASA (2009)) and the weight of the freight on the flight. Depending on the flight, passengers are thus allocated between 33% and 100% of the burdens of the flight. The unweighted average allocation factor for passengers over all flights was 86%.

In all cases the calculations used weighted averages (weighted according to passenger.kms for passenger transport and tonne.kms for belly-freight and dedicated freight transport) to establish annual averages.

Table 1: Market share per haulage distance and aircraft category

Haulage distance	Total passenger.kms	Total tonne.kms		Share of total freight transport	
	All passenger transport	Belly-freight	Dedicated freight	Belly-freight	Dedicated freight
Very short haul	4.884E+11	6.774E+09	7.469E+08	90%	10%
Short haul	9.493E+11	1.518E+10	2.601E+09	85%	15%
Medium haul	2.562E+12	4.123E+10	1.360E+10	75%	25%
Long haul	2.009E+12	5.706E+10	5.064E+10	53%	47%
Unspecified distance[1]	6.008E+12	1.203E+11	6.758E+10	64%	36%

[1] Unspecified distance relates to the total of all haulage distances.

It may be noted that belly-freight accounts for 64% of total freight transport. However, the share of freight transported by belly-freight is much greater for short haulage distances, while dedicated freights have almost 50% market share for the movement of freight over long haulage distances.

Using this data extraction and analysis, the market share of the 40 most relevant aircraft models for the various distance classes and transport segments was established. The market share was established in terms of passenger.kms for passenger transport and in terms of tonne.kms for belly-freight and dedicated freight transport. This data is presented in Table 2 to Table 13.

It may be noted that flights of passenger planes not transporting freight are only accounted for in passenger transport but not for belly-freight transport in passenger planes. Also, weighting of flights to calculate the average data for passenger transport was done by the share of the flights on total passenger.kms. However, the average data for belly-freight transport was calculated using the share of the flights on total tonne.km transported in passenger planes. Both facts lead to a situation in which the fleet and the shares of plane types were different for passenger and belly-freight transports. Consequently, even though the same plane transports passengers and freight, the results could not be generated by an average plane operation and allocation to passengers and freight. Passenger and belly-freight transport were therefore modelled separately.

Table 2: Most relevant aircraft models and market share for very short haul passenger transport

Aircraft model	Passenger transport (million passenger.kms)	Share of top aircraft models passenger.kms
Airbus A320	75,629	16.4%
Boeing 737-700 (winglets) Passenger	64,575	14.0%
Boeing 737-800 Passenger	37,609	8.2%
Airbus A319	35,318	7.7%
Boeing 737-800 (winglets) Passenger	30,977	6.7%
Airbus A321	21,806	4.7%
Canadair Regional Jet 900	17,087	3.7%
Canadair Regional Jet	16,320	3.5%
Canadair Regional Jet 700	13,506	2.9%
ATR 72	13,164	2.9%
Embraer 190	12,152	2.6%
Embraer 175	9,272	2.0%
Boeing 737 Passenger	8,778	1.9%
Boeing 717-200	8,582	1.9%
Boeing 737-300 (winglets) Passenger	7,324	1.6%
Boeing (douglas) MD-88	6,615	1.4%
Embraer RJ145	6,328	1.4%
Boeing 737-900 Passenger	6,119	1.3%
Embraer 170	5,989	1.3%
Boeing 737-300 Passenger	5,290	1.1%
Embraer RJ 135/140/145	4,943	1.1%
Embraer 195	4,755	1.0%
Boeing 737-700 Passenger	4,479	1.0%
Boeing (douglas) MD-80	4,309	0.9%
Boeing 737-500 Passenger	3,888	0.8%
Airbus A330-300	3,718	0.8%
Embraer 175 (Enhanced Winglets)	3,468	0.8%
ATR42 /ATR72	3,438	0.7%
DHvilld-Bombardier DHC8 Dsh 8	3,009	0.7%
Airbus A330-200	2,726	0.6%
Airbus A318 /319 /320 /321	2,546	0.6%
Airbus A320 (sharklets)	2,443	0.5%
Boeing (douglas) MD-90	2,359	0.5%
Boeing 777-200/200ER Passenger	2,103	0.5%
Boeing 737-600 Passenger	2,065	0.4%
Boeing 777-300ER Passenger	1,997	0.4%
Boeing 737-400 Passenger	1,726	0.4%
Boeing 767 Passenger	1,636	0.4%
Canadair (Bombardier) Regional Jet 1000	1,615	0.4%
Airbus A330	1,519	0.3%

Table 3: Most relevant aircraft models and market share for short haul passenger transport

Aircraft model	Passenger transport (million passenger.kms)	Share of top aircraft models passenger.kms
Airbus A320	179,440	19.7%
Boeing 737-700 (winglets) Passenger	108,517	11.9%
Boeing 737-800 Passenger	95,064	10.4%
Boeing 737-800 (winglets) Passenger	84,426	9.3%
Airbus A319	69,144	7.6%
Airbus A321	54,279	6.0%
Canadair Regional Jet 900	26,085	2.9%
Canadair Regional Jet 700	23,151	2.5%
Boeing 737 Passenger	20,475	2.2%
Boeing 737-300 (winglets) Passenger	18,865	2.1%
Boeing (douglas) MD-80	14,603	1.6%
Embraer 190	14,518	1.6%
Boeing (douglas) MD-88	14,508	1.6%
Boeing 737-900 Passenger	14,355	1.6%
Canadair Regional Jet	13,571	1.5%
Boeing 717-200	13,254	1.5%
Airbus A330-300	12,816	1.4%
Embraer 175	12,407	1.4%
Boeing 737-300 Passenger	9,225	1.0%
Embraer 170	8,923	1.0%
Boeing 737-700 Passenger	8,176	0.9%
Embraer RJ 135/140/145	7,322	0.8%
Embraer RJ145	7,311	0.8%
Boeing 777-200/200ER Passenger	6,897	0.8%
Airbus A330	6,868	0.8%
Boeing (douglas) MD-90	6,798	0.7%
Airbus A320 (sharklets)	6,250	0.7%
Embraer 175 (Enhanced Winglets)	6,051	0.7%
Boeing 757 (Passenger)	5,586	0.6%
Boeing 777-300ER Passenger	5,419	0.6%
Embraer 195	5,230	0.6%
Airbus A330-200	4,942	0.5%
Boeing 737-400 Passenger	4,359	0.5%
Boeing 787	3,642	0.4%
Boeing 767-300 Passenger	3,622	0.4%
Fokker 100	3,411	0.4%
Boeing 737-500 Passenger	3,112	0.3%
Boeing 777-300 Passenger	2,829	0.3%
Boeing 737-900 (winglets) Passenger	2,765	0.3%
Airbus A318 /319 /320 /321	2,671	0.3%

Table 4: Most relevant aircraft models and market share for medium haul passenger transport

