ZÜRICH AIRPORT

Aircraft Ground Handling Emissions

Methodology and Emission Factors Zurich Airport

Contents

1. Introduction

1.1. Airport emissions

Handling activities related to aircraft during ground time may be a significant contributor to local air pollution at an airport (figure 1). Such activities include all vehicles and machinery serving the aircraft on its parking position (e.g. high loaders, baggage belts, passengers stairs) and circulating on airside operating surfaces and service roads (e.g. lavatory trucks, catering trucks, cargo tractors).

In the context of local air quality management, it is important to assess the emissions of those sources for various pollutants. Such information can be used for goals setting, technology observations, mitigation planning and/or for use in dispersion modelling.

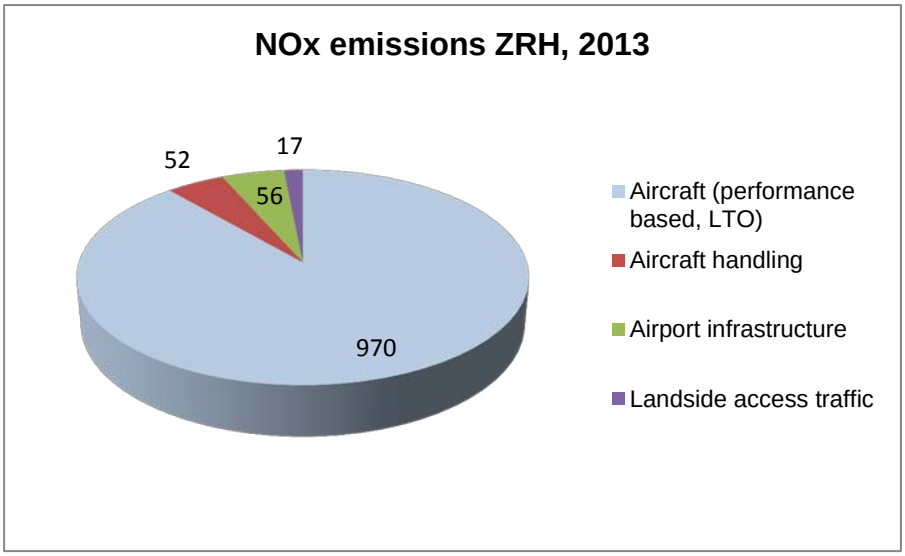

Figure 1 NOx emission by source groups (Zurich airport, 2013, total: 1,094 t),

1.2. Study update

The scope of the initial study in 2006 included the discussion of the developed and applied methodology and the presentation of a set of emission factors. The base year was 2003 and reflected the state of technology at that time.

This current study repeats the description and discussion of the 2003 methodology for better understanding and presents emission factors for both the years 2003 and for 2013.

The methodology discussed is limited to ground handling equipment. Other aircraft or airport related emission calculation methodologies (e.g. for APU, airside vehicle traffic, aircraft and airport maintenance) are well described in ICAO Document 9889 [1] and will only be covered briefly.

2. Characterization of aircraft ground handling

The interdependencies of aircraft ground handling is qualitatively characterised in figure 2.

