

Air Quality Assessment Sensitivities - Zurich Airport Case Study



Air Quality Assessment Sensitivities - Zurich Airport Case Study


Table of Content

1	Introduction	3
1.1	Airport Emission Calculations	3
1.2	Zurich Airport Case Study	3
2	Zurich Airport.....	5
3	Airport Emission Inventory	6
3.1	Aircraft Emission Sensitivities.....	6
3.1.1	Aircraft Main Engines.....	6
3.1.2	Aircraft APU	8
3.1.3	Other Aircraft Emissions	9
3.2	Other Airport Emissions.....	9
3.2.1	Aircraft Handling	9
3.2.2	Airport Infrastructure	10
3.2.3	Landside Access.....	10
3.3	Total Airport Emissions.....	10
3.4	Global Emissions	11
3.5	Special Reporting on CO ₂	11
3.6	Airport Emissions in the Context of Regional Emissions	12
4	Pollutant Concentrations from Dispersion Modelling	14
4.1	Modelled NO ₂ -Concentration.....	14
4.1.1	NO ₂ -Concentrations of scenarios with variation in emissions.....	14
4.1.2	Aircraft and airport sources.....	15
4.1.3	NO ₂ -Concentrations of scenarios with variation in meteorological data	16
4.1.4	NO ₂ -Concentrations of scenarios with variation in emissions and meteo.....	18
4.2	Measured Ambient Air Quality.....	18
4.3	Airport Specific NO ₂ -Impacts on Local Air Quality.....	19
5	Conclusions.....	21
6	Reference Information.....	22
6.1	Abbreviations	22
6.2	References	23
6.3	LASPORT Zurich Airport Study Setup.....	24
6.4	Aircraft Emission Calculation and Concentration Modelling Approaches	25
6.5	Detailed Aircraft Engine Emissions.....	26

Imprint

Published by: Flughafen Zürich AG, P.O. Box, CH-8058 Zurich, www.zurich-airport.com
 Emanuel Fleuti, Silvio Maraini
 In cooperation with Dr. Ulf Janicke, Janicke Consulting, www.janicke.de

Date: December 2009

Status: Final /  2009-12_ZRH_AirQuality-Sensitivity_v1.doc

1 Introduction

1.1 Airport Emission Calculations

In response to legal requirements, obligations under capital development program permits or corporate social responsibility, more and more airports undertake local air quality assessments with calculated emission inventories, modelled pollutant concentrations and measured air quality levels.

A comprehensive guidance manual has been developed by ICAO's Committee on Aviation and Environmental Protection (CAEP) as "Document 9889" [1], with a preliminary edition in 2007 and the first edition in 2010. It incorporates best airport business practices and guidance from aircraft and engine manufacturers and aviation organisations. This document provides a systematic approach to local air quality assessments at various levels depending on the purpose of the assessment and the available resources and information. To this end, the manual provides guidance for simple, advanced and sophisticated approaches with each level requiring more complex information. While a simple approach may give reasonable indications on the local air quality emissions, it is recommended to try and use the best possible data and level of sophistication for such assessments.

One of the questions often asked is what the difference in results is between simple methods and more advanced methods and, subsequently, whether efforts are justified to acquire additional data and information for more complex assessments.

The purpose of this study is to demonstrate the sensitivities in air quality assessments at one airport using the different approaches and levels of expertise described in the ICAO guidance manual.

1.2 Zurich Airport Case Study

The case study is based on Zurich airport's 2008 traffic unless otherwise stated. The data includes all aircraft operations and aircraft handling activities, as well as the operation and maintenance of the airport infrastructure and all landside road access in the closer vicinity of the airport. It includes all sources as described in ICAO Doc 9889 (Table 1-1). The substances considered in the study are nitrogen oxides (NO_x), hydrocarbons (HC), carbon monoxide (CO), particulate matter (PM) and the greenhouse gas carbon dioxide (CO₂). Other substances are of lesser relevance in the context of Zurich airport and are thus not included in this study.

The model used for the study is LASPORT version 2.0 (LASAT for airports) [2]. This model was initially developed in 1999 on behalf of the German Airports Association (ADV) and further developed in 2008-2009 to incorporate the various approaches and calculation guidance as described in ICAO Doc 9889. It is being used for ICAO CAEP policy assessments and simulations alongside other international local air quality models.

The model is able to calculate emissions at various levels of detail, depending on the availability of data (Figure 1-1 for aircraft engine emissions). In processes include the aircraft performance module ADAECAM (advanced aircraft emission calculation method), which considers actual atmospheric conditions such as wind, temperature, pressure and humidity, and assumptions on the actual take-off mass of aircraft [3]. For a visual impression of the study set-up of Zurich airport in LASPORT, refer to Section 6.3.

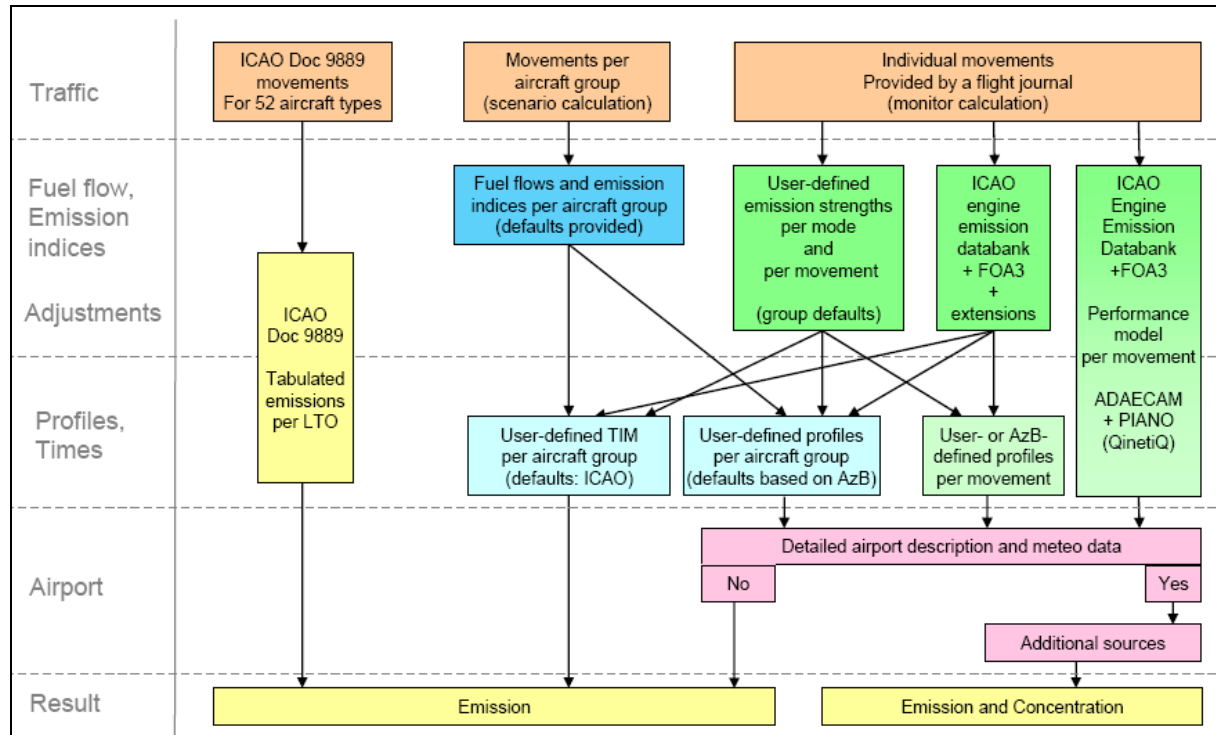


Figure 1-1: LASPORT aircraft calculation methods

For the purpose of this study, the emission sources "aircraft main engine" and "aircraft APU" are analysed in more detail using the various approaches described in ICAO Doc 9889. The other sources (Table 1-1) are included in order to put all emission sources in context, but are not calculated with various levels of complexity. The relevant calculation method is described in more detail in each section.

Table 1-1: Zurich Airport Emission Sources

Source Group	Emission Source	Comments
Aircraft	Main Engines	Includes engine ignition to idle
	Auxiliary Power Units	
	Brakes and Tyres	PM only
Aircraft Handling	Ground Support Equipment	Includes GPU
	Aircraft Refuelling	HC only
	Aircraft De-icing	De-icing agents and applying machinery (trucks)
	Airside vehicle traffic	
Airport Infrastructure	Power plant/boiler house	Includes all furnaces
	Emergency power generation	
	Airport Maintenance	Building, greenery, surface de-icing
	Aircraft Maintenance	Hangars, paint shops, engine run-ups
	Fuel stations and fuel farm	HC only
	Construction activities	
	Fire training	
Landside Access	Vehicles	Closer vicinity of airport
	Trains	Energy (CO ₂) only

2 Zurich Airport

Zurich airport is the largest airport in Switzerland and the country's main gateway for air travel (Figure 2-1). It is used as a hub airport by its main carrier, Swiss International Airlines. It is embedded in a densely populated area with downtown Zurich only approximately 8.5 km distant. While there is little industry in the area, there are several main highways and main roads connecting the city, the airport and the many communities.

