Sensitivity of Aircraft Operational Improvements

LAQ Modeling of Landing and Take-off Cycles

Contents

1. Introduction

1.1. Study context and setup

Aviation has endorsed ambitious goals to improve fuel efficiency and reduce impacts on the climate and local air quality in the coming decades. To achieve these goals will require not only developments in engine technology but also in the operation of aircraft. Such developments are expected to be delivered through programs like SESAR (Single European Sky ATM Research) or NextGen (Next Generation Air Transportation System). While some measures are aimed at reducing fuel burn during cruise flight, other measures aim at reducing fuel burn and emissions at or around airports.

Today, aircraft emissions at and around airports are quantified using specific local air quality models, usually compliant with ICAO Doc 9889 (Airport Air Quality Guidance Manual, 2011). Such models are designed for different levels of complexity with regards to data input and processing. Historically, Zurich airport has been using the advanced model LASPORT, now with the integrated performance model ADAECAM.

The purpose of this study is twofold:

- To model a series of aircraft operational improvements (scenarios) using actual Zurich airport air traffic data of the year 2010 and to quantify the changes in fuel burn, CO_2 emissions and NOx emissions if such scenarios were applied at Zurich airport. It should also give a feel about which measures or parameters have the largest impact on fuel burn and emissions at the airport
- To identify limitations of the applied model with regard to modeling specific operational changes

Operational improvements have been suggested in the area of aircraft taxiing (e.g. with less than all engines operating and modified taxi-times). In addition, effects of reversed thrust application and the influence of changing ambient conditions are studied. In a second set, modifications have been suggested for the operation of long-haul aircraft with different taxi-routes (upon arrival and departure) and take-off weight.

The study supports work done within SESAR (WP 16, Transversal Activities, Environment). It also supports modeling work done routinely at Zurich airport with the intent to identify potential areas of model development in the future.

