

Aircraft Ground Handling Emissions at Zurich Airport

Methodology and Emission Factors



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1 Introduction

1.1 Airport Emissions

Handling in total is usually the second largest contributor to local air pollution at an airport (figure 1-1). It includes emissions from the non moving aircraft (e.g. Auxiliary Power Units, APU), all Ground Support Equipment (GSE, including GPU) for handling aircraft, but also vehicles circulating on airside premises (e.g. sweeper trucks, crew busses, catering trucks, cargo tractors, etc).

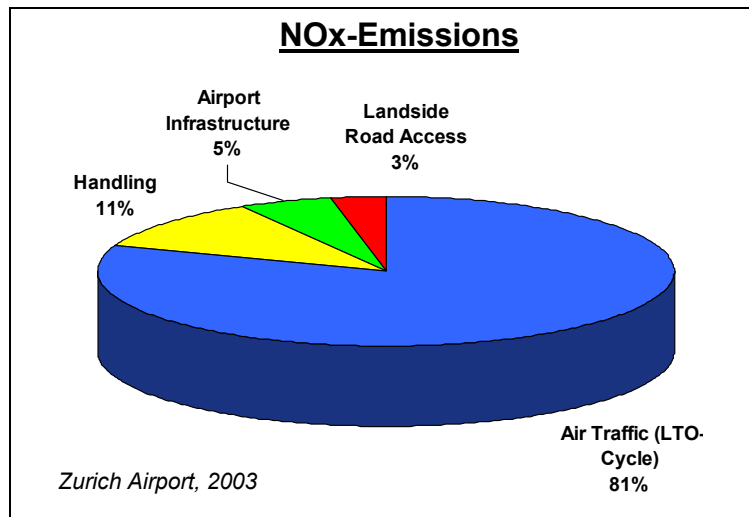


Figure 1-1: Emission Source Groups (based on present methodology¹) with a total of 1,310 t NOx in 2003

1.2 Study Scope

The scope of this study is to present a methodology and emission factors for the emissions of ground handling equipment. Base year is 2003 for Zurich Airport with a total of 269,392 movements, 17.0 millions passengers and 411,500 tons of cargo/airmail.

The methodology discussed is limited to ground handling equipment, i.e. APU are not considered, except for a few explanatory remarks. There are quite some data on APU available today and the emission calculation generally follows the methodology similar as applied for aircraft main engines: $\text{Time}_{\text{Mode}} \times \text{Fuel Flow}_{\text{Mode}} \times \text{Emission Index}_{\text{Mode}}$.

Also airside vehicle traffic is not considered in detail, as again the methodology for emission calculations of moving vehicles has been defined by the Swiss Agency for Environment, Forests and Landscape and proper emission factors provided for passenger cars, delivery vans and heavy duty vehicles. This methodology has always been applied in Zurich airport emission assessments (is it further described in chapter 6).

Finally, equipment for airport maintenance is not considered as well. The number and operation's profile depend to a large degree on the characterisation of the airport itself and is not system representative.

¹ Emissions calculated by total fuel used per type (gasoline, diesel) and average emissions factors that also reflect vehicle type (passenger car, van, heavy duty vehicle).

2 Characterisation of Aircraft Ground Handling

The interdependencies of aircraft ground handling is qualitatively characterised in figure 2-1.