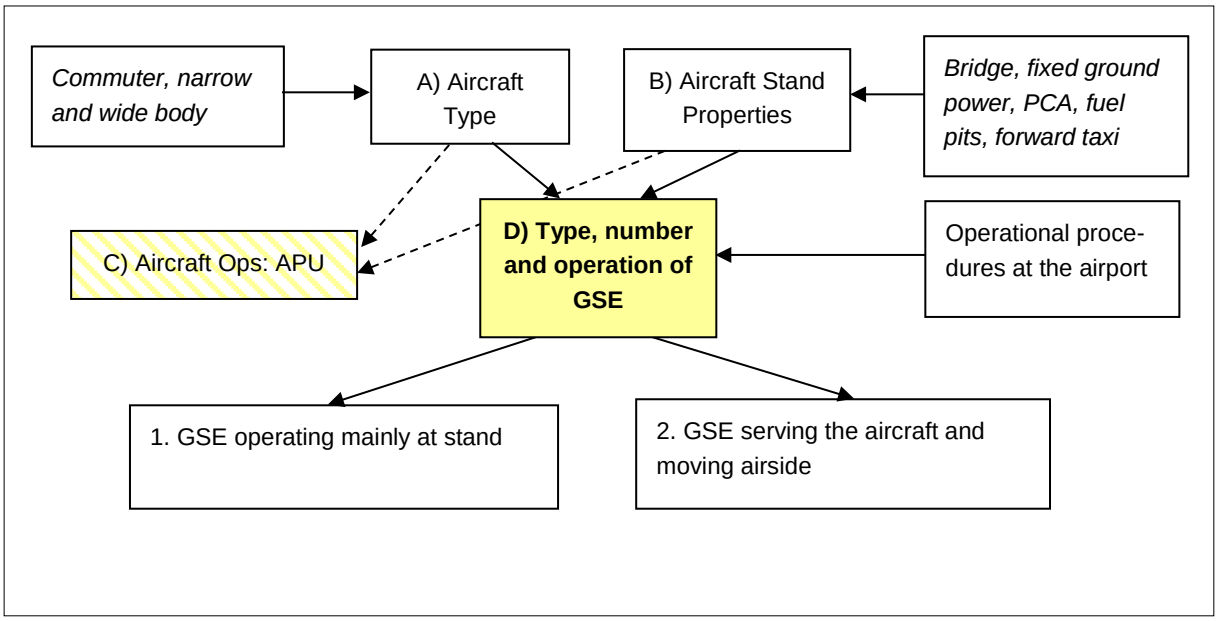

Figure 2 Characterization of GSE

It has to be recognised that the type and number of GSE are determined by the aircraft (size) and the aircraft stand (location and installations) as well as applicable operational procedures at the airport (e.g. APU restrictions). In consequence, any default attribution of ground support equipment must be reflected by all factors.

2.1. Aircraft types (A)

The size of the aircraft influences sometimes the stand allocation and often the handling procedures (number and types of GSE required).

Aircraft-Group	**Handling characterization**
Large and Medium Size Aircraft (B-777, B-747, A340, A380, MD11)	• Passenger Baggage in containers • Large cargo volume • Turn around time could include moving aircraft (day-parking) • APU available
Medium Size Aircraft (A300, A330, B-767, B-787)	• Passenger Baggage in containers • Large cargo volume • Turn around time could include moving aircraft (day-parking) • APU available
Small Aircraft (B-757, B-737, A319-A321, EMB190, CS100)	• Passenger Baggage in containers • Small cargo volume • Short turn around times • APU available
Commuter Aircraft	• Passenger Baggage open

(RJ-85, EMB-145, CL65, CRJ)	• No cargo volume (mail only) • Short turn around times • APU available • Built-in passenger stairs
Business Jets	• Passenger Baggage open • No cargo volume • APU available • Built-in passenger stairs
Turboprop Aircraft (S20, DH8, AT42/72)	• Passenger Baggage open • No cargo volume • Short turn around times • Sometimes no APU available • Built-in passenger stairs
General Aviation Propeller Aircraft	• No Baggage, Cargo, APU, Stairs • Limited handling
General Aviation Helicopter	• No Baggage, Cargo, APU, Stairs • Limited handling

Table 1 Aircraft group characterization

2.2. Aircraft stand (B)

At airports, two types of aircraft stands can be found:

- pier stands where a passenger loading bridge connects the aircraft to the building and
- remote stands where an aircraft is parked free of direct building connections (for passenger and/or cargo operations).

The stands themselves can show considerable differences in terms of place and technical equipment which influence number and operations and thus emissions from GSE. They could also differ for reasons of dedicated usage, e.g. whether a stand is used for cargo aircraft of for passenger aircraft.