Aircraft model	Passenger transport (million passenger.kms)	Share of top aircraft models passenger.kms
Airbus A320	427,978	17.4%
Boeing 737-800 (winglets) Passenger	360,265	14.7%
Boeing 737-800 Passenger	329,771	13.4%
Boeing 737-700 (winglets) Passenger	236,855	9.6%
Airbus A321	184,861	7.5%
Airbus A319	128,711	5.2%
Boeing 737-900 Passenger	79,231	3.2%
Airbus A330-300	62,412	2.5%
Boeing 737 Passenger	61,831	2.5%
Airbus Industrie A321 (Sharklets)	52,711	2.1%
Boeing 757 (Passenger)	51,842	2.1%
Airbus A330	31,918	1.3%
Boeing 777-300ER Passenger	29,063	1.2%
Boeing 777 Passenger	28,299	1.2%
Airbus A330-200	28,051	1.1%
Boeing (douglas) MD-80	25,382	1.0%
Boeing 737-700 Passenger	24,467	1.0%
Boeing 777-200/200ER Passenger	24,202	1.0%
Boeing 737-300 (winglets) Passenger	23,804	1.0%
Boeing 767-300 Passenger	23,149	0.9%
Canadair Regional Jet 900	20,439	0.8%
Boeing 757-300 Passenger	16,963	0.7%
Embraer 190	16,810	0.7%
Boeing 737-300 Passenger	15,654	0.6%
Boeing 777-300 Passenger	15,383	0.6%
Airbus A320 (sharklets)	14,277	0.6%
Canadair Regional Jet 700	13,929	0.6%
Boeing 737-900 (winglets) Passenger	13,461	0.5%
Embraer 175	13,167	0.5%
Airbus A300-600 Passenger	12,878	0.5%
Boeing 757-200 Passenger	11,922	0.5%
Boeing 767 Passenger	9,930	0.4%
Airbus A318 /319 /320 /321	9,835	0.4%
Embraer 175 (Enhanced Winglets)	8,799	0.4%
Boeing 787-8	8,762	0.4%
Embraer 170	8,673	0.4%
Boeing 787	8,496	0.3%
Boeing (douglas) MD-90	8,422	0.3%
Boeing 737-400 Passenger	8,162	0.3%
Boeing 747 (Passenger)	7,909	0.3%

Table 5: Most relevant aircraft models and market share for long haul passenger transport

Aircraft model	Passenger transport (million passenger.kms)	Share of top aircraft models passenger.kms
Boeing 777-300ER Passenger	291,877	14.7%
Airbus A330-200	204,056	10.3%
Airbus A330-300	195,622	9.8%
Boeing 777 Passenger	126,225	6.4%
Airbus A380-800 Passenger	118,780	6.0%
Boeing 787-8	92,637	4.7%
Boeing 747-400 (Passenger)	91,708	4.6%
Boeing 777-200/200ER Passenger	81,132	4.1%
Airbus A330	69,856	3.5%
Boeing 777-300 Passenger	63,217	3.2%
Airbus A340-300	61,307	3.1%
Boeing 767-300 Passenger	60,355	3.0%
Boeing 787	47,896	2.4%
Boeing 787-9	45,882	2.3%
Boeing 767 Passenger	41,659	2.1%
Boeing 737-800 Passenger	38,023	1.9%
Boeing 767-300 (winglets) Passenger	31,388	1.6%
Boeing 777-200LR	29,885	1.5%
Airbus A320	24,677	1.2%
Boeing 737-800 (winglets) Passenger	24,148	1.2%
Boeing 757 (Passenger)	23,405	1.2%
Airbus A340-600	22,410	1.1%
Boeing 757-200 Passenger	22,115	1.1%
Airbus A310-300 Passenger	21,210	1.1%
Boeing 747-400 (Mixed Configuration)	18,268	0.9%
Boeing 757-200 (winglets) Passenger	14,938	0.8%
Boeing 767-400 Passenger	14,936	0.8%
Airbus Industrie A350-900	13,074	0.7%
Airbus A340-500	12,999	0.7%
Boeing 747 (Passenger)	12,404	0.6%
Boeing 737-900 Passenger	11,212	0.6%
Airbus Industrie A321 (Sharklets)	10,091	0.5%
Airbus A300-600 Passenger	9,945	0.5%
Airbus A321	9,539	0.5%
Airbus Industrie A380 Passenger	7,435	0.4%
Boeing 737-900 (winglets) Passenger	7,362	0.4%
Boeing 737-700 (winglets) Passenger	4,080	0.2%
Airbus A319	3,957	0.2%
Boeing 757-300 Passenger	3,524	0.2%
Airbus A318 /319 /320 /321	3,466	0.2%

Table 6: Most relevant aircraft models and market share for very short haul belly-freight transport

Aircraft model	Freight transport (million tonne.kms)	Share of top aircraft models tonne.kms
Airbus A320	2,785	42.0%
Airbus A319	985	14.8%
Boeing 737-800 Passenger	778	11.7%
Canadair Regional Jet	290	4.4%
Embraer 195	233	3.5%
ATR 72	164	2.5%
Airbus A330-200	151	2.3%
Airbus A321	131	2.0%
Airbus A330-300	92	1.4%
Canadair Regional Jet 700	84	1.3%
Boeing 777-300ER Passenger	77	1.2%
Embraer 190	60	0.9%
DHvilld-Bombardier DHC8 Dsh 8-400/8Q	59	0.9%
Boeing 717-200	52	0.8%
Boeing 737-500 Passenger	52	0.8%
Boeing (douglas) MD-80	50	0.8%
Boeing 767 Passenger	48	0.7%
Boeing 737-400 Passenger	44	0.7%
Airbus A330	43	0.6%
Airbus A318	43	0.6%
Boeing 767-300 Passenger	42	0.6%
Boeing 757 (Passenger)	40	0.6%
Fokker 100	39	0.6%
Boeing 777-200/200ER Passenger	37	0.6%
Boeing 777-300 Passenger	36	0.5%
Boeing 737-900 Passenger	33	0.5%
Boeing 777 Passenger	28	0.4%
DHvilld-Bombardier DHC8 Dsh 8	27	0.4%
Boeing 747-400 (Passenger)	23	0.3%
Fokker 70	23	0.3%
Boeing (douglas) MD-83	17	0.3%
Embraer 170	17	0.3%
Embraer 175	12	0.2%
Airbus A310 Passenger	12	0.2%
Boeing 737-800 (winglets) Passenger	12	0.2%
Boeing 757-300 Passenger	5	0.1%
DHvilld-Bombardier DHC8-200 Dsh 8/8Q	4	0.1%
Boeing 737-400 (Mixed Configuration)	4	0.1%
Embraer 120 Brasilia	4	0.1%

Table 7: Most relevant aircraft models and market share for short haul belly-freight transport