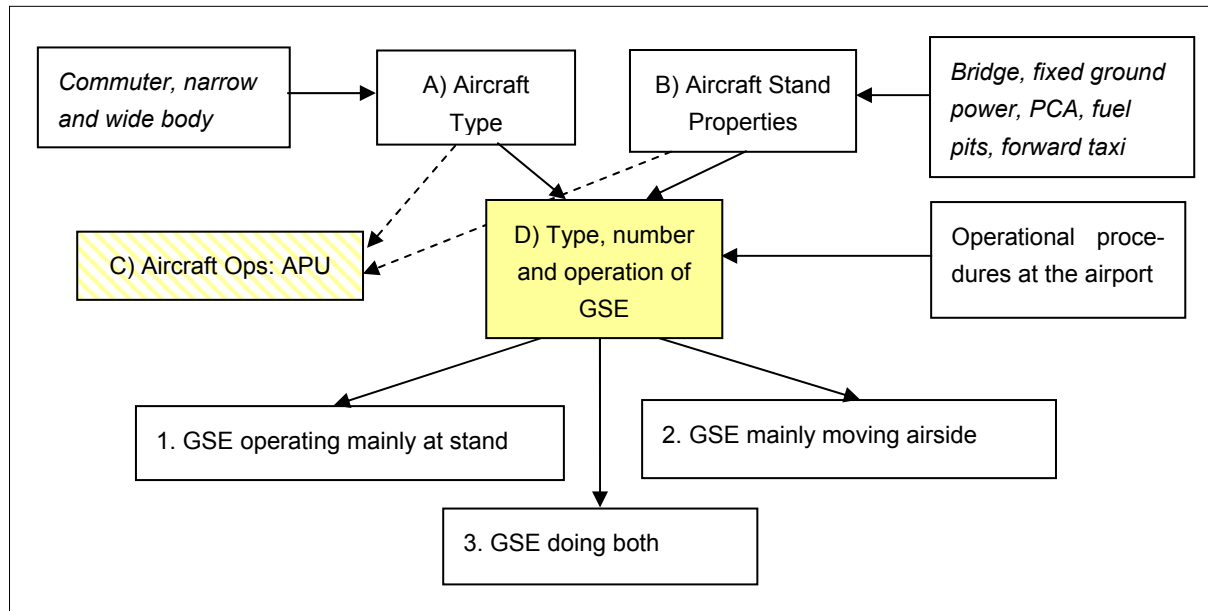


Figure 2-1: Characterisation of GSE.

It has to be recognised that the type and number of GSE are determined by the aircraft and the aircraft stand 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 Type (A)

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

Table 2-1: Aircraft Group Characterisation

Aircraft-Group	Characterisation
Large and Medium Size Aircraft (B-777, B-747, B-767, A340, A330, MD11)	<ul style="list-style-type: none"> • Wide Body, double aisle • 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)	<ul style="list-style-type: none"> • Narrow Body, single aisle • Passenger Baggage in containers • Small cargo volume • Short turn around times • APU available
Commuter Aircraft (RJ-85, EMB-145, CL65)	<ul style="list-style-type: none"> • Narrow Body, single aisle • Passenger Baggage open • No cargo volume (mail only) • Short turn around times • APU available • Built-in passenger stairs

Turboprop Aircraft (S20, DH8, AT42/72)	<ul style="list-style-type: none"> • Narrow Body, single aisle • Passenger Baggage open • No cargo volume • Short turn around times • Sometimes no APU available • Built-in passenger stairs
Business Jets	<ul style="list-style-type: none"> • Narrow Body, single aisle • Passenger Baggage open • No cargo volume • APU available • Built-in passenger stairs
General Aviation Propeller Aircraft	<ul style="list-style-type: none"> • No Baggage, Cargo, APU, Stairs • Limited handling
Helicopter	<ul style="list-style-type: none"> • No Baggage, Cargo, APU, Stairs • Limited handling

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 or for passenger aircraft.

Table 2-2: Properties of Aircraft Stands

Properties	GSE and Ops Consequences	Remarks
Stand equipped with passenger loading bridge leading to terminal	<ul style="list-style-type: none"> • Doesn't require passenger stairs; 	
Stand equipped with fixed 400 Hz	<ul style="list-style-type: none"> • 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)	<ul style="list-style-type: none"> • Doesn't require GPU; • APU required for main engine start-up only; 	Stationary only together with 400 Hz
Additionally equipped with kerosene pipeline	<ul style="list-style-type: none"> • Doesn't require refuelling tanker truck; 	Common on stands with bridge
Proper layout for self powered break away	<ul style="list-style-type: none"> • Doesn't require push-back tractor. 	Not possible on stands with bridge