Properties	**GSE and Ops Consequences**	**Remarks**
Stand equipped with passenger loading bridge leading to terminal	• Doesn't require passenger stairs;	
Stand equipped with fixed 400 Hz	• Doesn't require GPU; • APU still required for heating/cooling and for main engine start-up	Common on stands with bridge
Additionally equipped with PCA (stationary or through ACU)	• Doesn't require GPU; • APU required for main engine start-up only;	Stationary only together with 400 Hz
Additionally equipped with kerosene pipeline	• Doesn't require refuelling tanker truck;	Common on stands with bridge
Proper layout for self powered break away	• Doesn't require push-back tractor.	Not possible on stands with bridge

Table 2 Properties of aircraft stands

According to these properties there would be in theory 32 different types of stands available at an airport. Actually there are far less, as not all property combinations are possible (e.g. no self powered taxi away with a passenger bridge or no stationary PCA without a stationary 400 Hz). Usually, there are less than 10 aircraft stand types available at all and maybe 4-6 at any given airport.

2.3. Aircraft APU operations (C)

The APU is used on the ground to:

- provide electrical energy to the aircraft systems during ground times (400 Hz, 115V or 28V);
- provide pre-conditioned air (heating or cooling depending on the outside temperature);
- provide bleed air for the start-up of the main engines;

APU don't need to be used as a standard back-up system, although some airlines use the APU as power support for take-off if they operate at max take-off weight and unfavourable meteorological conditions.

APU-Mode	Operations	Alternatives
Idle	--	--
400 Hz	Provides electricity when aircraft is on ground and in operations (e.g. pre-flight)	Mobile (electric or diesel) GPU or stationary system
PCA	Provides pre-conditioned air (cooling or heating) if needed for pre-flight (boarding) or post-flight (disembarking) activities;	Mobile (electric or diesel) GPU, ACU (air climate unit) or stationary system; Electric semi-mobile ACU for open stands are possible;
Bleed air	Provides necessary bleed air to start-up first main engine; 3 minutes ops time is sufficient.	ASU (air starter unit) (very few);

Table 3 APU operations and alternatives

A detailed emission calculation description can be found in the ICAO Doc 9889 [1].

2.4. GSE operations (D)

The considerations as outlined in sections 2.1-2.3 determine largely the operations of the whole of the GSE equipment as a function of the aircraft and stand. Within this, the type, engine and number of the individual GSE and their total actual time of operations for an aircraft turn-around determine the amount of emissions.

3. GSE emission calculation methodology

3.1. Emission methodology flowchart

The following figure shows the relevant static and dynamic elements used to determine the emission factors for aircraft handling.