Aircraft model	Freight transport (million tonne.kms)	Share of top aircraft models tonne.kms
Airbus A320	8,119	54.5%
Airbus A319	1,914	12.8%
Boeing 737-800 Passenger	1,164	7.8%
Airbus A330-300	303	2.0%
Airbus A330-200	253	1.7%
Airbus A321	249	1.7%
Embraer 195	248	1.7%
Canadair Regional Jet	241	1.6%
Boeing 777-300ER Passenger	239	1.6%
Airbus A330	188	1.3%
Boeing (douglas) MD-80	180	1.2%
Canadair Regional Jet 700	153	1.0%
Boeing 757 (Passenger)	149	1.0%
Boeing 737-400 Passenger	148	1.0%
Boeing 767-300 Passenger	135	0.9%
Boeing 777-300 Passenger	131	0.9%
Boeing 777-200/200ER Passenger	116	0.8%
Fokker 100	98	0.7%
Boeing 737-500 Passenger	94	0.6%
Boeing 717-200	75	0.5%
Boeing 767 Passenger	72	0.5%
Embraer 190	61	0.4%
Boeing 737-800 (winglets) Passenger	58	0.4%
Boeing 737-900 Passenger	57	0.4%
Boeing 777 Passenger	57	0.4%
Boeing 737-900 (winglets) Passenger	50	0.3%
Embraer 175	42	0.3%
ATR 72	41	0.3%
Boeing 747-400 (Passenger)	39	0.3%
Embraer 170	32	0.2%
Boeing (douglas) MD-83	26	0.2%
Boeing 737 Passenger	23	0.2%
Airbus A310 Passenger	22	0.1%
Boeing 777-200LR	22	0.1%
DHvilld-Bombardier DHC8 Dsh 8-400/8Q	21	0.1%
Boeing 787	20	0.1%
Airbus A300-600 Passenger	20	0.1%
Boeing 737-700 (winglets) Passenger	18	0.1%
Boeing (douglas) MD-82	18	0.1%

Table 8: Most relevant aircraft models and market share for medium haul belly-freight transport

Aircraft model	Freight transport (million tonne.kms)	Share of top aircraft models tonne.kms
Airbus A320	19,766	48.6%
Airbus A319	3,706	9.1%
Boeing 737-800 Passenger	1,820	4.5%
Airbus A330-300	1,638	4.0%
Boeing 777-300ER Passenger	1,379	3.4%
Airbus A330-200	1,317	3.2%
Boeing 757 (Passenger)	1,223	3.0%
Airbus A321	1,059	2.6%
Airbus A330	932	2.3%
Boeing 777-300 Passenger	789	1.9%
Boeing 767-300 Passenger	675	1.7%
Boeing 777 Passenger	569	1.4%
Boeing 737-800 (winglets) Passenger	537	1.3%
Boeing 747-400 (Mixed Configuration)	439	1.1%
Airbus A300-600 Passenger	430	1.1%
Boeing (douglas) MD-80	350	0.9%
Boeing 777-200/200ER Passenger	337	0.8%
Boeing 737 Passenger	314	0.8%
Boeing 767 Passenger	291	0.7%
Boeing 747 (Passenger)	288	0.7%
Boeing 737-900 (winglets) Passenger	283	0.7%
Embraer 195	263	0.6%
Boeing 767-300 (winglets) Passenger	215	0.5%
Airbus A380-800 Passenger	188	0.5%
Boeing 757-200 Passenger	184	0.5%
Boeing 737-900 Passenger	168	0.4%
Boeing 737-700 (winglets) Passenger	144	0.4%
Canadair Regional Jet 700	143	0.4%
Boeing 737-400 Passenger	143	0.4%
Boeing 757-300 Passenger	140	0.3%
Boeing 777-200LR	130	0.3%
Boeing 737-500 Passenger	124	0.3%
Boeing 757-200 (winglets) Passenger	111	0.3%
Airbus A310-300 Passenger	108	0.3%
Airbus A300B4 /A300C4 /A300F4	104	0.3%
Boeing 747-400 (Passenger)	98	0.2%
Airbus A310 Passenger	88	0.2%
Airbus A340-300	79	0.2%
Boeing 737-300 Passenger	77	0.2%
Boeing 767-400 Passenger	60	0.1%

Table 9: Most relevant aircraft models and market share for long haul belly-freight transport

Aircraft model	Freight transport (million tonne.kms)	Share of top aircraft models tonne.kms
Airbus A330-200	10,850	19.0%
Boeing 777-300ER Passenger	8,328	14.6%
Airbus A330-300	5,015	8.8%
Airbus A380-800 Passenger	4,779	8.4%
Boeing 777 Passenger	3,559	6.2%
Boeing 777-300 Passenger	3,349	5.9%
Boeing 767-300 Passenger	2,454	4.3%
Boeing 777-200/200ER Passenger	2,236	3.9%
Boeing 747-400 (Passenger)	2,154	3.8%
Airbus A330	1,975	3.5%
Boeing 747-400 (Mixed Configuration)	1,922	3.4%
Airbus A340-300	1,654	2.9%
Boeing 767 Passenger	1,223	2.1%
Boeing 767-300 (winglets) Passenger	1,083	1.9%
Airbus A320	1,059	1.9%
Boeing 777-200LR	991	1.7%
Airbus A310-300 Passenger	659	1.2%
Boeing 757 (Passenger)	587	1.0%
Boeing 757-200 Passenger	396	0.7%
Airbus A300-600 Passenger	332	0.6%
Airbus A340-600	315	0.6%
Boeing 747 (Passenger)	308	0.5%
Boeing 767-400 Passenger	257	0.5%
Boeing 737-800 (winglets) Passenger	253	0.4%
Boeing 757-200 (winglets) Passenger	243	0.4%
Boeing (douglas) MD-11 Passenger	213	0.4%
Airbus Industrie A380 Passenger	128	0.2%
Airbus A319	128	0.2%
Boeing 787	117	0.2%
Boeing 737-800 Passenger	116	0.2%
Boeing 737-900 (winglets) Passenger	95	0.2%
Airbus A310 Passenger	83	0.1%
Airbus A321	42	0.1%
Boeing 757-300 Passenger	39	0.1%

Table 10: Most relevant aircraft models and market share for very short haul dedicated freight transport

Aircraft model	Freight transport (million tonne.kms)	Share of top aircraft models tonne.kms
Boeing 747-400F (Freighter)	278	37.6%
Boeing 767 Freighter	80	10.8%
Boeing 747 (Freighter)	60	8.1%
Airbus A330-200 Freighter	50	6.8%
Boeing (douglas) MD-11 (Freighter)	48	6.5%
Boeing 777-200F Freighter	43	5.8%
Boeing 747-8f (Freighter)	37	5.0%
Boeing 737 (Freighter)	36	4.9%
Boeing 737-300 (Freighter)	21	2.8%
Boeing 757-200PF (Freighter)	19	2.6%
Boeing 777 Freighter	18	2.4%
Boeing 727 (Freighter)	15	2.0%
Airbus A300 (Freighter)	8	1.1%
Airbus A300-600 Freighter	6	0.8%
Airbus A310-300 Freighter	5	0.7%
Boeing 737-400 (Freighter)	4	0.5%
Airbus A330 Freighter	4	0.5%
Boeing (douglas) DC6A /B /C Freighter	3	0.4%
Boeing (Douglas) DC9 Freighter	2	0.3%
Convair 440 /580 /600 /640 (Freighter)	1	0.1%
Canadair Regional Jet Freighter	1	0.1%