1.2. Maps

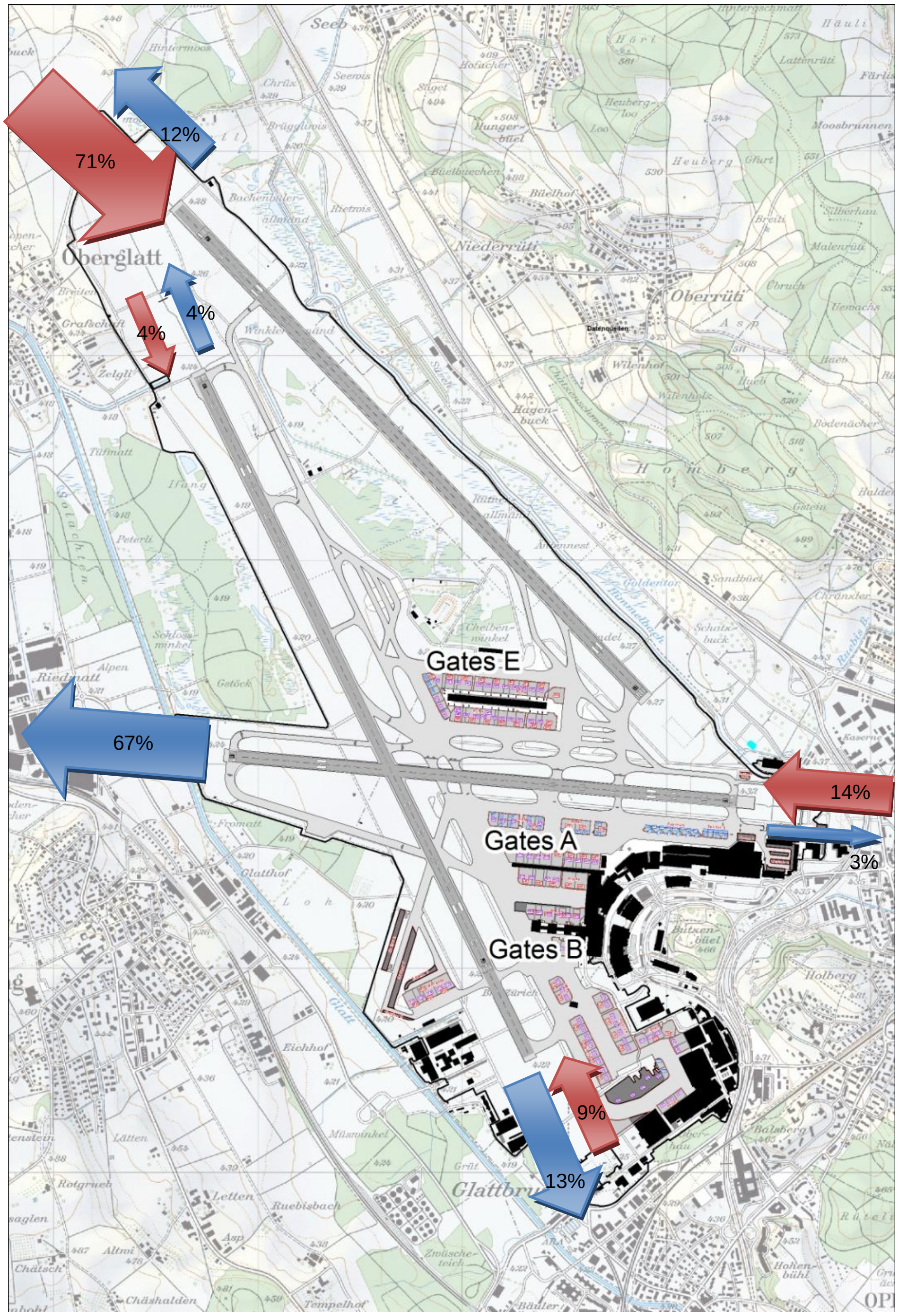


Figure 1 Airport Zurich overview map and runway usage 2010.

1.3. Traffic Data Zurich Airport 2010

Aircraft Type	*Arrivals (1/a)*	*Departures (1/a)*	*Movements (1/a)*	*Percent (1/a)*
Large	5'531	5'533	11'064	4.12
Medium	6'366	6'369	12'735	4.75
Small	90'752	90'741	181'493	67.63
Regional	10'109	10'119	20'228	7.54
Business	7'292	7'317	14'609	5.44
Turboprop	7'243	7'257	14'500	5.40
Piston	4'662	4'716	9'378	3.49
Heli Large	132	132	264	0.10
Heli Small	2'037	2'041	4'078	1.52
Total	*134'124*	*134'225*	*268'349*	*100*

Table 1: Movements at Zurich Airport 2010, used for base case calculation (without touch and go and go around).

Aircraft Type	*Model Family*
Large	A380, A340, B777, B747
Medium	A330, B767, A310
Small	A320, BAe 146, F100, B737
Regional	Embraer E-Jets, CRJ, CL60, Gulfstream IV/V…

Table 2: Aircraft type data base.

2. Calculation specifications

2.1. Emission calculation

Lasport 2.0 (Janicke consulting) was used for all emission calculation in this document.

2.2. Terminology

Monitor Calculation: Aircraft traffic specified in a movement journal based on detailed airport setup.
Simple Monitor Calculation: Aircraft traffic specified in a movement journal without accounting for airport details.
Scenario Calculation: Aircraft traffic specified by general traffic information.

ADAECAM emission strengths and profiles: For each movement and LTO phase, the trust-dependent emission strengths and departure profiles are calculated with the performance model ADAECAM on the basis of the specified engine UID, number of engines, distance to the destination airport for departures (for estimating takeoff weight and departure profile) and given values of ambient temperature, pressure and relative humidity.

ICAO emission strengths and profiles: Based on the specified aircraft type, engine UID and number of engines, the emission strengths per LTO phase based on the ICAO engine emission data bank and the default profile according to the LASPORT default profile set are inserted for each movement.

3. Scenarios

3.1. Scenarios for all aircraft traffic 2010 at Zurich Airport

The following scenario calculations are based on the actual aircraft traffic at Zurich Airport of the year 2010.

3.1.1. Base Cases

The base cases show the results of the emission calculation for the air traffic LTO cycle of Zurich Airport for 2010. There are three base cases calculated in the three different calculation modes. Due to the fact that the later on calculated scenarios have to be calculated in one of the three different calculation modes, the comparison should be done with the base case in the same mode.

The monitor calculation is the most accurate calculation based on the performance model of the detailed air traffic movement journal of Zurich Airport from 2010. The movement journal contains real taxi times for each movement. A digitized site map is used to define the exact positions and lengths of runways, taxiways, aircraft position areas and roads.

The simple monitor calculation uses the detailed movement journal, but disregards the airport details, so there's no exact runway length and taxiway path. The roll-off distance can be chosen, and reverse thrust mode can be accounted for in this calculation mode. The movement journal is the same as for the monitor calculation.