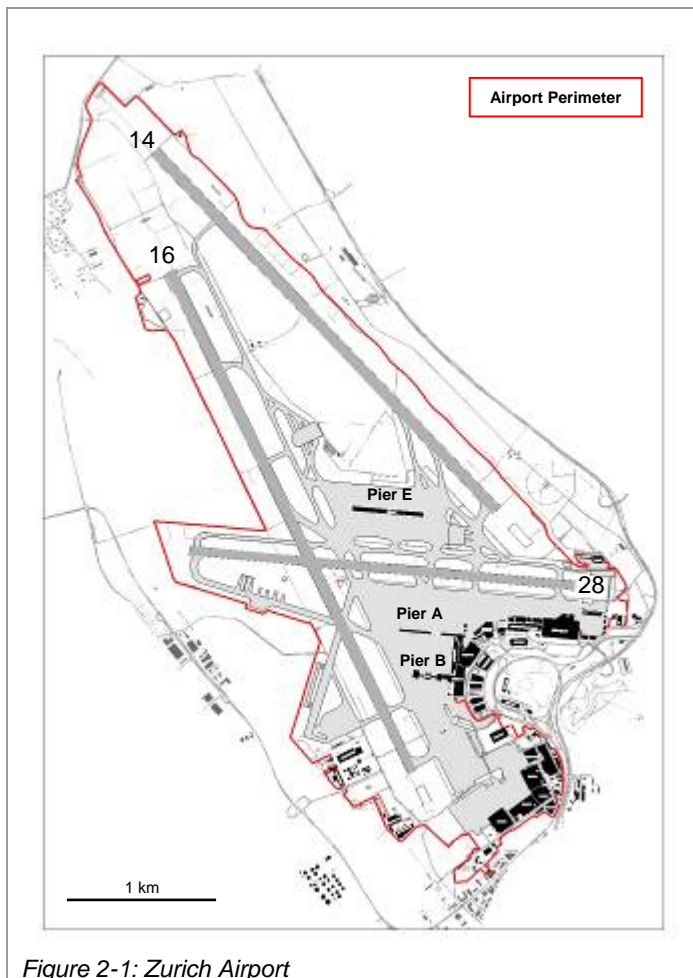


Figure 2-1: Zurich Airport

Traffic	2008
- Commercial Movements	231,775
- General Aviation Movements	43,216
Total Movements	274,991
Passengers (millions.)	22.1
Cargo/mail (t)	419,843
Work Load Units (millions.)	26.3
Number of Destinations	174
Number of Airlines	88
Infrastructure	
Runways	3
Aircraft positions	
- Pier Stands (ZRH mix)	90
- Remote Stands (ZRH mix)	48
- Long term Parking	6
- General Aviation (max.)	114
Airport Perimeter (km ²)	8.8

Zurich airport is operated by Flughafen Zürich AG, a private company under a concession of the Federal Department of Energy, Transport, Environment and Communications. A number of tasks are performed by third parties, e.g. aircraft handling and maintenance services, cargo services, fuel services, air navigation services and security.

Provisions in the airport's operating manual require the airport to annually report NO_x emissions from aircraft, handling and infrastructure to the federal and cantonal authorities. If an implied threshold of 2,400 t of NO_x/a is exceeded, the airport is required to conduct an additional analysis (emissions and concentrations) and develop a new mitigation plan to be endorsed by the federal authorities.

3 Airport Emission Inventory

3.1 Aircraft Emission Sensitivities

As described in ICAO Doc 9889, aircraft emissions include emissions from the main engines, the APU (auxiliary power units), main engine start-up and the particulate matter emissions from brake and tyre wear. In this section, emissions from the aircraft main engines and the APU are calculated using different method approaches and variations in performance affecting parameters.

3.1.1 Aircraft Main Engines

Emission inventories of aircraft in the vicinity of airports are traditionally calculated using ICAO engine exhaust emission data and the ICAO reference LTO cycle, the latter sometimes adapted to airport specific taxi times. Initially intended for certification purposes, the LTO cycle cannot sufficiently account for operational issues (de-rated take-off, climb profiles). Consequently, an operational aircraft LTO cycle has also been defined as the basis for performance based modelling (Figure 3-1).

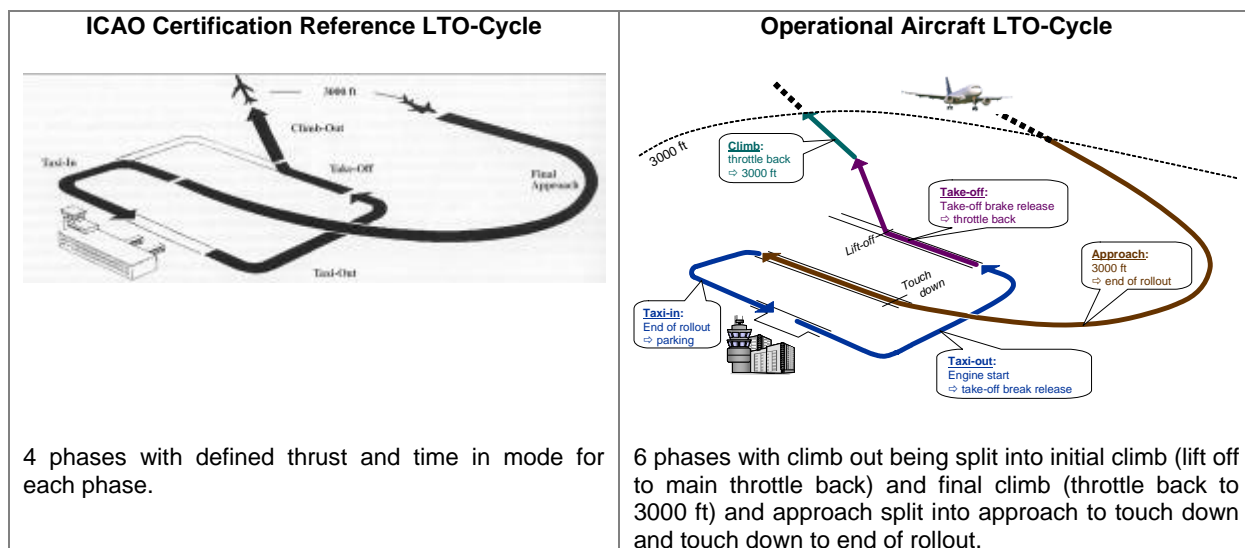


Fig. 3-1: ICAO reference and operational aircraft LTO cycle

In a first set of sensitivity calculations, the approaches as listed in Doc 9889 are applied, ranging from a very simple approach (publicly available look-up table) to a very advanced approach (sets of publicly available information, with some data under license agreements). Specifically the following approaches have been used (Table 3-1; for more detailed information, refer to Section 6.4):

Table 3-1: Calculation Scenarios

Scenario	Fleet and engines	Emission calculation
A	Number of cycles for a given set of aircraft (Simple Method)	UNFCCC look up table (Simple A)
B	Aircraft types with default/representative engine (Advanced Method)	ICAO certification reference LTO cycle and EEDB (Simple B)
C	Actual aircraft engine combinations (by UID) (Sophisticated Method)	
D		ICAO certification reference LTO cycle with actual aircraft taxi times (Simple B and Advanced A)
E		Performance based modelling with operational LTO cycle (cf Fig. 3-1) (Advanced B): Meteorological parameters: daily 06-22 hours average

The results of the first set of sensitivity calculations (Scenarios A through E) are listed in Table 3-2 for the various substances. For more detailed results (emissions per individual LTO-mode), refer to the tables in Annexe 6-4.

Table 3-2 Aircraft Engine Emission summary results

	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E
Substance	(UNFCCC Table)	(Repres' fleet, ICAO certification LTO)	(Detailed fleet, ICAO certification LTO)	(Detailed fleet, actual taxi times)	(Detailed fleet, performance based)
NOx (t/a)	1'078	1'273	1'242	1'179	912
HC (t/a)	110	136	207	141	215
CO (t/a)	1'099	1'214	1'686	1'146	1'354
PM (t/a)	-	13	13	11	10
CO₂ (t/a)	268'096	330'351	333'820	281'828	248'691

The results from Scenarios A to E reflect the increase in calculation complexity for the same set of traffic data. The differences in results between Scenarios B and C are only due to the more refined fleet identification by using the detailed fleet (Sophisticated Method with each aircraft with its actual engine identification) versus the representative fleet (Advanced Method with each aircraft with a typical representative engine).

The differences between Scenarios C and D result from the variation in the taxi-time of aircraft by using the actual taxi-time for each individual movement, as opposed to using the ICAO certification time in mode of 26.0 minutes for each aircraft cycle.

The results in Scenario E finally reflect the most advanced modelling methodology that uses the integrated performance model, ADAECAM (advanced aircraft emission calculation model). As would be expected from previous studies [e.g. 4, 5], the actual fuel burn (resulting in CO₂) as well as NOx and PM emissions are considerably lower than when using traditional calculation approaches. Conversely, the emissions from HC and CO are higher, due to the inverse relationship between fuel burn and emission indices for those substances.

The results of Scenario A seem to give fairly good results compared to Scenario E. However, there are various factors that influence the end results: variety of aircraft models, actual engine considered, taxi time and other times in mode. While for Zurich airport, the factors overestimating and underestimating the results seem to balance out, this could be very different for other airports. As such, it cannot generally be concluded that the Scenario A is "almost" as good as the Scenario E.

Zurich Airport has calculated aircraft engines emissions since 1991, using the Scenario D method. With the availability of the more advanced model LASPORT 2.0, Zurich Airport changed the aircraft engine calculation method to the Scenario E method in 2008.

A second set of sensitivity calculations has been performed focussing on the sensitivity of ambient conditions. Specifically, the meteorological parameters have been changed, using varying assumptions for temperature, pressure and humidity [6]. The results are listed in the following Table 3-3 (aircraft engine emissions up to 3,000 ft, without start-up, in metric tonnes) for the aircraft movement data for the year 2007.