Table 11: Most relevant aircraft models and market share for short haul dedicated freight transport

Aircraft model	Freight transport (million tonne.kms)	Share of top aircraft models tonne.kms
Boeing 747-400F (Freighter)	1,017	39.4%
Boeing 747 (Freighter)	268	10.4%
Boeing 747-8f (Freighter)	203	7.9%
Boeing 777-200F Freighter	193	7.5%
Boeing 767 Freighter	192	7.4%
Boeing 757-200PF (Freighter)	124	4.8%
Boeing 777 Freighter	113	4.4%
Boeing 737-300 (Freighter)	76	2.9%
Airbus A310-300 Freighter	66	2.6%
Airbus A330 Freighter	59	2.3%
Boeing 737 (Freighter)	55	2.1%
Airbus A330-200 Freighter	54	2.1%
Airbus A300 (Freighter)	52	2.0%
Boeing (douglas) MD-11 (Freighter)	44	1.7%
Boeing 727 (Freighter)	32	1.2%
Boeing 737-400 (Freighter)	18	0.7%
Airbus A300-600 Freighter	8	0.3%
Boeing (Douglas) DC9 Freighter	3	0.1%

Table 12: Most relevant aircraft models and market share for medium haul dedicated freight transport

Aircraft model	Freight transport (million tonne.kms)	Share of top aircraft models tonne.kms
Boeing 747-400F (Freighter)	5,149	38.0%
Boeing 747 (Freighter)	1,856	13.7%
Boeing 747-8f (Freighter)	1,433	10.6%
Boeing 767 Freighter	1,133	8.4%
Airbus A330-200 Freighter	1,033	7.6%
Boeing (douglas) MD-11 (Freighter)	749	5.5%
Boeing 777-200F Freighter	633	4.7%
Airbus A330 Freighter	338	2.5%
Airbus A310-300 Freighter	262	1.9%
Airbus A300 (Freighter)	219	1.6%
Boeing 727 (Freighter)	190	1.4%
Airbus A300-600 Freighter	161	1.2%
Boeing 757-200PF (Freighter)	158	1.2%
Boeing 777 Freighter	130	1.0%
Boeing 737 (Freighter)	42	0.3%
Boeing 737-300 (Freighter)	37	0.3%
Boeing 767-200 Freighter	20	0.1%
Boeing 737-400 (Freighter)	8	0.1%

Table 13: Most relevant aircraft models and market share for long haul dedicated freight transport

Aircraft model	Freight transport (million tonne.kms)	Share of top aircraft models tonne.kms
Boeing 747-400F (Freighter)	17,806	35.2%
Boeing 777-200F Freighter	8,856	17.5%
Boeing 747-8f (Freighter)	8,036	15.9%
Boeing 747 (Freighter)	7,452	14.7%
Boeing 777 Freighter	2,898	5.7%
Boeing (douglas) MD-11 (Freighter)	2,712	5.4%
Airbus A330-200 Freighter	1,204	2.4%
Airbus A330 Freighter	793	1.6%
Boeing 767 Freighter	560	1.1%
Airbus A310-300 Freighter	94	0.2%
Boeing (douglas) DC10 (Freighter)	62	0.1%
Boeing 727 (Freighter)	37	0.1%
Boeing 767-300 Freighter	33	0.1%
Airbus A300-600 Freighter	33	0.1%
Boeing 757-200PF (Freighter)	32	0.1%
Boeing 737 (Freighter)	27	0.1%

2 Aircraft production

2.1 Introduction to aircraft production

2.1.1 Introduction to global aircraft production

The aircraft production industry is dominated by Airbus and Boeing (Datamonitor, 2008, Pearlstein, 2018), who have recently bought out or are in the process of buying out rivals, such as Bombardier and Embraer (Pearlstein, 2018). Together these manufacturers delivered 1,436 (688 for Airbus and 748 for Boeing) commercial aircraft during 2016 (Airbus, 2018, Boeing, 2018).

2.1.2 Aircraft production data

The nature of the aircraft production industry and the limited number of industrial players has meant that data on the composition of aircraft is typically considered confidential information and as such, any data or even estimates of this are difficult to obtain (Lopes, 2010, Jemiolo, 2015). As such, a recent journal article (based off the Jemiolo (2015) thesis) was used as the source for information on empty operating weights (OEWs), material breakdown, maximum seating capacities and lifetime distances (Cox et al., 2018). This article combined available information from manufacturers and online sources to estimate:

- The material breakdown of aircraft (in terms of aluminium, titanium, nickel, steel and composite material percentage of OEW) for each year since 1970;
- The OEWs, maximum seating capacities, body type (regional, narrow or wide bodied) and production period for each aircraft model produced since 1970; and

- The maximum seating capacity and lifetime flight distance for each aircraft size category (regional, small narrow bodied, large narrow bodied, small wide bodied and large wide bodied).

This complete set of information is presented as supporting information to the journal article (Cox et al., 2018).

Using this information and the market share of the various aircraft models (see Table 2 to Table 13) the weighted average aircraft for each transport segment and haulage distance was calculated. This information is presented Table 14, Table 15 and Table 16.

This calculation involved matching each aircraft listed in the market share tables with the correlating aircraft in the data presented by Cox et al. (2018). In certain cases a direct match could not be made and for these an applicable aircraft model (as listed in the by Cox et al. (2018) data tables) was chosen (e.g. the market share tables had both "Boeing 737-900" and "Airbus A318/319/320/321" as aircraft models and these were matched to "Boeing 737-800" and "Airbus A319" in the Cox et al. (2018) data). The material composition of each aircraft model was calculated as the average of the material composition for the first and last years of production (or current material composition for aircraft that are still manufactured). The aircraft models were also matched to an applicable aircraft size category using the body type and maximum seating capacities of each size category. This was used to determine the lifetime flight distance of each aircraft model.