In the scenario mode the emission calculation bases on general traffic information per aircraft group. No real taxi times, but a function of the taxi route (from the imported airport map) and the velocity. ICAO emission strengths and LASPORT profile are used.

Case	Base Case monitor						
Calculation mode	Monitor Calculation						
Arrivals	134'124						
Departures	134'225						
Total Movements	268'349						
Details	ADAECAM emission strengths and profiles. Maximum Emission height: 914.4 m						
Changes to Case	-						
Emissions LTO Cycle (t)							
	Total	Approach Final	Approach Ground	Idle	Take-off Ground	Climb Initial	Climb Final
NO_x	**861.86**	177.97	5.10	118.16	206.51	185.96	168.15
FB	**79'340**	19'674	1'280	29'717	10'321	8'994	9'355
CO_2	**250'318**	62'071	4'038	93'757	32'562	28'376	29'514

Case	Base Case simple monitor						
Calculation mode	Simple Monitor Calculation						
Arrivals	134'124						
Departures	134'225						
Total Movements	268'349						
Details	ADAECAM emission strengths and profiles. Maximum Emission height: 914.4 m Roll off distance (Large,Medium,Small,Regional,Business,Turboprop): 1800 m Roll off distance (Piston): 1100 m						
Changes to Case	-						
Emissions LTO Cycle (t)							
	Total	AF	AG	ID	TG	CI	CF
NO_x	**861.83**	177.97	3.42	119.81	206.51	185.96	168.15
FB	**79'340**	19'674	843	30'154	10'321	8'994	9'355
CO_2	**250'318**	62'071	2'659	95'136	32'562	28'376	29'514

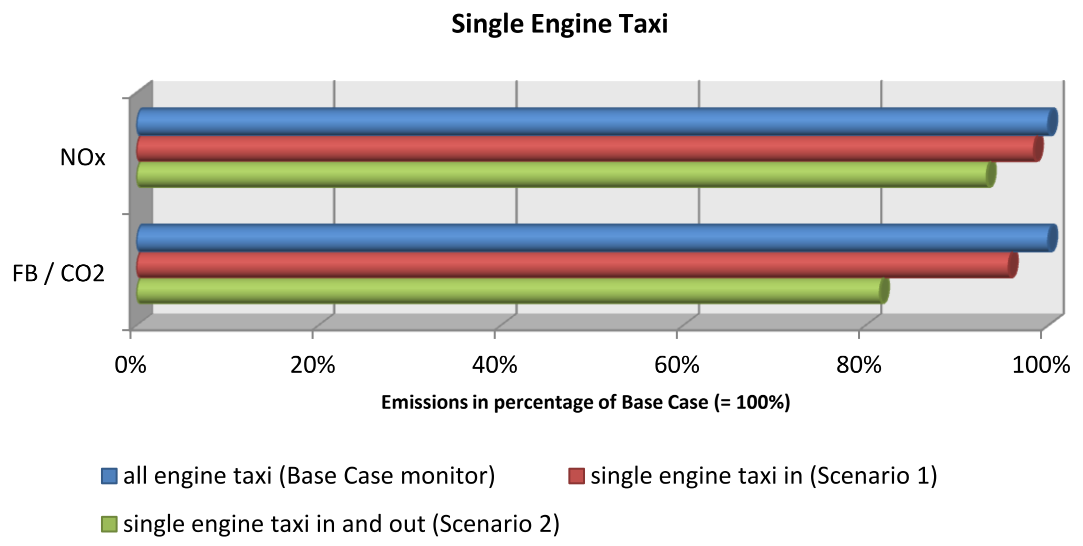
Case	Base Case Scenario						
Calculation mode	Scenario Calculation						
Arrivals							
Departures							
Total Movements	268'349						
Details	ICAO emission strengths and LASPORT profiles. Maximum Emission height: 914.4 m Taxi times are calculated mean times for each runway/aircraft stand combination.						
Changes to Case	-						
Emissions LTO Cycle (t)							
	Total	AF	AG	ID	TG	CI	CF
NO_x	**1'056.78**	175.25	5.17	117.73	307.40	155.64	295.58
FB	**87'580**	20'520	1'309	29'495	12'515	8'141	15'602
CO_2	**276'316**	64'741	4'128	93'055	39'484	25'684	49'224

3.1.2. Single Engine Taxi

Single Engine Taxi for IDLE in or in and out. Aircraft with two engines are modeled using only one, aircraft with three or four engines are modeled using two engines.