Table 3-3: Aircraft engine emission results for varying atmospheric conditions (t/a and percent)

Case Name	Description	Fuel burn		NOx		HC	
ICAO-LTO	Certification (ICAO) fuel flows, emission indices, and times-in-mode	100,372	100%	1,172	100%	198	100%
ICAO-LSP	Certification (ICAO) fuel flows and emission indices, individual LASPORT default profiles	84,192	84%	1,072	91%	141	71%
ADC-ISA	ADAECAM emissions and profiles, ISA conditions (15.0C, 1013.25 hPa, 60%)	74,363	74%	834	71%	181	91%
ADC-TY	ADAECAM emissions and profiles, ISA conditions but plain annual average temperature (10.3C)	74,363	74%	751	64%	217	110%
ADC-TPRY	ADAECAM emissions and profiles, annual averages for temperature, pressure, humidity (10.3C, 967.48 hPa, 77%)	74,363	74%	806	69%	186	94%
ADC-TPRD	ADAECAM emissions and profiles, time series of temperature, pressure, humidity in form of daily means (average between 6:00 and 22:00)	74,363	74%	858	73%	203	103%
ADC-TPRH	ADAECAM emissions and profiles, time series of temperature, pressure, humidity in form of hourly means	743,63	74%	864	74%	208	105%

Temperature has the strongest effect on the emission indices. On average, the NOx emissions increase by about 2% with an increase of ambient temperature by 1°C. Sensitivity to pressure and relative humidity is smaller, but not negligible. HC (and CO) emissions are more sensitive to ambient changes than NOx emissions.

3.1.2 Aircraft APU

Aircraft APU are used on the ground to provide electricity and air conditioning to the aircraft. However, air conditioning is only needed for temperatures typically outside the range of 0°C-18°C or during long periods on the ground. In addition, APU are used for the main engine start-up. At Zurich airport, all pier stands are equipped with fixed ground power and pre-conditioned air, and the use is mandated by the airport operating manual [7]. At open stands, mobile GPU are available for electricity, but there are insufficient mobile air conditioning units for all stands. As such, the actual operating time of APU has to be independently modelled by considering the aircraft ground time, the aircraft stand allocation and the ambient conditions (temperature).

To demonstrate the sensitivity of the APU emissions, various scenarios are calculated using two approaches for both the Simple and Advanced Methods (Table 3-4). In Approach A, it is assumed that there is no fixed ground power or GPU available and in Approach B, the fixed ground power is used to its fullest extent. The Simple and Advanced Methods differ in the availability of information on APU types and assignments, and the APU operating times. APU

emission factors (Simple and Advanced) and generic operating times (Simple) are found in the ICAO Doc 9889.

Table 3-4: APU emission using various methodologies

	Simple Method (A)	Advanced Method (A)	Simple Method (B)	Advanced Method (B)
Fleet definition and emission indices.	Aircraft fleet in 2 categories (short and long haul), each with generic APU	Aircraft individually assigned with one of seven generic APU-types	Aircraft fleet in 2 categories (short and long haul), each with generic APU	Aircraft individually assigned with one of seven generic APU-types
APU operating times	45 min short haul (SH or narrow body) 75 min long haul (LH or wide body))	Modelled actual time (assuming no fixed ground power, local regulation applied (limited max. APU operating times))	Generic estimate, depending on gate electrification: <ul style="list-style-type: none"> • 15' NB/WB with • 52' NB without • 75' WB without 	Modelled actual time (dependent on aircraft stand, ground time and ambient temperatures)
Substance				
NO _x (t/a)	107.0	111.7	63.2	19.5
HC (t/a)	5.3	13.9	2.9	7.5
CO (t/a)	36.9	65.0	25.3	22.2
PM (t/a)	3.3	12.9	2.1	2.6
CO ₂ (t/a)	39,521	42,190	23,022	8,978

Approach A shows little differences for fuel burn (or CO₂) and NO_x between the Simple and Advanced Methods. While some differences can occur from the assumptions in operating times, the largest part of the difference occurs by applying more detailed emission factors (seven generic APU models instead of two) for HC, CO and PM. Approach B, describing a scenario as applied at Zurich airport (fixed ground power and PCA available on most stands), shows larger differences in NO_x and CO₂ with lower emissions from the Advanced Method. This is driven by both the more detailed emission factors and the refined modelling of the APU operating times. For simplicity reasons, the (small) effects on the GPU emissions have not been taken into account.

3.1.3 Other Aircraft Emissions

Other aircraft emissions include engine start-up to idle (HC emissions) and brake and tyre wear. Both types of emissions are not considered in the Simple Method, but are accounted for in the Advanced Method. Engine start-up to idle emission calculation follows the ICAO Doc 9889 guidance. Aircraft brake and tyre PM emission factors are based on work done for the Heathrow Project for Sustainable Development (HPSD).

3.2 Other Airport Emissions

Emissions from airport operation further include aircraft handling, airport infrastructure and landside access. They are calculated using various methods as pre-processors to the LASPORT system. They are briefly described in the following section, while the emission calculation results are summarised in Table 3-5. There is no separate modelling with simple and advanced methods, as only advanced methods have been developed for Zurich airport.

3.2.1 Aircraft Handling

- Ground Support Equipment: In this bottom up approach, each type of GSE is identified for the service of an aircraft and its operating time estimated depending on aircraft size (large, medium, small, regional, business, turboprop), type of operation (arrival or departure) and stand usage (pier or remote stand).

Emission indices from industry sources are used and average handling emission loads per operation calculated [8].

- Aircraft refuelling: HC emissions from refuelling activities, dependant on the aircraft stand (fuel pit available or fuelling by trucks).
- Aircraft de-icing: Emissions from the application of de-icing agents with the agent itself and the emissions of the machinery (de-icing trucks).
- Airside vehicle traffic: Emissions from vehicles circulating on the airside area of the airport. All airside roads are identified and vehicle counts of cars, vans and trucks conducted. For each road segment, an average traffic pattern (speed) is determined and the specific emission indices applied as suggested by the Federal authorities [9].

3.2.2 Airport Infrastructure

- Power plant/boiler house and emergency power stations: Specific operational parameters (operating hours, fuel consumption, load factor, installed capacity) and fuel and emission indices are used for all power and heat producing plants, including stand alone furnaces and emergency power stations.
- Airport maintenance: This includes cleaning agents, building maintenance and repairs as well as maintenance of the greeneries. Surface de-icing is also included with emissions from de-icing agents and from the machinery. Emission factors are used as suggested by the industry.
- Aircraft maintenance: This includes aircraft hangars with cleaning and paint shops (emission factors from the industry) and all engine test runs and run-ups, using detailed statistics on engine type, run-up operation and ICAO engine emission factors.
- Fuel stations and fuel farm: Operational information on fuel stored and dispensed with emission indices from industry.
- Construction activities: A specific model has been developed using emission factors for construction equipment and airport specific construction activities (e.g. apron resurfacing), thus generating emission loads per unit of typical tasks.
- Fire training: Amount and specific emission factors are used for various typical training agents for the airport fire service (e.g. butane, kerosene, wood).

3.2.3 Landside Access

- Road access: The methodology applied is the same for the airside vehicle traffic. It also includes turn-off, start-up and evaporation emissions from vehicles. The system boundary is where vehicles would turn off from the regional road system into the dedicated airport road system. This is on average a distance of approximately 3 km from the central terminal area (see illustration in Section 6.3).
- Trains: CO₂-emissions only are calculated using factors provided by the Swiss Federal Railway and passengers counts at the airport. The study area covers the train lines from the airport to both the city of Zurich (South, 5 km) and Winterthur (Northeast, 8 km).

3.3 Total Airport Emissions

The total airport emissions including all four source groups are listed in Table 3-5. For the aircraft emissions, only results for one simple and one advanced method for the aircraft are listed (aircraft: Scenarios B and E; APU: Approach B). The results of the methods as discussed in Section 3.1 are thus set in context with all other airport related emissions.

Table 3-5: Total airport emission sources in a simple and advanced method

Source	NOx (t)		HC (t)		CO (t)		PM (t)		CO ₂ (1,000 t)	
	Simple	Adv.	Simple	Adv.	Simple	Adv	Simple	Adv	Simple	Adv
Aircraft	1,336	932	178	263	1,239	1,376	19	16	353.4	257.7
Aircraft Handling	75	75	22	22	29	29	4	4	6.3	6.3
Infrastructure	58	58	82	82	33	33	2	2	40.4	40.4
Landside Traffic	26	26	11	11	135	135	1	1	11.5	11.5
Total	1,495	1,091	293	378	1,436	1,573	26	23	411.6	315.9
Difference		-27%		+29%		+10%		-12%		-23%
Aircraft share		85%		70%		87%		70%		82%

The results demonstrate the general prediction that the gain in accuracy when increasing the level of calculation and modelling sophistication leads to lower emissions in CO₂, NOx and PM and higher emissions in HC and CO. Depending on the governing requirements for emission inventory calculations, extra efforts are justified to better reflect the emissions from the airport activities.

The aircraft share of the total airport emissions is demonstrated for the chosen assumptions of the boundaries for both the aircraft and the landside traffic. In addition, the results do not give any indication for the concentrations or the impacts in the airport area.

3.4 Global Emissions

Although Zurich Airport is unable to influence global emissions from aircraft and their impacts on the climate, it is actively committed to supporting international efforts to reduce emission levels. EUROCONTROL – the European Organisation for the Safety of Air Navigation – has estimated that the volume of overall emissions resulting from all IFR flights from Zurich Airport in 2008 includes approximately 13,220 tonnes of nitrogen oxides (NOx) and 2.97 million tonnes of carbon dioxide (CO₂). This has been calculated using the model AEM (advanced emissions model) and EUROCONTROL's own flight database and includes the LTO cycle [10]. In order to avoid potential double counting, only one way (departing flights) are calculated with the LTO cycle applied fully to Zurich airport.

3.5 Special Reporting on CO₂

Based on the available data and the modelling of the respective emissions, the CO₂-emission foot print of the airport can be derived. For this purpose the GHG Protocol [11], in combination with the ACI Guidance Manual on Airport GHG Emissions Management [12] has been applied and the results listed in Table 3-6.