Table 14: Weighted average passenger aircraft

Flight type	OEW (tonnes)	Percentage composition					Maximum seats	Lifetime distance (million km)
		Al	Ti	Ni	Steel	Composite		
Very short haul	38.3	57%	4.7%	2.4%	11.6%	24%	163	49
Short haul	43.1	58%	4.7%	2.4%	11.6%	24%	184	51
Medium haul	52.4	57%	4.7%	2.4%	11.6%	24%	221	55
Long haul	134.9	57%	4.7%	2.4%	11.6%	25%	457	94
Unspecified length	78.0	57%	4.7%	2.4%	11.6%	24%	291	67

Table 15: Weighted average belly-freight aircraft

Flight type	OEW (tonnes)	Percentage composition					Maximum seats	Lifetime distance (million km)
		Al	Ti	Ni	Steel	Composite		
Very short haul	46.6	58%	4.7%	2.4%	11.6%	24%	191	52
Short haul	50.5	58%	4.7%	2.4%	11.6%	23%	204	54
Medium haul	65.3	59%	4.7%	2.3%	11.7%	22%	251	61
Long haul	142.2	57%	4.7%	2.4%	11.6%	24%	479	96
Unspecified length	99.2	58%	4.7%	2.4%	11.6%	23%	351	77

Table 16: Weighted average dedicated freight aircraft

Flight type	OEW (tonnes)	Percentage composition					Maximum seats	Lifetime distance (million km)
		Al	Ti	Ni	Steel	Composite		
Very short haul	137.8	67%	4.4%	1.8%	12.2%	14%	500	99
Short haul	145.0	67%	4.4%	1.8%	12.2%	14%	530	103
Medium haul	150.6	67%	4.4%	1.8%	12.2%	14%	545	105
Long haul	167.7	66%	4.5%	1.9%	12.1%	16%	605	112
Unspecified length	163.1	66%	4.5%	1.9%	12.1%	15%	589	110

It may be noted that larger, heavier aircraft are favoured for use as dedicated freights and for longer haulage distances.

2.2 Modelling approach

Global aircraft production has up until this time been modelled as two datasets, namely "*aircraft production, long haul*" and "*aircraft production, medium haul*", which only differentiated the production of aircraft based on haulage distance. However, as presented above, the aircraft used for different transport segments and for different haulage distances vary considerable in terms of operating empty weights, percentage compositions, maximum seating capacities and lifetime distances. Therefore, due to the large differences between the different categories, and to match the 15 transport dataset categories, it was decided to disaggregate aircraft production into the datasets listed in Appendix 1.

2.2.1 System boundaries

The aircraft production process starts from obtaining the material inputs required for construction.

The aircraft production process ends with the production of one aircraft. The dataset includes the materials (aluminium, titanium, nickel, steel and composite material), energy (electricity and heat), kerosene (for aircraft testing) and water used in the production. Emissions of VOCs from aircraft manufacturing and painting processes are also included. The material requirements for and emissions from the production of composite materials are included via an input of carbon fibre reinforced plastic.

The dataset does not included information on the electronics or interior materials (plastics, textiles etc.) used for production due to a lack of available information (as discussed in Section 2.1.2).

2.2.2 Material use

Material use for aircraft production was calculated from the OEWs and material composition of the average aircraft in each category (Table 14, Table 15 and Table 16). Composite material was modelled in a separate dataset, as discussed below, and linked as an input exchange.

2.2.2.1 Composite material

Carbon fibre reinforced plastic (CFRP) is a structural material formed from extremely thin carbon fibres in a polymeric matrix. The composite has high tensile strength, low thermal expansion and a very high strength-to-weight ratio. These properties have made it an important structural material that is widely used in the aircraft manufacturing industry (Uhlmann et al., 2014, Pramanik et al., 2017).

As such, the composite material used for aircraft manufacture was modelled as a separate dataset, entitled "*carbon fibre reinforce plastic, injection moulded*", based on the dataset presented as supplementary data by Cox et al. (2018).

This data presented by Cox et al. (2018) included the material and energy required for the production of carbon fibres, along with the waste and emissions associated with production. The transformation of these fibres into the composite material was also considered. This data is presented in Table 17.

Table 17: Requirements for the production of 1 kilogram of carbon fibre reinforced plastic

Item	Units	Value
Materials required		
Organic chemicals	kg	0.03
Acrylonitrile	kg	2.31
Energy required		
Heat	MJ	237.3
Electricity	kWh	58.4
Processing required		
Injection moulding	kg	1
Emissions and waste		
Chemical oxygen demand	kg	4.62e-5
Carbon dioxide	kg	3.14
Waste heat	MJ	756
Waste (modelled as waste asphalt)	kg	0.23

2.2.3 Production consumable and energy use

Production water and energy use was calculated from data on Airbus' European manufacturing facilities (Airbus, 2017). The breakdown of the total energy use in manufacturing into different fuels and electricity was based on data for Airbus internationally (Airbus, 2016).

The water and energy use was converted to a per seat value using the total number of seats produced in the year (158,775), which was calculated from the total number of planes delivered (688) (Airbus, 2017) and the average number of seats per aircraft. The average number of seats per plane was calculated from available aircraft model delivery data (545 A320 family, 49 A350 family and 28 A380 family deliveries (Airbus, 2016)) and the maximum seating capacity of aircraft models (Cox et al., 2018). This data is presented in Table 18.

Table 18: Water and energy use for production

	Units	Total use	Units for per seat value	Per seat use
Total energy	MWh	1,496,842	MWh/seat	9.43
Electricity	MWh	558,564	MWh/seat	3.52
Stationary fuels	MWh	536,430	MWh/seat	3.38
Natural gas	MWh	513,388	MWh/seat	3.23

Stationary fuels other than natural gas	MWh	15,124	MWh/seat	0.10
Mobile fuels	MWh	401,848	MWh/seat	2.53
Jet fuel	MWh	389,639	MWh/seat	2.45
Water consumed	m^3	1,366,154	m^3/seat	8.60

Total water and energy use was calculated from the per seat value using the maximum seating capacity of each average aircraft (Table 14, Table 15 and Table 16).

2.2.4 Production waste and emissions

Waste water discharge and volatile organic compound (VOC) emissions were calculated from data on Airbus' European manufacturing facilities (Airbus, 2017). The values were converted to a per seat value as for the production water and energy use values (Section 2.2.4).

Table 19: Waste water discharge and VOC emissions from production

	Units	Total use	Units for per seat value	Per seat use
Waste water discharge	m^3	153,061	m^3/seat	0.96
VOC emissions	tonnes	988	kg/seat	6.22

Total wastewater discharge and VOC emissions were calculated from the per seat value using the maximum seating capacity of each average aircraft (Table 14, Table 15 and Table 16).

Remaining water discharge (i.e. total water use minus wastewater discharge) was assumed to be emitted to air through evaporation and to surface water. It was assumed that 10% of this water was emitted to air through evaporation.

All solids (aluminium, titanium, nickel, steel and carbon fibre reinforced plastic) used in construction were assumed to be scrapped at aircraft end-of-life.