Case	Scenario 1			
Calculation mode	Monitor Calculation			
Arrivals	134'124			
Departures	134'225			
Total Movements	268'349			
Details	ADAECAM emission strengths and profiles.			
Changes to Case	Base Case monitor: **- Single engine taxi in.**			
Emissions LTO Cycle (t)				
	Base Case monitor	Scenario 1	Δ (t)	Δ (%)
NO_x	**861.86**	**848.32**	-13.54	-1.6%
FB	**79'340**	**75'904**	-3'436	-4.3%
CO_2	**250'318**	**239'478**	-10'840	-4.3%

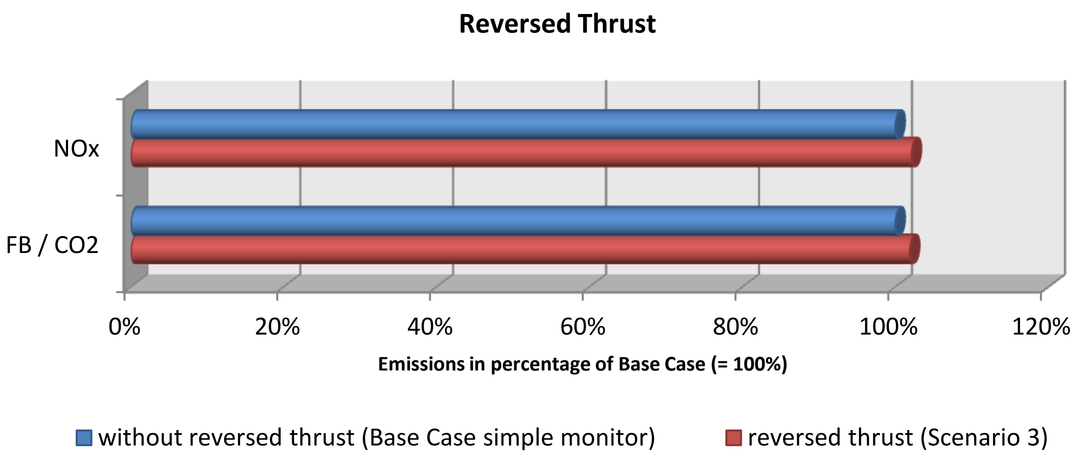
Case	Scenario 2			
Calculation mode	Monitor Calculation			
Arrivals	134'124			
Departures	134'225			
Total Movements	268'349			
Details	ADAECAM emission strengths and profiles.			
Changes to Case	Base Case monitor: **- Single engine taxi in and out.**			
Emissions LTO Cycle (t)				
	Base Case monitor	Scenario 2	Δ (t)	Δ (%)
NO_x	**861.86**	**803.76**	-58.10	-6.7%
FB	**79'340**	**64'703**	-14'637	-18.4%
CO_2	**250'318**	**204'138**	-46'180	-18.4%



3.1.3. Reversed Thrust

Comparison between landing without reversed thrust and a roll off distance of 1800 m (Piston 1100 m) and landing with reversed thrust and a roll off distance of 1400 m (Piston 900 m).

Case	Scenario 3			
Calculation mode	Simple Monitor Calculation			
Arrivals	134'124			
Departures	134'225			
Total Movements	268'349			
Details	ADAECAM emission strengths and profiles. Reversed thrust for LTO phase AG			
Changes to Case	Base Case simple monitor: Reversed thrust Roll off distance (Large,Medium,Small,Regional,Business,Turboprop): 1400 m Roll off distance (Piston): 900 m			
Emissions LTO Cycle (t)				
	Base Case simple monitor	Scenario 3	Δ (t)	Δ (%)
NO_x	**861.83**	**880.14**	18.31	+2.1%
FB	**79'340**	**80'843**	1'503	+1.9%
CO_2	**250'318**	**255'058**	4'740	+1.9%



3.1.4. Modifying taxi times

Taxi time for the base case scenario is the mean of the real taxi times for each runway/position area combination for arrival and departure. Scenario 4 contains the addition of two minutes taxi time (in total, for all aircraft). In scenario 5 the aircraft travel the defined path from runway to the position area (and back for departure) with a taxi velocity of 8.3 m/s and a waiting time prior to take-off of 4 minutes. The waiting time is changed for scenario 6 to 8 minutes.