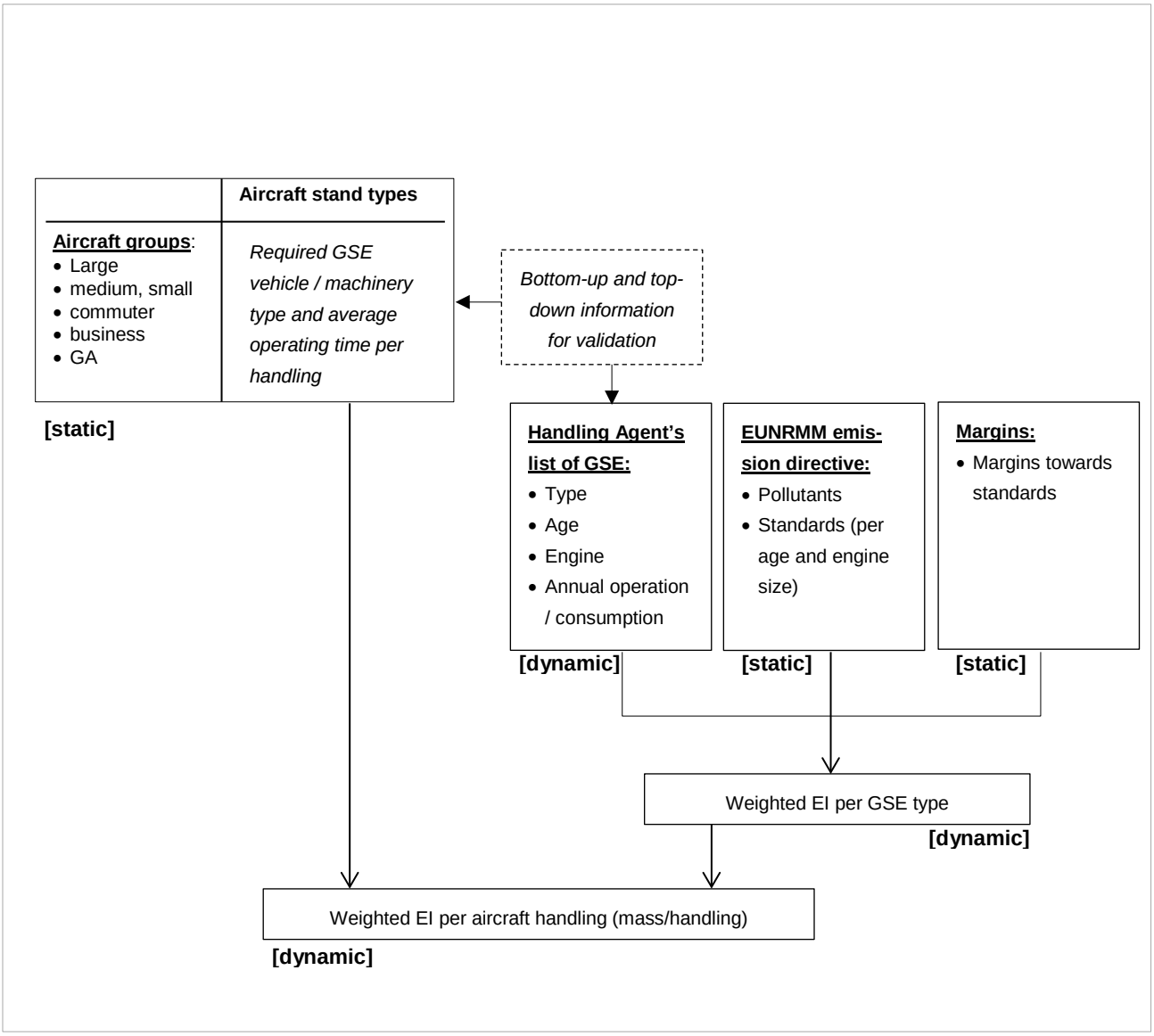

Figure 3 Emission methodology flowchart

3.2. GSE and aircraft handling survey

A detailed survey has been conducted by the handling agents and other service companies at Zurich Airport in May 2004 to obtain all necessary operational data. Aircraft handling operations have been monitored for different aircraft groups and stand types and the GSE usage averaged (minutes per operation).

Aircraft Group	Aircraft Stands
Large Aircraft: from MD-11, B-777, A340	For the stand groups: • pier stands and • remote stands the operating times for each individual GSE piece (cf. Annexe) were monitored (in minutes for handling) per aircraft group and averaged each for: • arrival and • departure handling operations.
Medium Aircraft: up to A330, B-767	
Small Aircraft: up to A321, B-737, B-757, F100	
Commuter: EMB, RJ, CRJ, CL	
Turboprops: Saab, ATR, DHC, Do328	
Business Jets	
General Aviation Propeller Aircraft (Piston and Turboprops)	
General Aviation Helicopters	

Table 4 GSE assignment and operating time survey 2004

A number of approximately 30 different pieces of ground support equipment types have been identified at Zurich airport that serve for handling and servicing aircraft (cf. Annexe).

3.3. Fuel and Emission Factors

The information on the actual GSE fleet is now being obtained from the various handling agents and tenants. This includes the GSE age, engine type and size, and the annual total of operating time and/or fuel consumption.