Table 3-6: CO₂-Emissions Zurich Airport in 2008

Scope	t CO ₂	Comments
Scope 1	30,788	Includes all Flughafen Zürich AG owned or operated sources: Power plant, furnaces, emergency power generators, company vehicles and machinery.
Scope 2	2,639	Purchased electricity for own consumption
Scope 3A	112,260	Scope 3 emissions that the airport operator can influence to some degree: aircraft taxiing, APU, GPU, road access traffic (on airport related roads only), construction on behalf of the airport operator, fire training. Aircraft taxiing is approximately 90,000 t.
Scope 3B	2,899,331	Scope 3 emissions that the airport operator cannot significantly influence: Aircraft LTO and global emissions (excl. taxiing), GSE, third party furnaces, aircraft maintenance (engine run-ups), rail access traffic. Of this total, 2,720,000 t of CO ₂ are contributed by the global en-route aircraft emissions ¹ and 160,000 t by the LTO cycle (excl. taxiing).

The results confirm the general finding at airports that the aircraft contributes the largest proportion of CO₂-emissions. Scope 1 and 2 emissions at Zurich airport constitute approximately 10% of airport emissions in the closer vicinity (LTO cycle, road traffic) and approximately 1% of the global airport induced CO₂ emissions. These results may differ slightly from data as calculated by using the model LASPORT. This is due to the modelling approach in LASPORT, where emissions have to be spatially and temporally resolved, thus requiring more complex modelling, while a simple inventory can rely on total fuel masses only.

3.6 Airport Emissions in the Context of Regional Emissions

While an airport constitutes an entity in itself, it is often set in context with other activities in the local geographic area with the goal of attributing a proportion of the total local emissions to the airport. This is possible only if the proper data is available. For the interpretation of the results, there are two main aspects to be carefully considered:

- The system boundaries within which the emissions are counted. The smaller an area is, the larger the airport's proportional share will be, although the airport itself may have a small emissions load.
- The activities that take place in the regional system. The less activities take place, the higher the airport's emissions contribution would be in the total context.

Consequently, putting an airport's emissions into a regional context will always be very site specific, so generalised conclusions and comparisons with other regions cannot be easily made.

For Zurich airport, the regional context is usually the Canton of Zurich, thus a political geographical system (Figure 3-2). The Canton of Zurich covers an area of approximately 35 by 50 km (maximum of 42 x 59 km) or 1,730 km² (Zurich airport: 9 km²). While Zurich airport is surrounded by several major motorways (four- to six-lane divided highways), there are few industrial activities close by with significant contributions to local air quality issues.

¹ From the AEM total global emissions, the ADAECAM LTO cycle emissions are subtracted to present en-route emissions, even though the ADAECAM LTO cycle is modelled differently from the AEM LTO cycle and yields slightly different results.

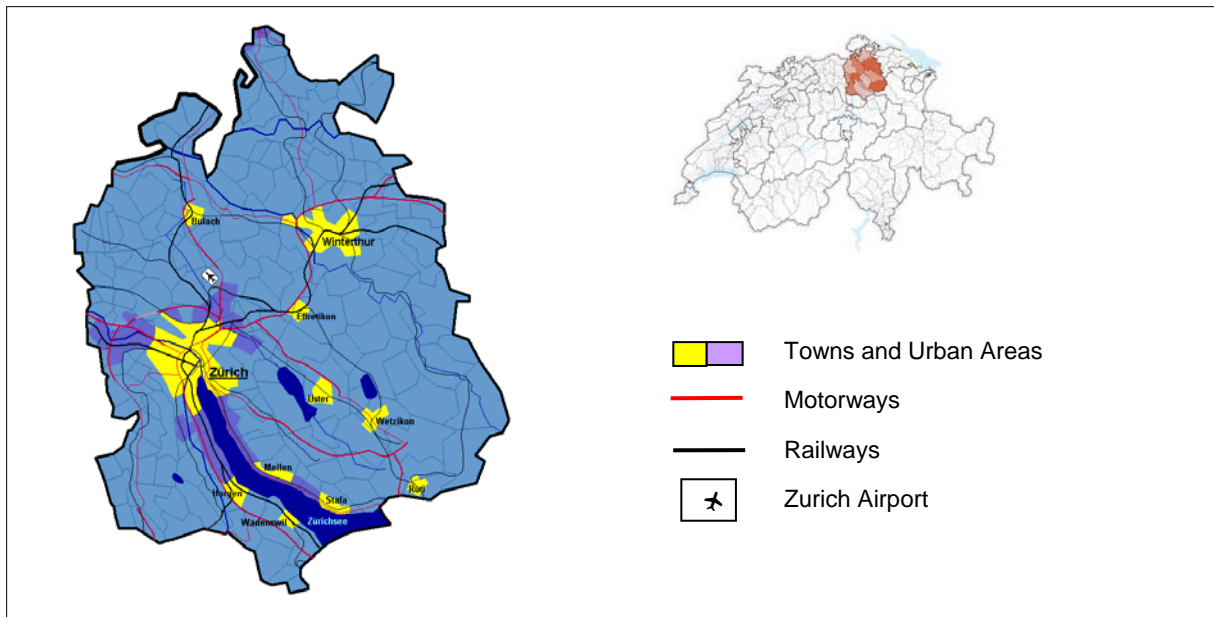


Fig. 3-2: Canton of Zurich within Switzerland

The cantonal authorities publish emission inventories at regular intervals, covering all activities in the canton including the airport. For this purpose, the airport usually submits a detailed emission inventory that is added to the cantonal inventory. The latest figures have been modelled for the year 2005, based on baseline data of the year 2000 (except for the airport data that were actual data for 2005, but still using the former calculation methodologies) [13]. The data is listed in Table 3-7 and also shows the contribution of the aircraft emissions to the total emissions. It has to be recognised that the emission masses do not reflect the impact contribution.

Table 3-7: Canton of Zurich emissions by source groups in 2005.

Source Group	Unit	NOx	VOC	PM10
Road and rail traffic	t/a	6,827	2,752	785
Furnaces and heatings	t/a	2,677	590	391
Industry	t/a	1,902	9,254	457
Agriculture	t/a	844	1,701	334
Aircraft (certification LTO, modified taxi time)	t/a	1,266	363	45 ¹
Total	t/a	13,415	14,660	2,012
Contribution of aircraft	%	9.4%	2.5%	2.2%

¹Including non-combustion effects

The results show an aircraft NOx contribution of 9.4% which is the second smallest source group. For PM and VOC emissions (2.2-2.5%), the aircraft contributes the least.

4 Pollutant Concentrations from Dispersion Modelling

4.1 Modelled NO₂-Concentration

The dispersion calculations in LASPORT are carried out with the Lagrangian particle model LASAT (Lagrange Simulation of Aerosol Transport). The model is setup and verified according to the German guideline VDI 3945 Part 3 and has undergone various validation tests over recent decades. The following physical processes, including time dependencies, can be simulated: transport by the mean wind field, dispersion in the atmosphere, sedimentation of heavy aerosols, deposition on the ground, washout of trace substances by rain and wet deposition, chemical reactions, gamma submersion (cloud radiation). Thermal plume rise is covered parametrically according to the German guideline VDI 3782 Part 3.

The emission sources considered for the concentration modelling are only airport related sources. As such, the concentration maps below only show the additional concentrations by airport sources and not the total concentrations. In consequence, it is not directly possible to state the level of compliance with national standards, as these always apply to total concentrations.

4.1.1 NO₂-Concentrations of scenarios with variation in emissions

Figure 4-1 shows the concentrations of all airport sources for the two emission modelling Scenarios B and E (Simple and Advanced emission calculation method). As the meteorological time series is the same in both cases, the difference is caused by the variation in the emission input.

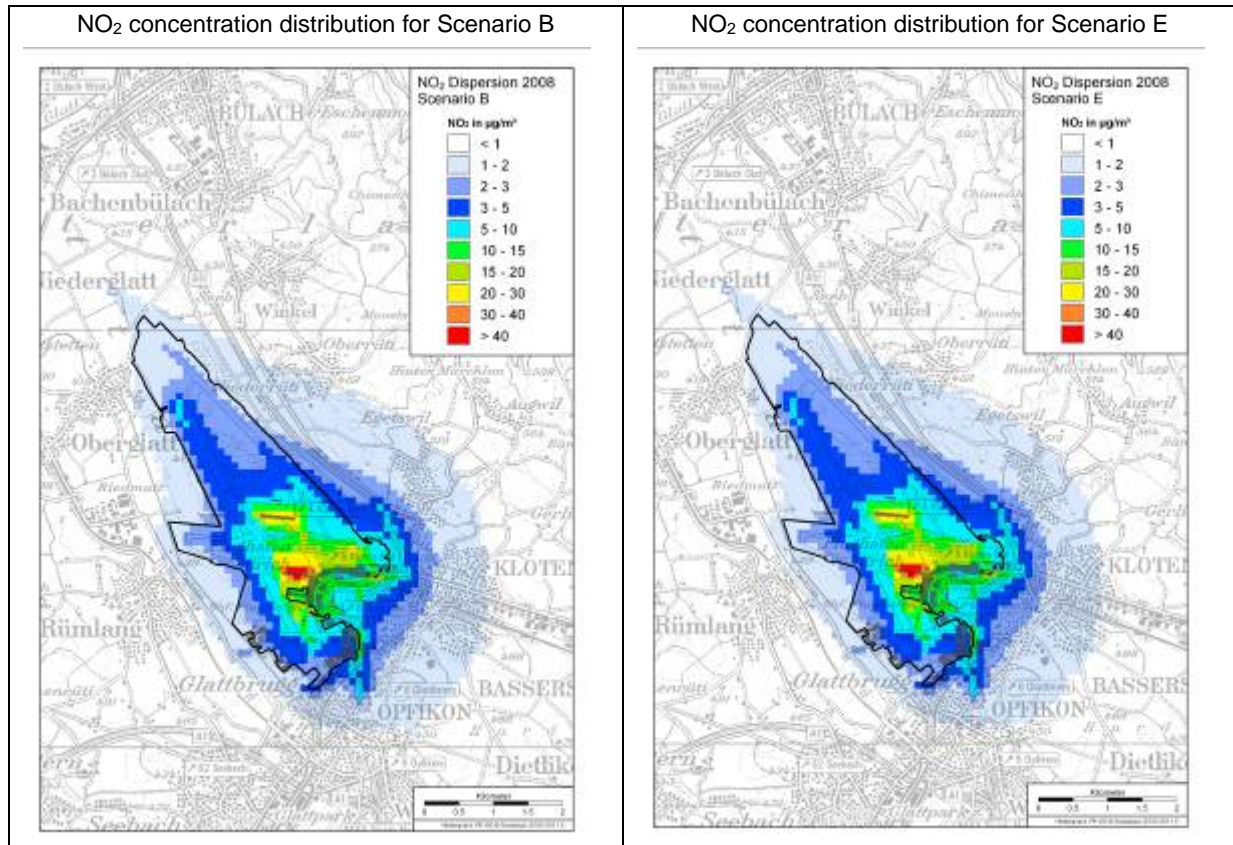


Fig. 4-1: NO₂ concentrations $\mu\text{g}/\text{m}^3$ annual mean for airport emission sources in Scenarios B and E

Both pictures indicate higher concentrations in areas of higher activities (apron, runway threshold, highways). With the given scale, the differences are not apparent. Figure 4-2 thus shows the difference calculation between Scenario E and Scenario B.