Case	Scenario 4			
Calculation mode	Scenario Calculation			
Arrivals				
Departures				
Total Movements	268'349			
Details	ICAO emission strengths and LASPORT profiles.			
Changes to Case	Base Case Scenario: Taxi times: Base Case Scenario +1 Minute taxi time for all aircraft for landing and +1 Minute for departure.			
Emissions LTO Cycle (t)				
	Base Case Scenario	Scenario 4	Δ (t)	Δ (%)
NO_x	**1'056.78**	**1'070.15**	13.37	+1.3%
FB	**87'580**	**90'966**	3'386	+3.9%
CO_2	**276'316**	**286'998**	10'682	+3.9%

Case	Scenario 5
Calculation mode	Scenario Calculation
Arrivals	
Departures	
Total Movements	268'349
Details	ICAO emission strengths and LASPORT profiles.
Changes to Case	Base Case Scenario: Taxi times: no mean values, but modeled from taxi route runway/aircraft stand (from digital airport map) and taxi velocity: 8.3 m/s. Waiting time prior to start: 4 Minutes.

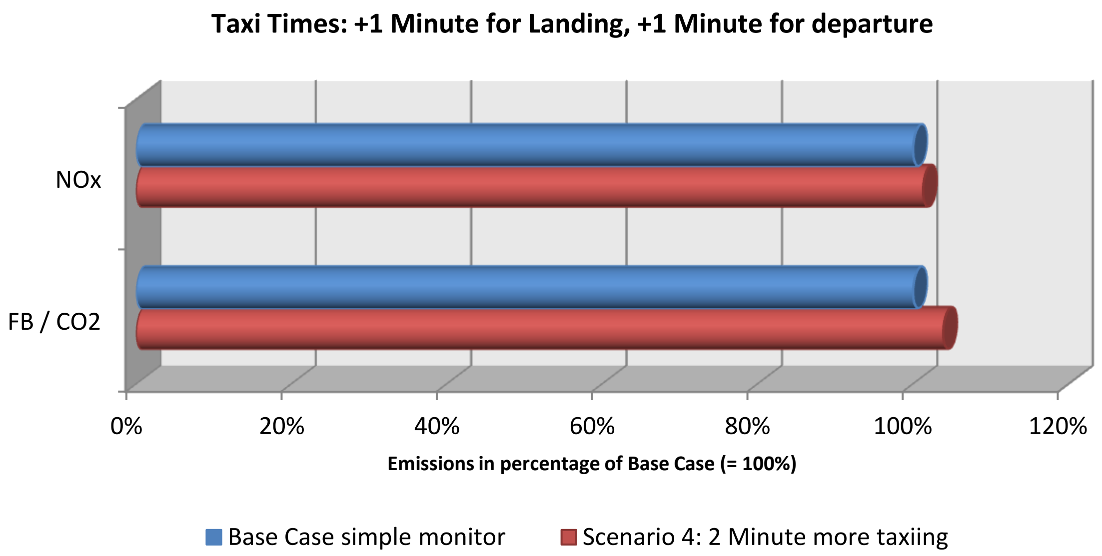
Emissions LTO Cycle (t)

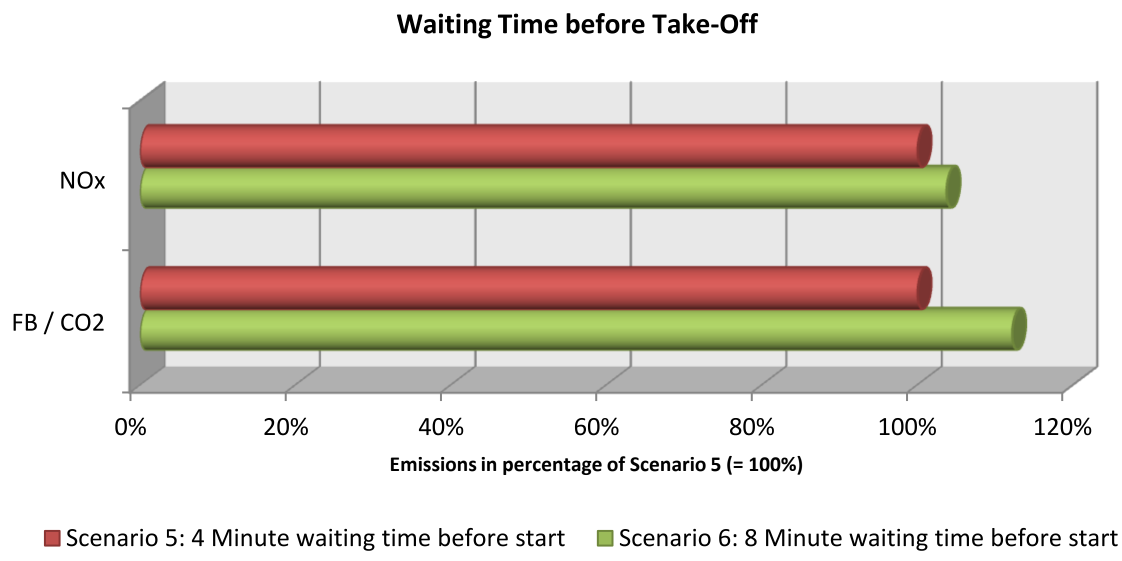
	Base Case Scenario	Scenario 5	Δ (t)	Δ (%)
NO_x	**1'056.78**	**1'023.26**	-33.52	-3.2%
FB	**87'580**	**79'431**	-8'149	-9.3%
CO_2	**276'316**	**250'603**	-25'713	-9.3%