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

Table 2-3: APU-Operations and Alternatives

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 half-mobile ACU for open stands are possible;
Bleed air	Provides necessary bleed air to "turn on" main engines; 3 minutes ops time is sufficient.	ASU (air starter unit) (very few);

A number of manufacturer's data on fuel flow and emission factors is available, including the link to the aircraft. The emission calculation methodology is similar to the one applied for aircraft main engines: $\text{Time}_{\text{Mode}} [\text{h}] \times \text{Fuel Flow}_{\text{Mode}} [\text{kg/h}] \times \text{Emission Index}_{\text{Mode}} [\text{g/kg}]$.

2.4 GSE Operations (D)

The considerations as outlined in 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 number of the individual GSE and/or their total actual time of operations for an aircraft turn-around determine the amount of emissions. Not all of the aircraft / stand combinations are possible (e.g. no turboprops on stand with passenger bridges).

3 GSE Emission Calculation Methodology

3.1 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. Aircraft handling operations have been monitored for different aircraft groups and stand types and the GSE usage averaged (list of GSE: Annexe 2).

Table 3-1: Setup for GSE and Handling Data Survey

Aircraft Group	Aircraft Stands
Large Aircraft: from MD-11, A340	For the stand groups: <ul style="list-style-type: none"> • pier stands and • remote stands the operating time of all individual GSE pieces (cf. annexe 2) were monitored (in minutes for handling) per aircraft group and averaged each for: <ul style="list-style-type: none"> • arrival and • departure handling operations.
Medium Aircraft: up to A330, B767	
Small Aircraft: up to A321, B757, F100	
Commuter: EMB, RJ, F70, CRJ, CL	
Turboprops: Saab, ATR, DHC, Do	
Business Jets	
General Aviation Propeller Aircraft (Piston and Turboprops)	
Helicopters	

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

3.2 Emission Calculation Methodology

All emissions are basically 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 an arriving and departing flight doesn't have the same flight number or arrival and departure are not in a timely sequence (e.g. for night stoppers).

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

$$\text{emission}_{\text{substance}} [\text{g}] = \text{engine size} [\text{kW}] \times \text{load factor} [\%] \times \text{emission factor} [\text{g/kWh}] \times \text{time} [\text{h}]$$

3.3 Fuel and Emission Factors

The information on the equipment has been retrieved from the handling agents and tenants. This includes the engine size, a typical work load and the time during which the equipment is in operation at the stand.

Emission factors have been taken from the EC Directive 97/68/EG (EC Non Road Mobile Machinery Stage 1, cf. annexe) or from the Euro 1, 2, 3 emission standards for heavy duty vehicles.

Further evaluations revealed that emission limits are usually not exhausted by the manufacturers of non road mobile machinery and that a certain "reserve" is being kept. This

has been confirmed and assessed by the Swiss Agency for Environment, Forests and Landscape (SAEFL) for the different substances²:

*Table 3-2: Difference of actual emissions to standards**

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

* based on EUNRMM Stage 2

3.4 Operational Data Validation

The validation of this bottom-up approach has been 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.

² Source: Communication SAEFL/Air Quality Control, 25. August 2004.

4 GSE Emissions Factors for ZRH

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

Table 4-1: NO_x-Emissions from Aircraft Ground Handling

Aircraft Group	kg NO _x / event	Pier Stands		Remote Stands	
		Arrival	Departure	Arrival	Departure
Large Aircraft: from MD-11, A340	GPU	-	-	0.167	0.167
	GSE	0.172	0.621	0.190	0.476
Medium Aircraft: up to A330, B767	GPU	-	-	0.167	0.167
	GSE	1.057	0.570	0.175	0.440
Small Aircraft: up to A321, B757, F100	GPU	-	-	0.167	0.167
	GSE	0.074	0.242	0.092	0.159
Commuter: EMB, RJ, F70, CRJ, CL	GPU	-	-	0.147	0.147
	GSE	0.047	0.220	0.047	0.086
Turboprops: Saab, ATR, DHC, Do	GPU	-	-	0.147	0.147
	GSE	0.035	0.207	0.035	0.042
Business Jets	GPU	-	-	0.010	0.020
	GSE	0	0	0	0.010
General Aviation Propeller Aircraft	All	0	0	0	0.010
Helicopters	All	0	0	0	0.010