The differences between the scenarios are mainly triggered by the difference in aircraft engine emissions. Those emissions changes are due to more refined emission data information and the application of performance modelling. The results show lower concentrations (-0.2 to $-0.8 \mu\text{g}/\text{m}^3$ NO_2) in the area of runway 28 (cf. Fig. 2-1), the main take-off runway for short and medium range aircraft that often take-off with less than 100% take-off thrust. Higher concentrations (0.2 to $0.8 \mu\text{g}/\text{m}^3$ NO_2) can be observed at the runway threshold 16, the main take-off runway for long-range aircraft. This could be attributed to the fact that emissions at take-off thrust (in these cases closer to 100% thrust setting) are emitted during a longer period of time (slow aircraft acceleration) than in the certification cycle with linear acceleration along take-off.

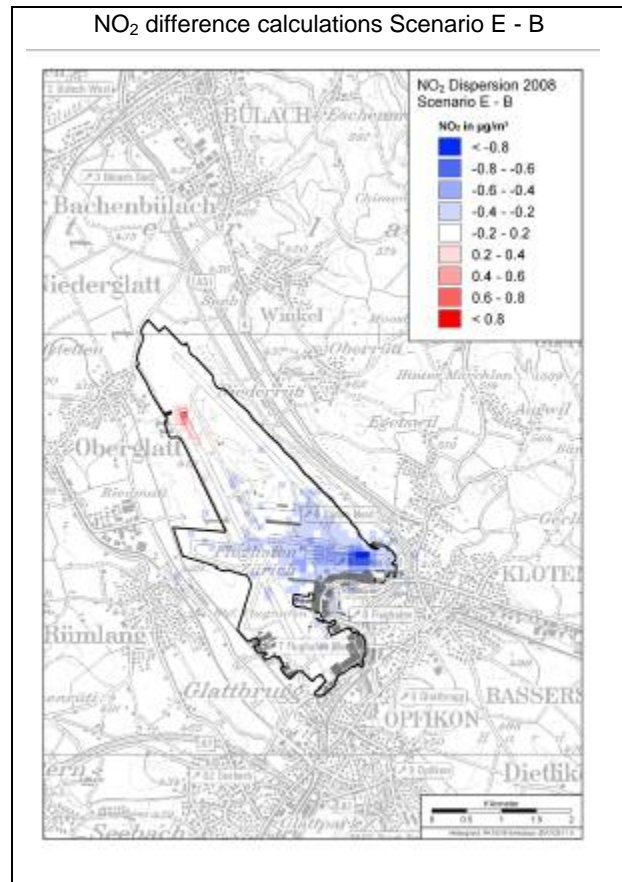


Fig. 4-2: Difference calculations E - B

4.1.2 Aircraft and airport sources

An important consideration is setting the aircraft (main) engine emissions in the LTO cycle in context to all other emission sources at the airport (including the aircraft APU emissions). The results for the NO_2 concentrations (Scenario E) are displayed in Figure 4-3 (a & b).

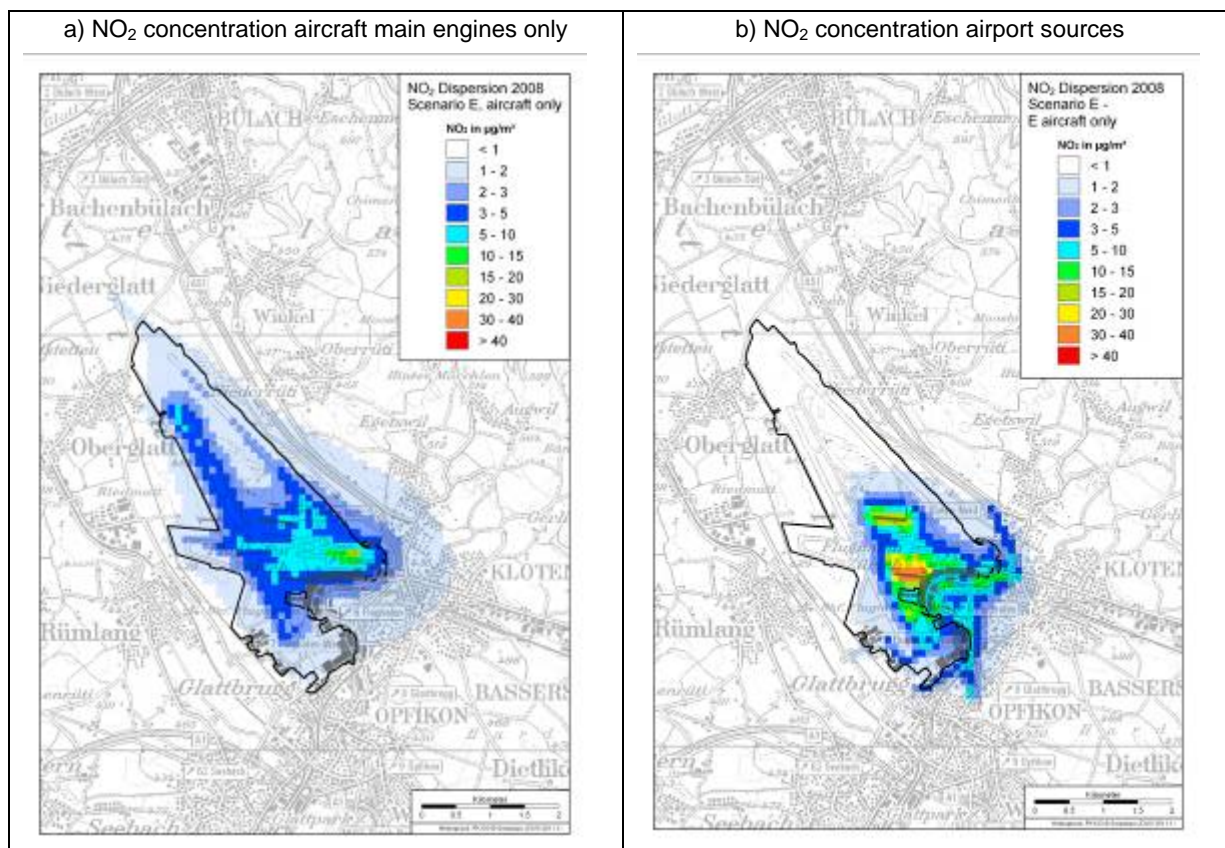


Fig. 4-3: NO_2 concentrations $\mu\text{g}/\text{m}^3$ annual mean for aircraft and airport emission sources in Scenario E.

The pictures show the different effects of ground based emissions (b) and the both ground and air based emissions from the aircraft (a). Ground based airport emissions tend to produce high concentrations, but are spatially rather contained within the airport and along the access roads while the ground/air based aircraft emissions are spread over a larger area, but with generally lower emissions. This is also due to the fact that only emissions up to a height of approximately 300m above ground contribute significantly to the concentrations on the ground. Emissions above this height contribute to the overall concentration picture only marginally and such concentrations may even be within the statistical uncertainty of the model.

A comparison between the Scenarios B and E for the aircraft-induced emission concentration only shows a very similar pattern as displayed in Figure 4-2.

4.1.3 NO_2 -Concentrations of scenarios with variation in meteorological data

For the dispersion calculation, a meteorological times series with values of wind speed and wind direction at a specified height above ground and the Monin-Obukhov length (or stability class) as a metric of the atmospheric stability are required. Wind directions and speeds are applied exactly as provided; the time series can consist of intervals of arbitrary length (typically one hour). For Zurich Airport, data from the airport meteorological station has been used for wind speed and direction, pressure, temperature and humidity. The atmospheric stability has been derived from data obtained by an ultrasound anemometer in 10-minute-intervals (Figure 4-4).

Sometimes, only wind speed and direction are available and no additional information on the atmospheric stability. For Zurich airport, it has been attempted to derive a time series based on publicly available 10-year average data [15]. Using only the most prominent wind direction with an average wind speed or the most prominent wind direction with most prominent wind

speeds have yielded unrealistic concentrations and cannot be used. The next step was to evaluate all wind direction/speed combinations and to create a one week time series with 10 minutes values according to the percentage distribution of the various combinations. These time series has been randomly distributed over the year. Also the stability classes have been assumed equally present and distributed randomly over the year (Figure 4-5).