Emission factors are taken from the initial EC Directive 97/68/EG and all subsequent amendments (the legislative file of Non-Road Mobile Machinery (NRMM) contains today seven directives: the "mother" Directive 97/68/EC**,** the amendments Directive 2002/88/EC, Directive 2004/26/EC, Directive 2006/105/EC, Directive 2010/26/EU, Directive 2011/88/EU, and the last amendment Directive 2012/46/EU) [2].

Further evaluations revealed that emission limits are usually not exhausted by the manufacturers of non-road mobile machinery and that a certain "margin" is being kept. This has been confirmed and assessed by the Federal Office for Environment for the different substances (table 5).

Substance	Emission Reduction Margin
NOx	- 10 %
HC	- 50 %
CO	- 50%
PM	- 20%

Table 5 Margins of emissions towards their respective limit [3]

3.4. Emission calculation

All emissions are calculated per aircraft turn-around, dependent of aircraft group (large, medium, etc) and aircraft stand (pier, remote) and split for arrival handling and departure handling for which the operating times had been derived. This splitting is relevant when linking the handling activities to flight tables where arriving and departing flights don't have the same flight number or arrival and departure are not in a timely sequence (e.g. for night stoppers)[1].

For an individual piece of equipment, the emissions have been calculated as:

$$emission_{substance}\ [g] = engine\ size\ [kW] \times load\ factor\ [\%] \times emission\ factor\ [g/kWh] \times time\ [h] \times margins\ (\%)$$

The availability of annual data is crucial in order to adjust the weighted emission factors, as the GSE database reflects technological improvements, fleet replacements and operational considerations of the handling agents. As such, the weighted emission factor for the handling a specific aircraft group becomes dynamic and improves the quality of the annual emission inventory considerably.

3.5. Operational Data Validation

The validation of this bottom-up approach is done through a simultaneous top-down comparison. From the detailed GSE database, the total of the operating hours (or the distance travelled if it was a vehicle mainly driving) is available for every piece of equipment. Thus the bottom-up total sum of operating hours from the survey has been compared with the total from the GSE database. The findings required some adaptation of the bottom-up times in order to match the database totals.

4. Aircraft handling emission factors

4.1. Application of emission factors

The emission factors represent averages over all operations. They also include handling activities of particular aircraft types or under particular procedures that could be very different from others or from a standard routine approach. Information related to this, however, is usually not available. In order to level this out, every handling cycle is treated equally, using this average emission factors.

The following emission tables relate to Zurich airport and for the study years 2003 and 2013 only, each representing a “technology range”. Emission factors can change by changing handling procedures (different equipment used or different handling times) and changing technology (electric GSE, CNG, latest standards).

It is anticipated that handling operations are similar among comparable airports. Differences are to some degree accounted for by splitting GPU from other GSE, pier from remote stands and arrival and departure operation.

[1] In this report, the emission figures are not split into arrival/departure, but accounted for one turn-around in total

4.2. Emission factor tables 2003

The emission table represents a GSE technology range of approximately 1988-2003.