Case	Scenario 6
Calculation mode	Scenario Calculation
Arrivals	
Departures	
Total Movements	268'349
Details	ICAO emission strengths and LASPORT profiles.
Changes to Case	Scenario 5: Taxi times: no mean values, but modeled from taxi route runway/aircraft stand (from digital airport map) and taxi velocity: 8.3 m/s. **Waiting time prior to start: 8 Minutes.**

Emissions LTO Cycle (t)

	Scenario 5	Scenario 6	Δ (t)	Δ (%)
NO_x	**1'023.26**	**1'061.43**	38.17	+3.7%
FB	**79'431**	**89'099**	9'668	+12.2%
CO_2	**250'603**	**281'108**	30'505	+12.2%





3.1.5. Ambient parameters

Fuel flows and emission indices that are provided in the ICAO engine emission data bank comprise certification based values. In an actual LTO cycle under realistic atmospheric and operational conditions, the emissions can be different. Thrust settings at take-off are often below 100% and depend on the actual aircraft weight (chapter 3.2.3). Emission indices depend on ambient conditions, in particular on temperature. The ADAECAM calculation model requires the ambient temperature, pressure and relative humidity at the ground for calculating the NO_x emissions of the LTO cycle. In the model, ambient parameters have no influence on fuel flow.

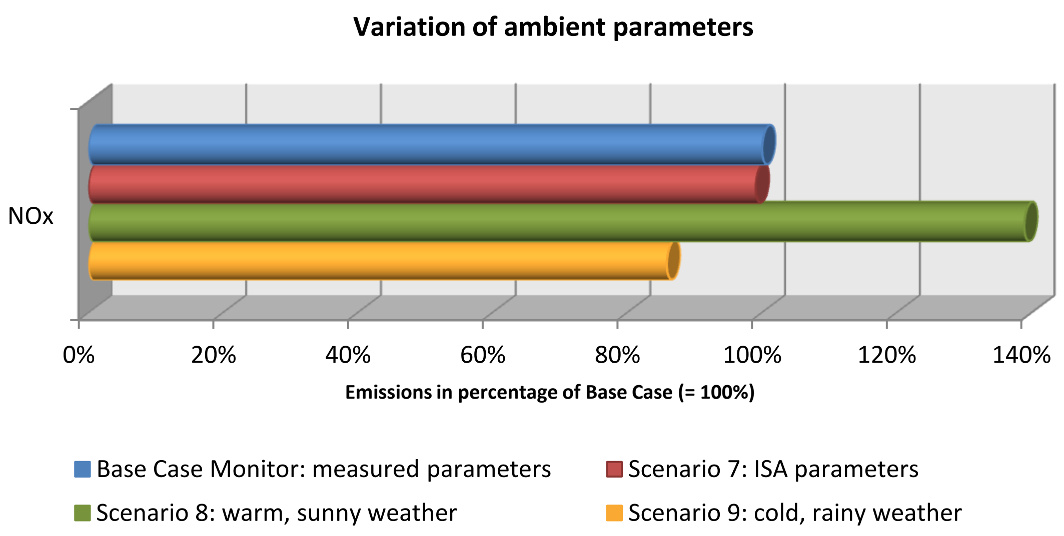
Ambient parameters

	Weather regime	Temperature (°C)	Pressure (QFE) (Pa)	rel. Humidity (%)
Base Case Monitor	Measured parameters	hourly mean	hourly mean	hourly mean
Scenario 7	ISA conditions	15	101'325	60
Scenario 8	Warm, sunny	25	98'000	50
Scenario 9	cold, rainy	5	96'000	90