2.2.5 Transport performance

The total transport performances of the average aircrafts were calculated using the lifetime kilometric performances (Table 14, Table 15 and Table 16) and the associated average load factors. The average load factors were calculated for the various transport segments as follows:

- Passenger transport: Passenger loading was determined from the maximum number of seats and a passenger load factor of 80% (ICAO, 2016). The total mass per passenger (passenger and luggage) was set at 105 kg (EASA, 2009).
- Belly-freight transport: Passenger loading was determined from the maximum number of seats and a passenger load factor of 80% (ICAO, 2016). The total passenger load was calculated using a passenger weight of 105 kg/occupied seat (EASA, 2009) and this was assumed to equal 86% of the total load (see 1.1.2).
- Dedicated freight transport: FFligth specific freight loading was taken from oag 2016.

The total transport performance of each aircraft is presented in Table 20, Table 21 and Table 22.

Table 20: Passenger aircraft transport performance

	Very short haul	Short haul	Medium haul	Long haul	Unspecified distance
Kilometric performance (million km / vehicle)	49	51	55	94	67
Average number of passengers	131	147	177	366	233
Passenger performance (passenger.km / vehicle)	6.4E+09	7.5E+09	9.7E+09	3.4E+10	1.6E+10

Table 21: Belly-freight aircraft transport performance

	Very short haul	Short haul	Medium haul	Long haul	Unspecified distance
Kilometric performance (million km / vehicle)	52	54	61	96	77
Average number of passengers	152	163	201	383	281
Average freight load (tonnes)	2.6	2.8	3.4	6.6	4.8
Freight performance (tonne.km / vehicle)	1.4E+08	1.5E+08	2.1E+08	6.3E+08	3.7E+08

Table 22: Dedicated freight aircraft transport performance

	Very short haul	Short haul	Medium haul	Long haul	Unspecified distance
Kilometric performance (million km / vehicle)	99	103	105	112	110
Average freight load (tonnes)	42.0	44.5	45.8	50.8	49.5
Freight performance (tonne.km / vehicle)	4.2E+09	4.6E+09	4.8E+09	5.7E+09	5.4E+09

2.2.6 Production volumes

The annual production volumes of the aircraft in each category cannot be directly determined from available information, as aircraft are used for various categories throughout their lifetime. The production volumes were therefore estimated using the total annual transport values (passenger.kms or tonne.kms) and the lifetime transport performance (passenger.kms or tonne.kms) of the various aircraft types. These production volumes are presented in Table 23.

Table 23: Aircraft production volumes

	Very short haul	Short haul	Medium haul	Long haul	Unspecified distance
Passenger aircraft	72	122	254	58	373
Belly-freight aircraft	49	98	193	90	324
Dedicated freight aircraft	0.2	1	3	9	12

It may be noted that summing the production volumes for the four haulage categories results in a total production volume of 949 aircraft. During 2016, Airbus and Boeing delivered 1,436 (688 for Airbus and 748 for Boeing) commercial aircraft (Airbus, 2018, Boeing, 2018).

2.2.7 Uncertainty

The production datasets are based on global air transport data, with the material of construction data based on a comprehensive study of aircraft production between 1970 and present. As such, the material of construction data is representative of global production and a lognormal distribution with a pedigree matrix of 2, 1, 1, 1, 1 was applied to these exchanges. Production consumables, energy use and emissions are based on data from one manufacturer's European facilities data. As such, these exchanges do not represent the entire global production industry and are representative of only the European region. Therefore, a lognormal distribution with a pedigree matrix of 3, 3, 1, 3, 2 was applied to these exchanges.

3 Air transport

3.1 Introduction to air transport

As discussed above, global air transport accounts for 170,508 million tonne.kms and 6,008,120 million passenger.kms annually (Table 1). Currently approximately 64% and 57% of airfreight tonne.kms are transported by belly-freight aircraft and over long distance haulage respectively, while only 33% of passenger.kms are due to long distance haulage. A detailed description of how information on global air transport was calculated is presented in Section 1.1.2.

Differences in transport segment and haulage distance impact the types of aircraft used and therefore the fuel usage and emissions generated (EcoTransIT, 2016, OAG, 2016, EEA, 2017). Furthermore, the haulage distance impacts the percentage of flights spent in take-off and descent, which impacts the average fuel use, emissions and location of emissions generated by aircraft transport (EcoTransIT, 2016, eurocontrol, 2018).

3.2 Modelling approach

The transport of freight by air travel has up until this time been modelled by two datasets, namely "*transport, freight, aircraft, intercontinental*" and "*transport, freight, aircraft, intracontinental*", which only differentiated aircraft freight transport based on haulage distance. However, as presented above there are large variances in the transport performances and aircraft used for different transport segments and haulage distances. As such it was decided to disaggregate air transport into 15 datasets, as listed in Appendix 1.

3.2.1 System boundaries

The datasets developed followed the modelling approach of the existing air transport datasets in ecoinvent i.e. they are divided into three components:

- Aircraft operation: This component contains all processes that are directly connected with the operation of the aircraft;
- Aircraft equipment: Aircraft equipment contains the processes that are connected with vehicle life cycle (other than operation), including manufacturing and disposal.

No maintenance processes are included as this information is not available and could not be sourced;

- Aircraft infrastructure: Comprising airport construction, maintenance and disposal.

Aircraft operation and equipment datasets are updated in this project. Aircraft infrastructure is not updated and uses the existing ecoinvent dataset, as insufficient data and resources were available to update this dataset.

The air transport process starts with the demand for construction of an aircraft and the consumption of fuel. The scope of the dataset includes the operation of the aircraft, with the production of the aircraft and the airport facilities contained in linked datasets.

The air transport process ends with the service of transporting one tonne of freight over a distance of one kilometre (for freight transport datasets) or one passenger over a distance of one kilometre (for passenger transport datasets). The dataset includes the operation of the aircraft, production of the aircraft and construction of the airport. The dataset includes the consumption of fuel, airborne gaseous emissions, particulate emissions and heavy metal emissions. Shares of emissions to the lower and upper part of the atmosphere are taken from the shares of the distances covered in the flight phases below and above 7,315m (FL240).

3.2.2 Allocation between passengers and freight

As discussed above in Section 1.1.2, allocation between freight and passengers was achieved using passenger and freight loading data (OAG, 2016) and a passenger weighting (load of passenger and baggage) of 105 kg (EASA, 2009).

3.2.3 Fuel use and emissions

Fuel consumption and most major emissions (non-methane volatile organic compounds (NMVOCs), methane, sulphur dioxide, particulates, carbon monoxide and nitrogen oxides) were calculated from OAG (2016) data covering 99.5% of all scheduled flights in 2016 and data presented in the *EMEP/EEA air pollutant emission inventory guidebook 2016* (EEA, 2017). Linear regression fits were used to approximate fuel consumption and sulphur dioxide emissions for all plane types, while third-degree polynomials were used to approximate other emissions. The coefficient of determination (R^2) values for the linear regression lines were greater than 0.999, while the values were greater than 0.99 for almost all plane types for the polynomial fit lines. The fuel consumption determined in this manner is presented in Table 24.