Pier Stands						
Aircraft group	**Unit**	**NOx**	**HC**	**CO**	**PM**	**CO_2**
Large Aircraft	kg/ac	0.793	0.063	0.267	0.050	n.a.
Medium Aircraft	kg/ac	0.727	0.058	0.243	0.045	n.a.
Small Aircraft	kg/ac	0.316	0.025	0.104	0.019	n.a.
Commuterl Aircraft	kg/ac	0.267	0.021	0.085	0.015	n.a.
Turboprops	kg/ac	0.243	0.020	0.075	0.013	n.a.
Business Jets	kg/ac	-	-	-	-	
GA Propeller Aircraft	kg/ac	-	-	-	-	
Helicopters	kg/ac	-	-	-	-	
Open Stands						
Aircraft group	**Unit**	**NOx**	**HC**	**CO**	**PM**	**CO_2**
Large Aircraft	kg/ac	0.666	0.053	0.232	0.043	n.a.
Medium Aircraft	kg/ac	0.615	0.049	0.213	0.040	n.a.
Small Aircraft	kg/ac	0.251	0.020	0.087	0.016	n.a.
Commuterl Aircraft	kg/ac	0.133	0.011	0.044	0.008	n.a.
Turboprops	kg/ac	0.077	0.007	0.025	0.004	n.a.
Business Jets	kg/ac	0.010	0.001	0.003	0.001	n.a.
GA Propeller Aircraft	kg/ac	0.010	0.001	0.003	0.001	n.a.
Helicopters	kg/ac	0.010	0.001	0.003	0.001	n.a.
GPU	**Unit**	**NOx**	**HC**	**CO**	**PM**	**CO_2**
All aircraft groups	kg/h	0.588	0.046	0.178	0.031	26.14

Table 6 Emission tables 2003

4.3. Emission factor tables 2013

The emission table represents a GSE technology range of approximately 1998-2013.

Pier Stands						
Aircraft group	**Unit**	**NOx**	**HC**	**CO**	**PM**	**CO_2**
Large Aircraft	kg/ac	0.463	0.041	0.197	0.029	43.760
Medium Aircraft	kg/ac	0.452	0.040	0.191	0.029	42.579
Small Aircraft	kg/ac	0.331	0.028	0.125	0.019	27.487
Commuterl Aircraft	kg/ac	0.234	0.020	0.086	0.012	19.819
Turboprops	kg/ac	0.194	0.016	0.070	0.009	17.026
Business Jets	kg/ac	-	-	-	-	-
GA Propeller Aircraft	kg/ac	-	-	-	-	-
Helicopters	kg/ac	-	-	-	-	-
Open Stands						
Aircraft group	**Unit**	**NOx**	**HC**	**CO**	**PM**	**CO_2**
Large Aircraft	kg/ac	0.535	0.046	0.241	0.032	51.272
Medium Aircraft	kg/ac	0.533	0.046	0.240	0.032	50.959
Small Aircraft	kg/ac	0.355	0.029	0.158	0.019	27.044
Commuterl Aircraft	kg/ac	0.130	0.011	0.047	0.007	9.396
Turboprops	kg/ac	0.118	0.010	0.037	0.006	21.807
Business Jets	kg/ac	0.052	0.004	0.016	0.003	17.001
GA Propeller Aircraft	kg/ac	0.052	0.004	0.016	0.003	17.001
Helicopters	kg/ac	0.052	0.004	0.016	0.003	17.001
GPU	**Unit**	**NOx**	**HC**	**CO**	**PM**	**CO_2**
All aircraft groups	kg/h	0.060	0.006	0.025	0.003	19.51

Table 7 Emission tables 2013

5. Ground Support Equipment Emissions

The derived GSE emission factors can be linked to the aircraft movement data table that already contains the size of the aircraft and the gate assignment. The emissions from ground support equipment operated at the various aircraft stands can easily be calculated for the entire time period in question. At the same time, the temporal and spatial information is available as well. This information can serve as input data into dispersion models (e.g. LASPORT[2]) for actual concentration modelling.

6. Airside Traffic Emission Calculation

Airside vehicle road traffic is calculated following the methodology as set out by the Swiss Federal Office for Environment. To facilitate the evaluation, the Agency has produced a software tool that provides vehicle emission factors for Switzerland, Germany and Austria.