Table 4-2: HC-Emissions from Aircraft Ground Handling

Aircraft Group	kg HC / event	Pier Stands		Remote Stands	
		Arrival	Departure	Arrival	Departure
Large Aircraft: from MD-11, A340	GPU	-	-	0.013	0.013
	GSE	0.014	0.049	0.016	0.038
Medium Aircraft: up to A330, B767	GPU	-	-	0.013	0.013
	GSE	0.013	0.045	0.014	0.035
Small Aircraft: up to A321, B757, F100	GPU	-	-	0.013	0.013
	GSE	0.006	0.019	0.007	0.013
Commuter: EMB, RJ, F70, CRJ, CL	GPU	-	-	0.012	0.012
	GSE	0.004	0.018	0.004	0.007
Turboprops: Saab, ATR, DHC, Do	GPU	-	-	0.012	0.012
	GSE	0.003	0.017	0.003	0.004
Business Jets	GPU	-	-	0.001	0.002
	GSE	0	0	0	0.001
General Aviation Propeller Aircraft	All	0	0	0	0.001
Helicopters	All	0	0	0	0.001

Table 4-3: CO-Emissions from Aircraft Ground Handling

Aircraft Group	kg CO / event	Pier Stands		Remote Stands	
		Arrival	Departure	Arrival	Departure
Large Aircraft: from MD-11, A340	GPU	-	-	0.050	0.050
	GSE	0.063	0.204	0.070	0.162
Medium Aircraft: up to A330, B767	GPU	-	-	0.050	0.050
	GSE	0.058	0.185	0.065	0.148
Small Aircraft: up to A321, B757, F100	GPU	-	-	0.050	0.050
	GSE	0.026	0.078	0.033	0.054
Commuter: EMB, RJ, F70, CRJ, CL	GPU	-	-	0.044	0.044
	GSE	0.016	0.068	0.016	0.028
Turboprops: Saab, ATR, DHC, Do	GPU	-	-	0.044	0.044
	GSE	0.012	0.063	0.012	0.013
Business Jets	GPU	-	-	0.003	0.006
	GSE	0	0	0	0.003
General Aviation Propeller Aircraft	All	0	0	0	0.003
Helicopters	All	0	0	0	0.003

Table 4-4: PM-Emissions from Aircraft Ground Handling

Aircraft Group	kg PM/ event	Pier Stands		Remote Stands	
		Arrival	Departure	Arrival	Departure
Large Aircraft: from MD-11, A340	GPU	-	-	0.009	0.009
	GSE	0.012	0.038	0.013	0.030
Medium Aircraft: up to A330, B767	GPU	-	-	0.009	0.009
	GSE	0.011	0.034	0.012	0.027
Small Aircraft: up to A321, B757, F100	GPU	-	-	0.009	0.009
	GSE	0.005	0.014	0.006	0.010
Commuter: EMB, RJ, F70, CRJ, CL	GPU	-	-	0.008	0.008
	GSE	0.003	0.012	0.003	0.005
Turboprops: Saab, ATR, DHC, Do	GPU	-	-	0.008	0.008
	GSE	0.002	0.011	0.002	0.002
Business Jets	GPU	-	-	0.001	0.001
	GSE	0	0	0	0.001
General Aviation Propeller Aircraft	All	0	0	0	0.002
Helicopters	All	0	0	0	0.002

Differences have been identified and related to the different use of GSE, e.g. the use of aircraft tractors for pier stands but not remote stands during the departure handling or the use of passenger stairs and large refuelling tanker trucks at remote stands.