Table 24: Fuel use per haulage distance and aircraft category

Haulage distance	Average fuel consumption (kg / tonne.km or kg / passenger.km)		
	Passenger transport	Belly-freight transport	Dedicated freight transport
Very short haul	0.038	0.239	0.034
Short haul	0.031	0.176	0.040
Medium haul	0.026	0.142	0.058
Long haul	0.027	0.114	0.094
Unspecified distance	0.028	0.133	0.076

The differences of the specific fuel consumption between the haulage distance classes is on one hand the result of the decreasing weight of the start and climb phase with increasing flight distance. On the other hand, and much more important, it is due to different plane types being used in different classes. In the case of dedicated freight, these differences even revers the effect of the decreasing specific fuel consumption caused by the lower share of start and climb phase in a long flight.

Carbon dioxide emissions were calculated from fuel consumption and the assumption that all carbon, which makes up 85% by mass, in kerosene is emitted as carbon dioxide (Spielmann et al., 2007). Water vapour emissions were calculated from fuel consumption and the assumption that all hydrogen in kerosene is emitted as water, resulting in an emission factor of 7.65e-6 m^3/kg kerosene (Spielmann et al., 2007)

Heavy metal emissions to air were extrapolated from the previous dataset (Spielmann et al., 2007) on the basis of kerosene consumption.

The shares of emissions to the upper and lower parts of the atmosphere were calculated from the shares of the distance covered in flight phases above and below 7,315 m (FL240). A typical take-off and descent procedure for an Airbus A320 was used to model this distance for all calculations (eurocontrol, 2018). As such, the shares of emissions to the upper and lower atmosphere for each haulage distance are presented in Table 25.

Table 25: Emissions to upper and lower atmosphere by haulage distance

Haulage distance	Mean distance (km)	Fraction of emissions (%)	
		Lower stratosphere and upper troposphere	Non-urban air or from high stacks
Very short haul	504	60%	40%
Short haul	1135	82%	18%
Medium haul	2265	91%	9%
Long haul	6559	97%	3%
Unspecified distance	1496	87%	13%

Formaldehyde, nitrous oxide, methane, ethylene oxide and hydrogen chloride emissions have been removed in the updated inventory because no reliable source could be found to model them. Furthermore, benzene and butadiene are no longer inventoried separately but included in the exchange "NMVOC", because accounting for them individually was deemed too inaccurate.

3.2.4 Demand for equipment

Demand for aircraft is calculated from the relevant aircraft lifetime transport performances, as shown in Table 20, and the applicable allocation factors. The allocation factor for passenger aircraft is calculated from total annual passenger.kms, a passenger weighting of 105 kg (EASA, 2009) and total annual belly-freight tonne.kms. The allocation factor for belly-freight aircraft is based on the fact that 86% of belly-freight load is due to passengers (see Section 1.1.2). This calculation is shown in Table 26, Table 27 and Table 28.

Table 26: Passenger aircraft demand

	Very short haul	Short haul	Medium haul	Long haul	Unspecified distance
Aircraft demand per unit (vehicle / passenger.km)	1.6E-10	1.3E-10	1.0E-10	2.9E-11	6.4E-11
Total passenger transport (passenger.kms)	4.88E+11	9.49E+11	2.56E+12	2.01E+12	6.01E+12
Total passenger transport (tonne.kms)	5.13E+10	9.97E+10	2.69E+11	2.11E+11	6.31E+11
Total belly-freight freight transport (tonne.kms)	6.77E+09	1.52E+10	4.12E+10	5.71E+10	1.20E+11
Allocation factor (%)	88%	87%	87%	79%	84%
Allocated aircraft demand (vehicle / passenger.km)	1.38E-10	1.16E-10	8.96E-11	2.30E-11	5.39E-11

Table 27: Belly-freight aircraft demand

	Very short haul	Short haul	Medium haul	Long haul	Unspecified distance
Aircraft demand per unit (vehicle / tonne.km)	7.3E-09	6.6E-09	4.7E-09	1.6E-09	2.7E-09
Allocation factor (%)	14%	14%	14%	14%	14%
Allocated aircraft demand (vehicle / tonne.km)	1.03E-09	9.26E-10	6.63E-10	2.22E-10	3.81E-10

Table 28: Dedicated freight aircraft demand

	Very short haul	Short haul	Medium haul	Long haul	Unspecified distance
Aircraft demand per unit (vehicle / tonne.km)	2.4E-10	2.2E-10	2.1E-10	1.8E-10	1.8E-10
Allocation factor (%)	100%	100%	100%	100%	100%
Allocated aircraft demand (vehicle / tonne.km)	2.39E-10	2.19E-10	2.09E-10	1.76E-10	1.84E-10

Aircraft maintenance is not included, due to a lack of available data to create a maintenance dataset, although de-icing of aircraft is included in the airport operations.

3.2.5 Demand for infrastructure

The construction, operation, maintenance and disposal of airport facilities are described in a previous global dataset. The dataset is representative of a medium-sized international airport (Zurich) and have not been updated. Airport demand was allocated between passenger and freight transport based on economic revenue data, as shown in Table 29.

Table 29: Zurich airport revenue streams for economic allocation of airport demand (Zurich Airport, 2016)

	Revenue (1000 CHF)	Percentage of revenue directly related to passengers or freight
Passenger related revenue	427,918	98.2%
Passenger charges	235,034	-
Security charges	173,934	-
PRM charges	12,887	-
Check-in	4,265	-
Gate and transfer desk	1,798	-
Freight related revenue	7,675	1.8%
Freight revenue	7,675	-
Aviation revenue related to both passengers and freight	184,809	N/A
Total aviation revenue	**620,402**	**N/A**

Airport demand per passenger or tonne of freight transported was then calculated using operational data (27.7 million passengers and 0.4 million tonnes of freight) for Zurich airport in 2016 (Zurich Airport, 2016). It was assumed that each flight requires two airports and that airports have a 100-year life span (Spielmann et al., 2007). This calculation is shown in Table 30 and Table 31.