To obtain the emission factors in g/km, a number of parameters can be chosen first:

- Choice of emission type: regular emission factors, cold start addition, fuel evaporation (after engine turn-off or while parking);
- Choice of vehicle type: passenger car, delivery van, heavy duty vehicles (as group and/or split by truck, trailer or semi), coaches, public transport busses, motorbike, motorcycles;
- Choice of one or more reference years;
- Choice of substances (pollutants, energy, CO_2);
- Choice of traffic scenario (e.g. "autobahn with speed limit 120 km/h" or "urban area main road with right-away", etc);
- Choice of road segment inclination;
- Choice of parameters influencing evaporation (ambient average temperature);

The programme then calculates the emission factors. The results can be viewed at different levels of detail:

- By vehicle category;
- By vehicle concept: this gives additionally the weighted emission factors for the different vehicle concept (e.g. passenger car + gasoline/catalytic converter or diesel, truck + Euro 2 standard (plus the weighting factor);

In the airport system, the roads are defined (spatial definition) and attributed with a traffic scenario. The number of vehicles of the different categories is added and the emissions calculated through the total distance covered on that road segment and per vehicle type.

[2] www.janicke.de

Annexes

A.1. Emission standards for GSE

Stage	Category	Valid as of	Power	CO (g/kWh)	HC (g/kWh)	NO_x (g/kWh)	PM (g/kWh)
Stage I	A	-/1.10.2001	130 ≤ P ≤ 560	5.0	1.3	9.2	0.54
	B	1.1.2001/1.10.2001	75 ≤ P < 130	5.0	1.3	9.2	0.70
	C	1.1.2001/1.10.2001	37 ≤ P < 75	6.5	1.3	9.2	0.85
Stage II	E	01.2001/02	130 ≤ P ≤ 560	3.5	1.0	6.0	0.2
	F	01.2002/03	75 ≤ P < 130	5.0	1.0	6.0	0.3
	G	01.2003/04	37 ≤ P < 75	5.0	1.3	7.0	0.4
	D	1.1.2001/1.10.2001	18 ≤ P < 37	5.5	1.5	8.0	0.8
Stage IIIA	H	01.2005/06	130 ≤ P ≤ 560	3.5		4.0 ($HC+NO_x$)	0.2
	I	01.2006/07	75 ≤ P < 130	5.0		4.0 ($HC+NO_x$)	0.3
	J	01.2007/08	37 ≤ P < 75	5.0		4.7 ($HC+NO_x$)	0.4
	K	01.2006/07	19 ≤ P < 37	5.5		7.5 ($HC+NO_x$)	0.6
Stage IIIB	L	01.2010/11	130 ≤ P ≤ 560	3.5	0.19	2.0	0.025
	M	01.2011/12	75 ≤ P < 130	5.0	0.19	3.3	0.025
	N	01.2011/12	56 ≤ P < 75	5.0	0.19	3.3	0.025
	P	01.2012/13	37 ≤ P < 56	5.0		4.7 ($THC+NO_x$)	0.025
Stage IV	Q	01.2013/14	130 ≤ P ≤ 560	3.5	0.19	0.4	0.025
	R	01.2013/14	56 ≤ P < 130	5.0	0.19	0.4	0.025

Emission standards for non-road machinery and vehicles. source [2]

A.2. List of Ground Support Equipment at Zurich Airport

Nr.	GSE	Description	Ops Type[3]	Operational Remarks	Engine, load, fuel
1		400 Hz Ground Power Unit	1		105-149 kW; 50% Diesel: 9.1-10.1 l/h
2		Mobile Air Starter/Air Climate Unit	1		150 kW; 50% Diesel: 18-24 l/h
3		Narrowbody towbarless aircraft tug	1		95 kW; 25% Diesel
4		Widebody towbarless aircraft tug	1		400-500 kW; 25% Diesel
5		Aircraft Tug (towbar)	1		95 kW; 25% Diesel
6	Not pictured	Gear mounted pushback tractor	1	Not used in Zurich	
7		Passenger Stairs	1	Open Stands only;	30-65 kW; 25% Diesel
8		Passenger Bus	2	Not attributed to stand emissions, but to airside traffic emissions only.	100 kW Diesel Euro 2 – Euro 5

[3] 1: operates at stand only; 2: operates at aircraft stand and apron (driving around)