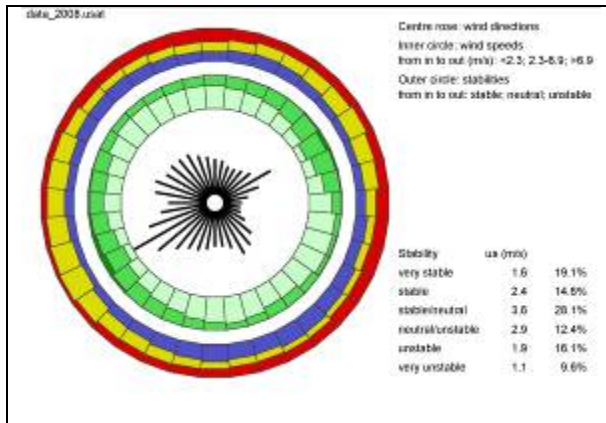


Fig. 4-4: Actual meteorological information for Zurich airport in 2008

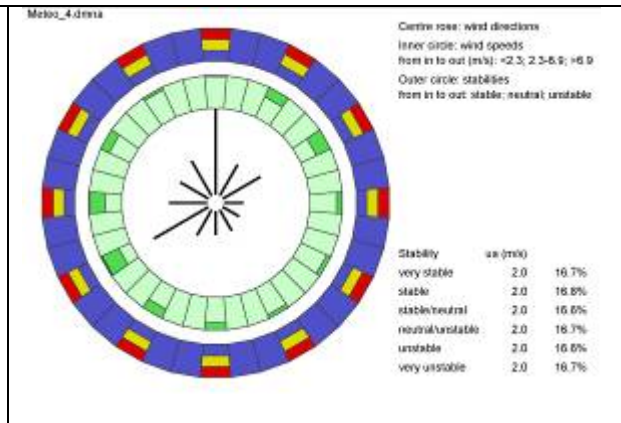


Fig. 4-5: Modelled simple meteorological information for Zurich airport

For Scenario B, this simple meteorological time series has been applied and the concentration modelled (Figure 4-6). The difference to the concentration distribution with the actual meteorological data is shown in Figure 4-7.

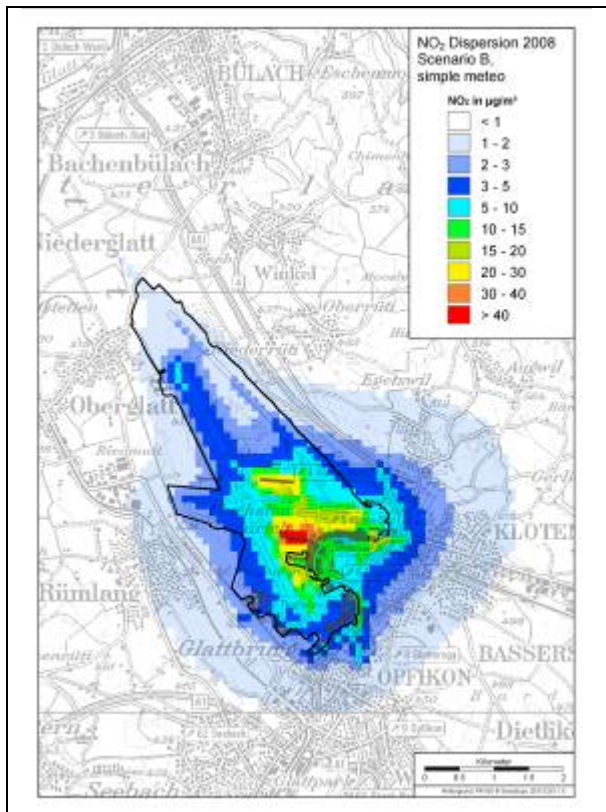


Fig. 4-6: Scenario B concentration distribution using a modelled simple meteorology.

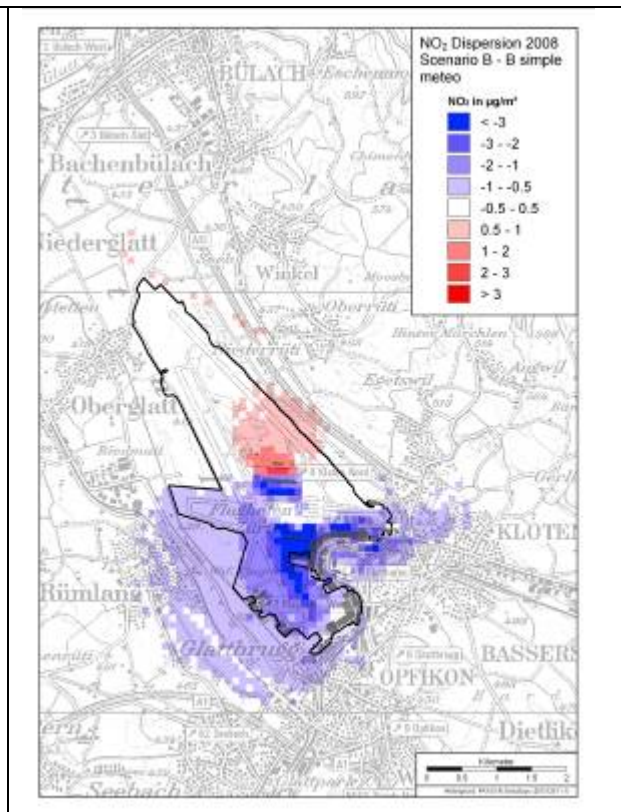


Fig. 4-7: Difference between the simple modelled and actual meteorology for Scenario B.

The modelled simple meteorology shows basically the same dispersion pattern as with actual meteorology. The differences show that with the modelled simple meteorology, the concentrations are mostly overestimated. This result depends on the details of how the

simplified meteorology has been set up and it cannot be generalised. However, it is generally true that the detail and quality of the meteorological input has a strong impact on the resulting concentration distribution.

4.1.4 NO₂-Concentrations of scenarios with variation in emissions and meteo

The previous sections have presented the different effects of changing the methodologies for emission input or for meteorological data. In many cases an application may suffer from both lack of information of emission sources and required meteorological data. A final analysis is presented demonstrating the the difference between Scenario B with a simple modelled meteorology and Scenario E with actual required meteorological information (Figure 4-8).

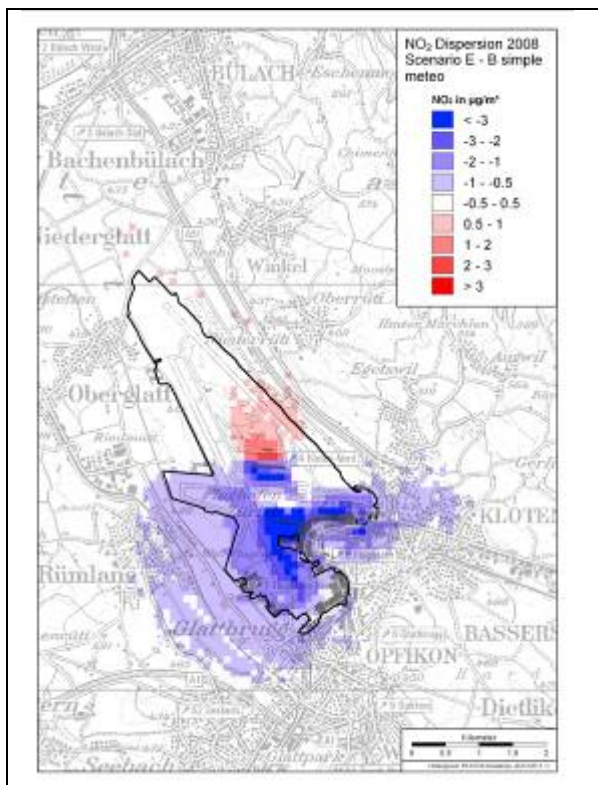


Fig 4-8: Difference between simple and advanced methods for both emissions and meteorological data

A comparison between Figures 4-7 and 4-8 shows few differences. This confirms other findings at Zurich airport that the variations in emissions have generally smaller effects than variations in meteorological conditions. This was first observed in 2001 after the September and October events (9/11 and Swissair grounding) when emissions dropped by 20% but showed virtually no effects on the NO₂ values that were measured at the airport's measurement station. It has to be noted that these findings hold true for Zurich airport, but may not necessarily be generalised.

4.2 Measured Ambient Air Quality

Zurich airport has conducted ambient air quality measurements at the airport since 1996 and in the airport region since 2001. The station locations were determined in cooperation with the cantonal authorities who also perform the measurements (data management and station maintenance). While the stations on the airport premises are automatic continuous measurement stations for NO, NO₂, O₃, SO₂ and PM₁₀, the stations outside the airport are NO₂ passive sampling tubes [14].