Table 30: Airport demand for passenger transport

	Very short haul	Short haul	Medium haul	Long haul	Unspecified distance
Airport passenger capacity (passengers / year)	27,666,428				
Passengers transported (passengers / year)	2,249,049	4,371,461	11,797,834	9,251,307	27,666,428
Allocation (%)	8%	16%	42%	33%	98%
Assumed transport distance (km)	600	1,150	2,750	8,000	3,125
Transport performance (passenger.km / year)	1.35E+09	5.03E+09	3.24E+10	7.40E+10	8.65E+10
Number of airports for each good	2	2	2	2	2
Airport lifetime (years)	100	100	100	100	100
Demand of airport (airport / passenger.km)	1.18E-12	6.17E-13	2.58E-13	8.88E-14	2.27E-13

Table 31: Airport demand for freight transport

	Very short haul	Short haul	Medium haul	Long haul	Unspecified distance
Airport freight capacity (tonnes / year)	433,577				
Freight transported (tonnes / year)	22,466	50,935	142,506	217,494	433,577
Allocation (%)	0.091%	0.207%	0.579%	0.884%	1.763%
Assumed transport distance (km)	600	1,150	2,750	8,000	3,125
Transport performance (tonne.km / year)	1.35E+07	5.86E+07	3.92E+08	1.74E+09	1.35E+09
Number of airports for each good	2	2	2	2	2
Airport lifetime (years)	100	100	100	100	100
Demand of airport (airport / tonne.km)	1.36E-12	7.07E-13	2.96E-13	1.02E-13	2.60E-13

3.2.6 Uncertainty

The transport datasets are based on global flight data and various emission factor sources. Fuel consumption and major emissions (carbon dioxide, water vapour, non-methane volatile organic compounds (NMVOCs), methane, sulphur dioxide, particulates, carbon monoxide and nitrogen oxides) are based on EMEP/EEA data or directly calculated from the stoichiometry of kerosene. This data can therefore be considered temporally, geographically and technologically relevant. As such, a lognormal distribution with a pedigree matrix of 2, 1, 1, 1, 2 was applied to these exchanges.

Heavy metal emissions were extrapolated from the previous global dataset. Uncertainty associated with these emission factors is discussed in detail by Spielmann et al. (2007). As such, the lognormal distribution and associated pedigree matrix applied to the previous dataset was used, with the temporal score updated.

Aircraft demand is based on global flight data and as such a lognormal distribution with a pedigree matrix of 2, 1, 1, 1, 2 was applied to this exchange. Airport demand is based on a single European airport and therefore lacks completeness or geographical context. Therefore a lognormal distribution with a pedigree matrix of 1, 4, 1, 5, 1 was applied to this exchange.

4 Overall modelling approach

The following section describes the temporal, geographical and technological considerations that apply to the various datasets.

4.1 Time and geographical boundaries

The datasets are representative of 2016, as the primary variables (passenger.kms, tonne.kms, aircraft usage and the calculation of kerosene usage) for both the production and operational datasets are derived from data on all scheduled flights in 2016 (OAG, 2016).

The geographical boundaries are global air transport of both freight and passengers. The market share for different aircraft models and operation of aircraft is representative of the global situation, as data covers all scheduled flights globally. Aircraft production is modelled using information on global aircraft weights and material breakdown, although production consumables, energy use and emissions are based on European production site data. Airport infrastructure was not updated and is based off the global dataset. The demand for infrastructure is based on global data, however the dataset itself is derived from data on Zurich international airport.

4.2 Technology level

The datasets are representative of air transport and aircraft production in 2016, as they are derived from global statistics of all scheduled flights for this period. The operational datasets considered the age distribution of the current global aircraft fleet. The production datasets represented current production technology, as they took into account evolving material composition data for aircraft manufacture. This was achieved through averaging the material composition breakdown for the first and last years of aircraft production.

4.3 Activity and markets

The datasets are representative of the production of aircraft and air transport of passengers and freight globally. They should therefore be used in this context. The datasets are averages across all freight types. If the haulage distance is unknown, then the unspecified distance dataset should be used, as this is the weighted average of all distance classes.

4.4 Summary of key parameters

The key parameters for global air freight are presented in Table 32.

Table 32: Summary of key global air freight parameters

Haulage distance	Mean distance (km)	Average fuel consumption (kg / tonne.km or kg / passenger.km)		
		Passenger transport	Belly-freight transport	Dedicated freight transport
Very short haul	504	0.038	0.239	0.034
Short haul	1135	0.031	0.176	0.040
Medium haul	2265	0.026	0.142	0.058
Long haul	6559	0.027	0.114	0.094
Unspecified distance	1496	0.028	0.133	0.076

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6 Appendix 1

Activity name	Geography	Reference product
carbon fibre reinforced plastic, injection moulded	GLO	carbon fibre reinforced plastic
aircraft production, passenger aircraft, very short haul	GLO	aircraft, passenger, very short haul
aircraft production, passenger aircraft, short haul	GLO	aircraft, passenger, short haul
aircraft production, passenger aircraft, medium haul	GLO	aircraft, passenger, medium haul
aircraft production, passenger aircraft, long haul	GLO	aircraft, passenger, long haul
aircraft production, passenger aircraft, unspecified distance	GLO	aircraft, passenger, unspecified distance
aircraft production, belly-freight aircraft, very short haul	GLO	aircraft, belly-freight, very short haul
aircraft production, belly-freight aircraft, short haul	GLO	aircraft, belly-freight, short haul
aircraft production, belly-freight aircraft, medium haul	GLO	aircraft, belly-freight, medium haul
aircraft production, belly-freight aircraft, long haul	GLO	aircraft, belly-freight, long haul
aircraft production, belly-freight aircraft, unspecified distance	GLO	aircraft, belly-freight, unspecified distance
aircraft production, dedicated freight aircraft, very short haul	GLO	aircraft, dedicated freight, very short haul
aircraft production, dedicated freight aircraft, short haul	GLO	aircraft, dedicated freight, short haul
aircraft production, dedicated freight aircraft, medium haul	GLO	aircraft, dedicated freight, medium haul
aircraft production, dedicated freight aircraft, long haul	GLO	aircraft, dedicated freight, long haul
aircraft production, dedicated freight aircraft, unspecified distance	GLO	aircraft, dedicated freight, unspecified distance
transport, passengers, passenger aircraft, very short haul	GLO	transport, passengers, aircraft, very short haul
transport, passengers, passenger aircraft, short haul	GLO	transport, passengers, aircraft, short haul
transport, passengers, passenger aircraft, medium haul	GLO	transport, passengers, aircraft, medium haul
transport, passengers, passenger aircraft, long haul	GLO	transport, passengers, aircraft, long haul
transport, passengers, passenger aircraft, unspecified distance	GLO	transport, passengers, aircraft, unspecified distance
transport, freight, aircraft, belly-freight, very short haul	GLO	transport, freight, aircraft, very short haul
transport, freight, aircraft, belly-freight, short haul	GLO	transport, freight, aircraft, short haul
transport, freight, aircraft, belly-freight, medium haul	GLO	transport, freight, aircraft, medium haul

Activity name	Geography	Reference product
transport, freight, aircraft, belly-freight, long haul	GLO	transport, freight, aircraft, long haul
transport, freight, aircraft, belly-freight, unspecified distance	GLO	transport, freight, aircraft, unspecified distance
transport, freight, aircraft, dedicated freight, very short haul	GLO	transport, freight, aircraft, very short haul
transport, freight, aircraft, dedicated freight, short haul	GLO	transport, freight, aircraft, short haul
transport, freight, aircraft, dedicated freight, medium haul	GLO	transport, freight, aircraft, medium haul
transport, freight, aircraft, dedicated freight, long haul	GLO	transport, freight, aircraft, long haul
transport, freight, aircraft, dedicated freight, unspecified distance	GLO	transport, freight, aircraft, unspecified distance