Nr.	GSE	Description	Ops Type[3]	Operational Remarks	Engine, load, fuel
9		Crew Bus	2	Not attributed to stand emissions, but to air-side traffic emissions only.	70-90 kW; 25% Diesel Euro 2 – Euro 5
10		Baggage Belt Loader	1		33 kW; 25% Diesel, electric
11		Cargo Loader	1		62 kW; 25% Diesel
12		Cargo Delivery	1		33 kW; 25% Diesel
13		Cargo Loader Main Deck	1	For cargo aircraft main deck only	59 kW; 25% Diesel
14		Catering Truck	2		85-130 kW; 10-25% Diesel
15		Water Truck	2		117 kW; 25% Diesel
16		Lavatory Truck	2		117 kW; 25% Diesel
17		Refuelling Dispenser Truck	2	Stands with fuel pits only;	66-110 kW; 10-50% Diesel

Nr.	GSE	Description	Ops Type[3]	Operational Remarks	Engine, load, fuel
18		GSE / GA Refuelling Truck	2		90 kW; 10-20% Diesel
19		Refuelling Tanker Truck	2	Stands without fuel pits only;	200 kW; 10% Diesel
20		Cabin Cleaning Truck	2		132 kW: 10-60 % Diesel
21		Cabin Cleaning Van	2		61 kW; 10-75% Diesel
22		Cabin Cleaning Vehicle	2		48 kW; 10-75 % Gasoline
23	Not pictured	Generator for Vacuum Cleaner	1		Typ I: 2.2 kW; 80% Gasoline Typ II: 3.5 kW; 80% Gasoline
24		Line Maintenance Truck	2	All stands, all a/c groups; upon request only.	70-120 kW; 25% Diesel
25		Baggage Cart Tractor	2		Electric, CNG
26		Baggage Hall Tractor	1		Electric

Nr.	GSE	Description	Ops Type[3]	Operational Remarks	Engine, load, fuel
27		Cargo Container Tractor	2		53-60 kW; 25% Diesel, electric
28		Large Fork Lift	1	Not a/c related (in cargo facilities)	30-120 kW; 25% Diesel
29		Fork Lift	1	Not a/c related (in cargo facilities)	66 kW; 25% Diesel
30		Aircraft De-icing Truck	2	On stands or de-icing pads with de-icing. Treated as area source, not handling due to very high variability.	184 kW; 25% Diesel
31		Cars	2	Only some are a/c related; considered in airside traffic emissions.	60 kW; 50% Gasoline, diesel, CNG

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A.3. Abbreviations

a/c	Aircraft
ac	Aircraft
ACU	Air climate unit
APU	Auxiliary Power Unit
ASU	Air starter unit
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
EC	European Community
EI	Emission Index
GPU	Ground Power Unit for aircraft
GSE	Ground Support Equipment
HC	Hydrocarbons
Hz	Hertz
ICAO	International Civil Aviation Organization
kWh	Kilo watt hours
LTO	Landing and take-off cycle for aircraft
NOx	Nitrogen oxides
NRMM	non road mobile machinery
PCA	Pre-conditioned air for aircraft
PM	Particulate matter

Figures

Tables

Sources

No.	Document Name
[1]	International Civil Aviation Organisation: Airport Air Quality Manual, Doc. 9889; 1st Edition, 2011
[2]	European Union: Directives 97/68/EC**,** the amendments Directive 2002/88/EC, Directive 2004/26/EC, Directive 2006/105/EC, Directive 2010/26/EU, Directive 2011/88/EU and Directive 2012/46/EU)
[3]	Federal Office for Environment, Air Quality Control: Personal communication, 25. August 2004
[4]	Federal Office for Environment: Handbook Emission Factors (HBEFA), Version 2.1

Version	Date	Name	Modifications
1	March 2006	Fleuti	Original study, published under Unique (Flughafen Zèrich AG)
2	April 2014	Fleuti	Study update and new emission factors

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