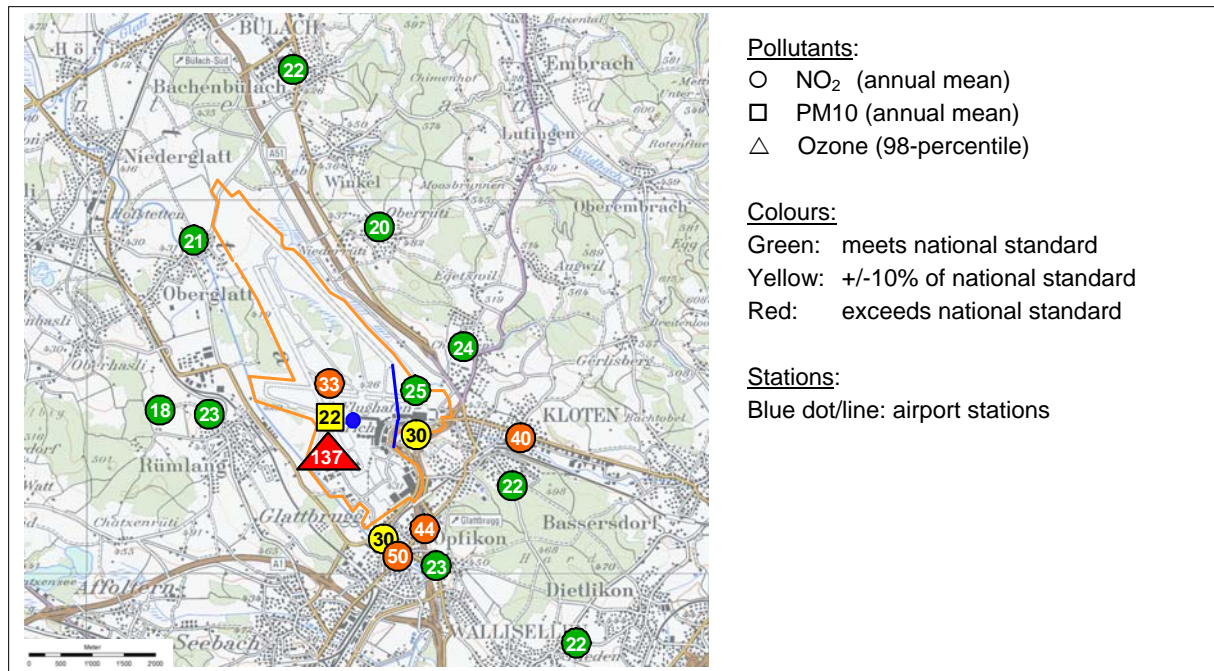


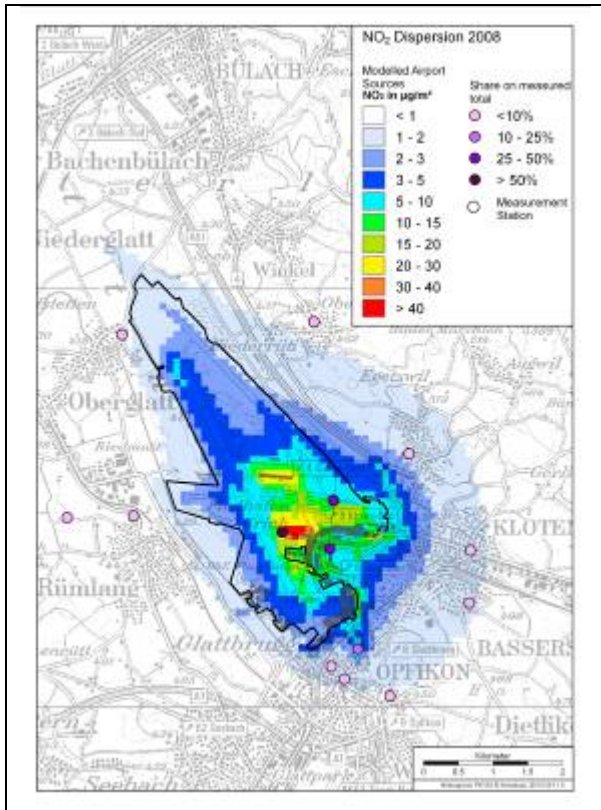
Fig. 4-9: Airport air pollution measurement stations for different pollutants and 2008 concentrations in $\mu\text{g}/\text{m}^3$

The results for NO₂ show legal compliance for most locations, but exceeded values at locations mainly dominated by road traffic and also in the middle of the airport premises (Figure 4-9). Ozone and PM10 are still showing exceeded values similar to those in many areas throughout Switzerland. SO₂ concentrations (not illustrated) are very low and of no significance.

4.3 Airport Specific NO₂-Impacts on Local Air Quality

In the context of local or regional studies it is often of interest to determine the impacts of airport related emissions in relation to the total impacts. As has been discussed, the emission masses are not a representative metric, because these results depend on the chosen system boundary. When using pollutant concentrations instead, at locations distant from the airport, the contribution of airport related emission sources can become insignificant. However, this can only be determined by modelling and not by measuring.

Consequently, the most appropriate approach to modelling should be to generate a regional model with all sources (airport and non-airport related) and then to identify the contributions of individual sources. This has been done for Zurich airport for a Scenario B calculation in 2004 [15]. In lieu of an actual regional modelling, the measurement station network for NO₂ in the airport region has been used to determine the modelled share from airport related sources to the total measured concentrations for 2008 (Figure 4-10).



The results for Zurich airport in 2008 show significant shares of airport impacts within the airport perimeter and areas of high activities (>25%). With increasing distance away from the airport, the share decreases rapidly and becomes less than 10% within 1 kilometre distance from the airport boundary. Other emission sources become thus predominant at locations removed from the airport.

Fig 4-10: Share of modelled airport sources on measured total concentrations.

5 Conclusions

The sensitivity analysis for Zurich airport emission and concentration dispersion modelling for 2008 has shown the following results:

- An increase in emission calculation complexity and accuracy reduces the calculated emission masses for NO_x, PM and CO₂ significantly, and increases the emissions from HC and CO at the same time.
- The variation of calculated emissions from the aircraft's main engines has the largest impact on the total emission mass.
- The emission mass is not a suitable metric to describe the significance of airports in the context of regional air quality, as aircraft emissions are often counted up to 914 m above the airport level, whilst other sources are at ground level only.
- Regional assessments require too many local assumptions to allow comparisons between different regions.
- Aircraft pollutants spread over a larger area outside the airport perimeter than airport ground sources.
- As close as 1 km from an airport boundary, the contribution to pollutant concentration levels from airport sources can be 10% or less.
- The distribution of NO_x concentration tends to be more dependent on meteorological conditions than on the variation in emissions. Therefore, when modelling dispersion, the accuracy of the meteorological data can be more important than the level of sophistication of the emissions calculations.

Depending on the specific requirements set forward by authorities or by stakeholder interests it is important to define the necessary level of complexity for emission calculation and concentration modelling. As specified in ICAO Doc 9889, the application of simple approaches may be sufficient. However, where a lower level of uncertainty in the modelling is required, more complex approaches have to be adopted. This increases the range and quality of the data required and the necessary data processing and modelling expertise. For Zurich airport, the application of advanced or sophisticated approaches in combination with a suitable dispersion model is important in the stakeholder dialogue.

6 Reference Information

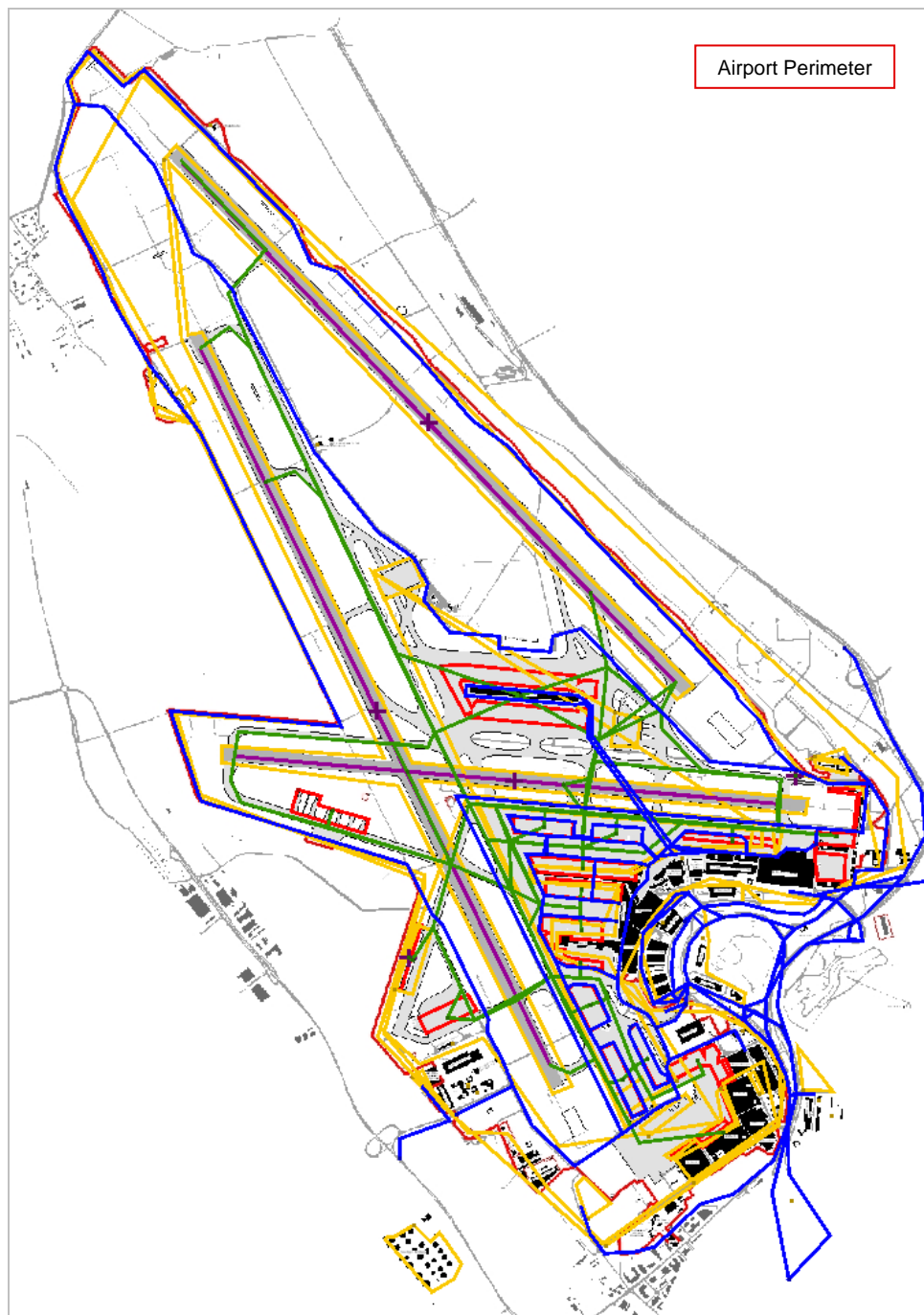
6.1 Abbreviations

ACI	Airport Council International, Geneva, Switzerland
ADAECAM	Advanced Aircraft Emission Calculation Method
AIP	Aeronautical Information Publication
CAEP	Committee in Aviation and Environmental Protection (ICAO)
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
FOCA	Federal Office for Civil Aviation, Bern, Switzerland
FOEN	Federal Office for the Environment, Bern, Switzerland
GHG	Greenhousegas Protocol (www.ghgprotocol.org)
HC	Hydrocarbons
IATA	International Air Transport Association, Geneva
ICAO	International Civil Aviation Organisation, Montreal
LASAT	Langrangian Simulation of Aerosol Transport
LASPORT	LASAT for Airports
LTO	Landing and Take-off Cycle
NO _x	Oxides of Nitrogen
PM	Particulate Matter
RWY	Runway
TWY	Taxiway
VOC	Volatile Organic Compounds