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 serves as input data into the dispersion model LASPORT³ for actual impact modelling.

The factors as tabled in chapter 4 are basically applicable to Zurich airport. By singling out the GPU operations which vary according to stand installations and turn around times, the calculated emissions are limited to actual handling operations that apply to the average aircraft class and thus might be comparable to some degree with other airports. GSE equipment is usually very similar and this also holds true for handling procedures.

6 Airside Traffic Emission Calculation

Airside vehicle road traffic is calculated following the methodology as set out by the Swiss Agency for Environment, Forests and Landscape (SAEFL). To facilitate the evaluation, the Agency has produced a software tool that provides vehicle emission factors for Switzerland, Germany and Austria⁴.

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, CO₂);
- 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.

³ www.janicke.de

⁴ SAEFL: Handbook Emission Factors (HBEFA), Version 2.1

7 Annexe

7.1 Emission Standards and Indices for GSE

EC Non Road Mobile Machinery (EEC EUNRMM Stage 1)⁵:

g/kWh	Power Band	CO	HC	NOx	PM	Introduction
Stage 1	37-75 kW	6.50	1.30	9.20	0.85	1. October 2001
	75-130 kW	5.00	1.30	9.20	0.70	1. October 2001
	130-650 kW	5.00	1.30	9.20	0.54	1. October 2001
Stage 2	18-37 kW	5.50	1.50	8.00	0.80	1 January 2001
	37-75 kW	5.00	1.30	7.00	0.40	1 January 2004
	75-130 kW	5.00	1.00	6.00	0.30	1 January 2003
	130-560 kW	3.50	1.00	6.00	0.20	1 January 2002

FAV-2 for Heavy Duty Vehicles (Switzerland / Austria), after 1.10.1991:

	g/kWh
CO	4.9
HC	1.23
NOx	9.0
Particle	0.7

Emission Factors for GSE Engines (in grams per BHP-hr)⁶: (for information purposes only)

Engine Type	Coolant	Horsepower	HC	NOx	CO	PM
Gasoline	Air	1 – 24	10.0	2.0	360.0	0.2
		25 – 50	7.0	3.0	400.0	0.0
	Water	25 – 9,999	4.0	4.0	240.0	0.0
Diesel	Water	1 – 50	1.0	11.0	4.4	0.7
		51 – 9,999	1.2	11.0	4.0	0.5
OEM Optimized CNG	Water	1 – 24	5.0	4.0	180.0	0.0
		25 – 50	2.0	6.0	120.0	0.0
		51 – 9,999	1.0	3.5	2.1	0.0
Existing CNG or LPG	Air	1 – 24	5.0	4.0	180.0	0.0
		25 – 50	4.0	6.0	200.0	0.0
	Water	1 – 24	5.0	4.0	180.0	0.0
		25 – 9,999	2.0	6.0	120.0	0.0











⁵ EC Directive 97/68/EG










⁶ Energy and Environmental Analysis, Inc.: Air Pollution Mitigation Measures for Airports and Associated Activity. Arlington, VA; May 1994.



7.2 List of Ground Support Equipment at Zurich Airport

Nr.	GSE	Description	Ops Type ⁷	Operational Remarks	Fuel and Emissions
1		400 Hz Ground Power Unit	1		105-149 kW; 50% Diesel: 9.1-10.1 l/h EEC EUNRMM Stage 1
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: 6 l/h EEC EUNRMM Stage 1
4		Widebody towbarless aircraft tug	1		400-500 kW; 25% Diesel: 22-25 l/h EEC EUNRMM Stage 1
5		Aircraft Tug (towbar)	1		95 kW; 25% Diesel: 6 l/h EEC EUNRMM Stage 1
6	Not pictured	Gear mounted push-back tractor	1	Not used in Zurich	
7		Passenger Stairs	1	Open Stands only;	30-65 kW; 25% Diesel: 1.8 l/h
8		Passenger Bus	2	Not attributed to stand emissions, but to airside traffic emissions only.	100 kW Diesel: 4-6 l/h (34-45 l/100km) Euro 0 – Euro 3 5,800 ccm
9		Crew Bus	2	Not attributed to stand emissions, but to airside traffic emissions only.	70-90 kW; 25% Diesel: 12-18 l/100km Euro 0 – Euro 2

⁷ 1: operates at stand only; 2: operates at apron (mainly driving around); 3: combination of 1 and 2.