6.2 References

- [1] ICAO: Local Air Quality Guidance Manual, ICAO Doc 9889; Edition to be published 2010.
- [2] Janicke Consulting: Operating Manual LASPORT 2.0, 2009
- [3] Qinetiq: An advanced method for calculating the emissions from aircraft engines in the vicinity of airports. Qinetiq/07/02460. October 2007.
- [4] Flughafen Zürich AG and Swiss International Air Lines: Aircraft NOx-Emissions within the Operational LTO Cycle. Zurich, 2004.
- [5] Flughafen Zürich AG: ADAECAM Case Study Zurich Airport 2006. Zurich, September 2007.
- [6] Janicke, Ulf: LASPORT applied in CAEP/goals assessment (2009). Status Report 2009-05-05.
- [7] Aeronautical Information Publication (AIP): LSZH, AD 2.21.2.5
- [8] Flughafen Zürich AG: Aircraft Ground Handling Emissions at Zurich Airport. Methodology and Emission Factors. Zurich, 2006.
- [9] Federal Office for the Environment (FOEN): Handbook emissions factors for road transport. Version 2.1. Bern, 2004
- [10] EUROCONTROL,
http://www.eurocontrol.int/environment/public/standard_page/AEM.html
(2009/09/21)
- [11] Greenhouse Gas-Protocol: www.ghgprotocol.org
- [12] Airport Council International (ACI): Guidance Manual: Airport Greenhouse Gas Emissions Management. Geneva. November 2009.
- [13] Baudirektion Kanton Zürich: Grundlagenbericht zum Massnahmenplan Lufthygiene 2008; Vernehmlassungsentwurf vom 8.10.2008 (*Canton of Zurich: Baseline study to the air quality mitigation plan 2008; consultation draft of October 8, 2008*)
- [14] Flughafen Zürich AG: Air Pollution Monitoring at Zurich Airport. Zurich, 2007.
- [15] MeteoSchweiz: Aeronautical Climatological Information Zurich LSZH, Arbeitsbericht Nr. 201. www.meteoswiss.ch
- [16] EUROCONTROL Experimental Center, Airport Local Air Quality Studies: Zurich Airport 2004, a comparison of modelled and measured air quality. EEC/SSE/2005/017. Paris, 2005.

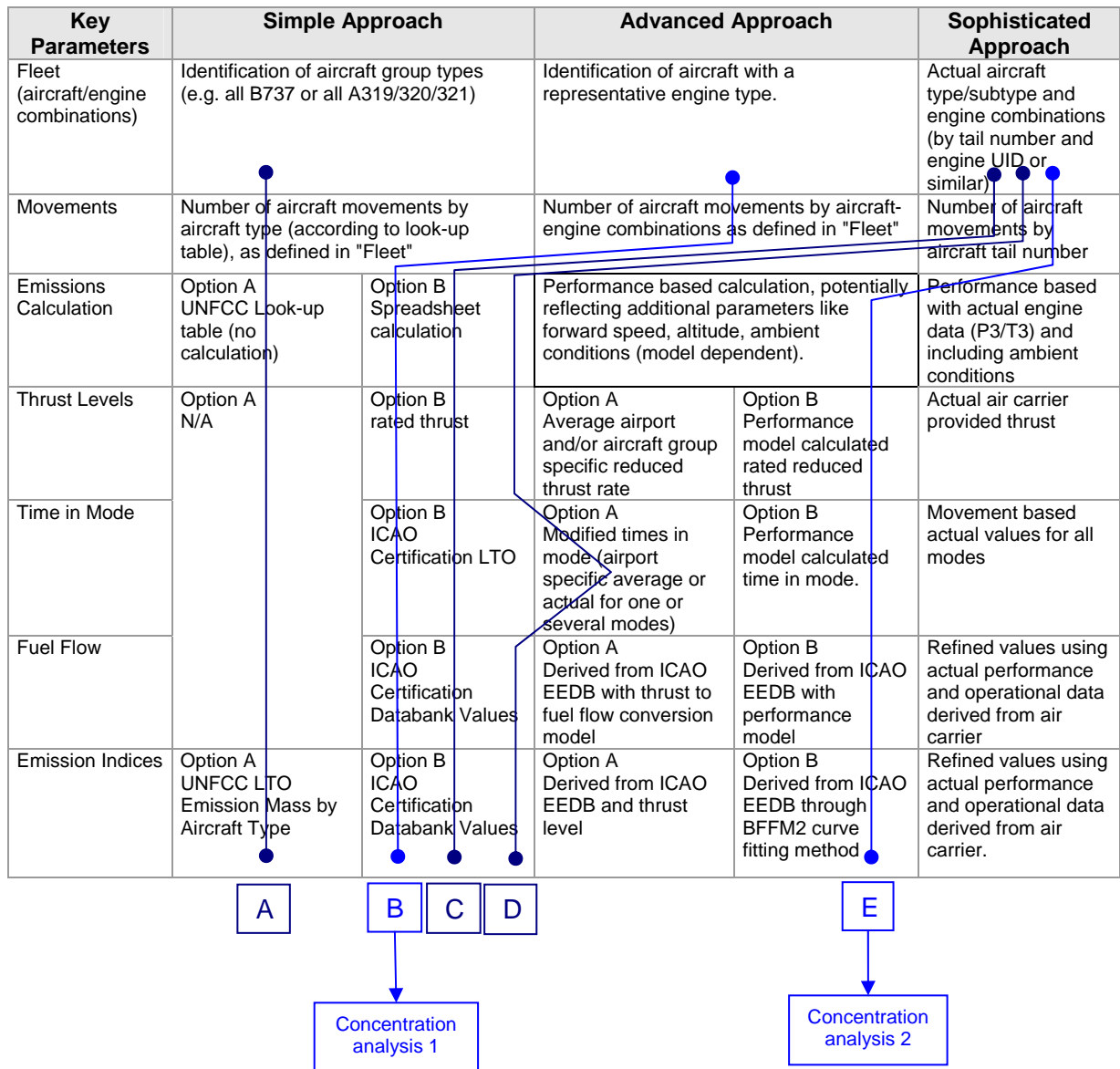
6.3 LASPORT Zurich Airport Study Setup



Color Scheme:

Purple:	Runways
Green:	Taxiways
Red:	Aircraft Stands
Blue:	Roads (airside and landside)
Yellow:	Other sources (infrastructure, fuelling, parking, ...)
Not displayed:	Departure routes

6.4 Aircraft Emission Calculation and Concentration Modelling Approaches



Scenarios A-E, with regard to ICAO Doc 9889, Annex A1, Table 1

6.5 Detailed Aircraft Engine Emissions

The following table shows the detailed results for the various elements in the Landing- and Take-Off cycle (LTO).

LTO-Cycle Mode	Approach A (UNFCCC Table)	Approach B (Rep. fleet, ICAO cert. LTO)	Approach C (Detailed fleet, ICAO cert. LTO)	Approach D (Detailed fleet, modif. ICAO LTO)	Approach E (Detailed fleet, performance based)
NOx (t/a)					
Take-off Ground (TG)	-	298	298	298	226
Climb Initial (CI)	-	612	600	600	200
Climb Final (CF)	-	-	-	-	178
Approach Final (AF)	-	173	168	168	189
Approach Ground (AG)	-	-	-	-	5
Idle (ID)	-	190	176	113	113
Total Aircraft Engines	1'078	1'273	1'242	1'179	912

HC (t/a)					
Take-off Ground (TG)	-	1	1	1	18
Climb Initial (CI)	-	2	3	3	16
Climb Final (CF)	-	-	-	-	16
Approach Final (AF)	-	4	26	26	30
Approach Ground (AG)	-	-	-	-	6
Idle (ID)	-	129	177	111	130
Total Aircraft Engines	110	136	207	141	215

CO (t/a)					
Take-off Ground (TG)	-	11	14	14	58
Climb Initial (CI)	-	30	51	51	49
Climb Final (CF)	-	-	-	-	62
Approach Final (AF)	-	66	186	186	204
Approach Ground (AG)	-	-	-	-	43
Idle (ID)	-	1'107	1'435	895	938
Total Aircraft Engines	1'099	1'214	1'686	1'146	1'354

PM (t/a)					
Take-off Ground (TG)	-	2	2	2	2
Climb Initial (CI)	-	5	4	4	1
Climb Final (CF)	-	-	-	-	1
Approach Final (AF)	-	2	3	3	3
Approach Ground (AG)	-	-	-	-	0
Idle (ID)	-	5	4	3	3
Total Aircraft Engines	-	13	13	11	10

CO ₂ (t/a)					
Take-off Ground (TG)	-	35'894	36'893	36'893	33'381
Climb Initial (CI)	-	92'842	95'310	95'310	28'894
Climb Final (CF)	-	-	-	-	29'549
Approach Final (AF)	-	59'135	60'603	60'603	63'626
Approach Ground (AG)	-	-	-	-	4'083
Idle (ID)	-	142'481	141'014	89'023	89'158
Total Aircraft Engines	268'096	330'351	333'820	281'828	248'691