Nr.	GSE	Description	Ops Type ⁷	Operational Remarks	Fuel and Emissions
10		Baggage Belt Loader	1		33 kW; 25% Diesel: 1.6 l/h EEC EURNRMM Stage 1
11		Cargo Loader	1		62 kW; 25% Diesel: 3.6 l/h EEC EURNRMM Stage 1
12		Cargo Delivery	1		33 kW; 25% Diesel: 3.6 l/h EEC EURNRMM Stage 1
13		Cargo Loader Main Deck	1	For cargo aircraft main deck only	59 kW; 25% Diesel: 3.6 l/h EEC EURNRMM Stage 1
14		Catering Truck	3		85-130 kW; 10-25% Diesel: 5 l/h Euro 2
15		Water Truck	3		117 kW; 25% Diesel: 3 l/h Euro 1
16		Lavatory Truck	3		117 kW; 25% Diesel: 3.5 l/h Euro 1
17		Refuelling Dispenser Truck	3	Stands with fuel pits only;	66-110 kW; 10-50% Diesel: 1.6 l/h Euro 1- Euro 3
18		GSE / GA Refuelling Truck	3		90 kW; 10-20% Diesel: 1.6 l/h Euro 1- Euro 3
19		Refuelling Tanker Truck	3	Stands without fuel pits only;	200 kW; 10% Diesel: 6.0 l/h Euro 1- Euro 3

Nr.	GSE	Description	Ops Type ⁷	Operational Remarks	Fuel and Emissions
20		Cabin Cleaning Truck	3		132 kW; 10-60 % Diesel: 5 l/h Euronorm: 2 5480 ccm / 2200 RPM
21		Cabin Cleaning Van	3		61 kW; 10-75% Diesel: 13 l/100 km Euro 1 2985 ccm / 3000 RPM
22		Cabin Cleaning Vehicle	3		48 kW; 10-75 % Gasoline: 1.6 l/h Euro 3 1296 ccm / 4200 RPM
23	Not pictured	Generator for Vacuum Cleaner	1		Typ I: 2.2 kW; 80% Gasoline: 1.5 kg/h 200 ccm / 3000 RPM Typ II: 3.5 kW; 80% Gasoline: 2.1 kg/h 2,760 ccm / 3000 RPM
24		Line Maintenance Truck	3	All stands, all a/c groups; upon request only.	70-120 kW; 25% Diesel: 5 l/h Euro 2 / FAV-1
25		Baggage Cart Tractor	3		electric
26		Baggage Hall Tractor	1		electric
27		Cargo Container Tractor	3		53-60 kW; 25% Diesel: 4 l/h EEC EUNRMM Stage 1
28		Large Fork Lift	1	Not a/c related (in cargo facilities)	30-120 kW; 25% Diesel: 4-7 l/h Euro 1
29		Fork Lift	1	Not a/c related (in cargo facilities)	66 kW; 25% Diesel: 5 l/h Euro 1

Nr.	GSE	Description	Ops Type ⁷	Operational Remarks	Fuel and Emissions
30		Aircraft De-icing Truck	3	On stands or de-icing pads with de-icing. Treated as area source, not handling due to very high variability.	184 kW; 25% Diesel: 8 l/h Euro 2
31		Cars	2	Only some are a/c related; considered in airside traffic emissions.	60 kW; 50% Gasoline: 9 l/100km Euro 2 – Euro 3

+++