Case	Scenarios 7, 8, 9
Calculation mode	Monitor Calculation
Arrivals	134'124
Departures	134'225
Total Movements	268'349
Details	ADAECAM emission strengths and profiles. Maximum Emission height: 914.4 m
Changes to Case	-

Emissions LTO Cycle (t)

	Base Case Monitor	Scenario 7	Scenario 8	Scenario 9
NO_x	**861.86**	**853.76**	**1'197.30**	**739.88**
FB	**79'340**	**79'340**	**79'340**	**79'340**
CO_2	**250'318**	**250'318**	**250'318**	**250'318**



3.2. Scenarios for selected aircraft groups

The subsequent scenarios are done with different aircraft groups for special regimes to show the difference on emission production of a change in the procedure.

3.2.1. Modeling different taxi routes for arrival

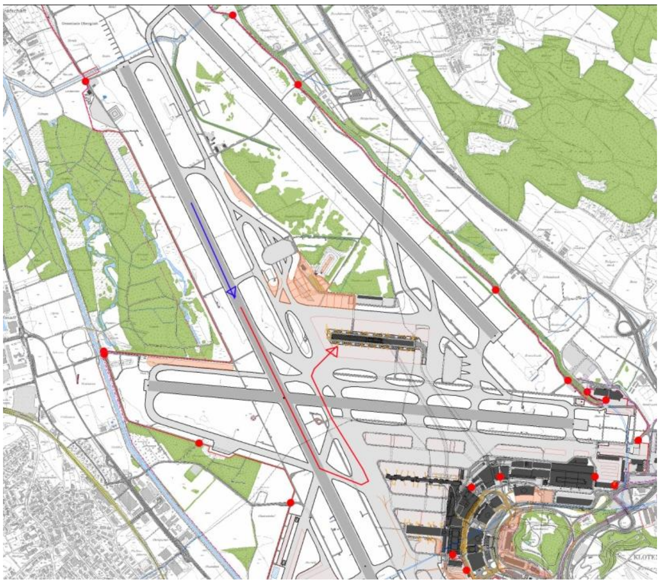


Figure 2 Landing RWY 16, taxi E7 to Pier E

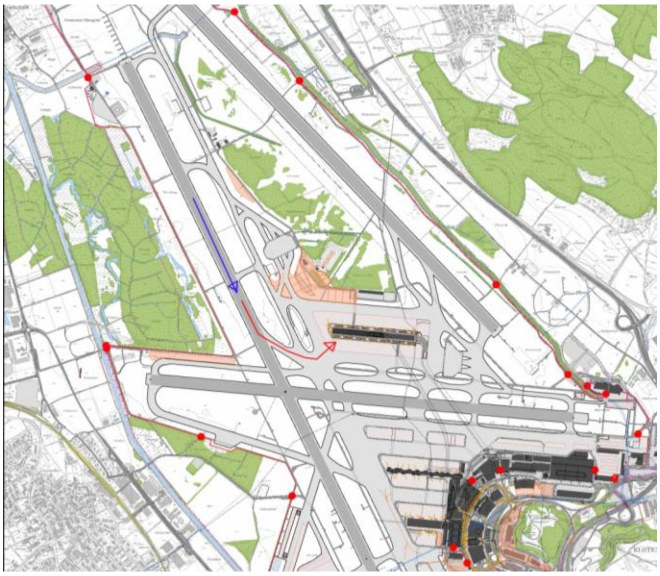


Figure 3 Landing RWY 16, taxi E5 to Pier E

Case	Scenario 10
Calculation mode	Monitor Calculation
Arrivals	5'531
Departures	0
Total Movements	5'531
Details	Only arrival of aircraft of group 'Large' on Runway 16. Taxi via TWY E7 to pier E (figure 2). Taxi times: no mean values, but modeled from taxi route runway/aircraft stand (from digital airport map) and taxi velocity: 8.3 m/s. No waiting time for crossing RWY 10/28.
Changes to Case	

Emissions arrival (t)

	Scenario 10
NO_x	**30.65**
FB	**2'879**
CO_2	**9'082**

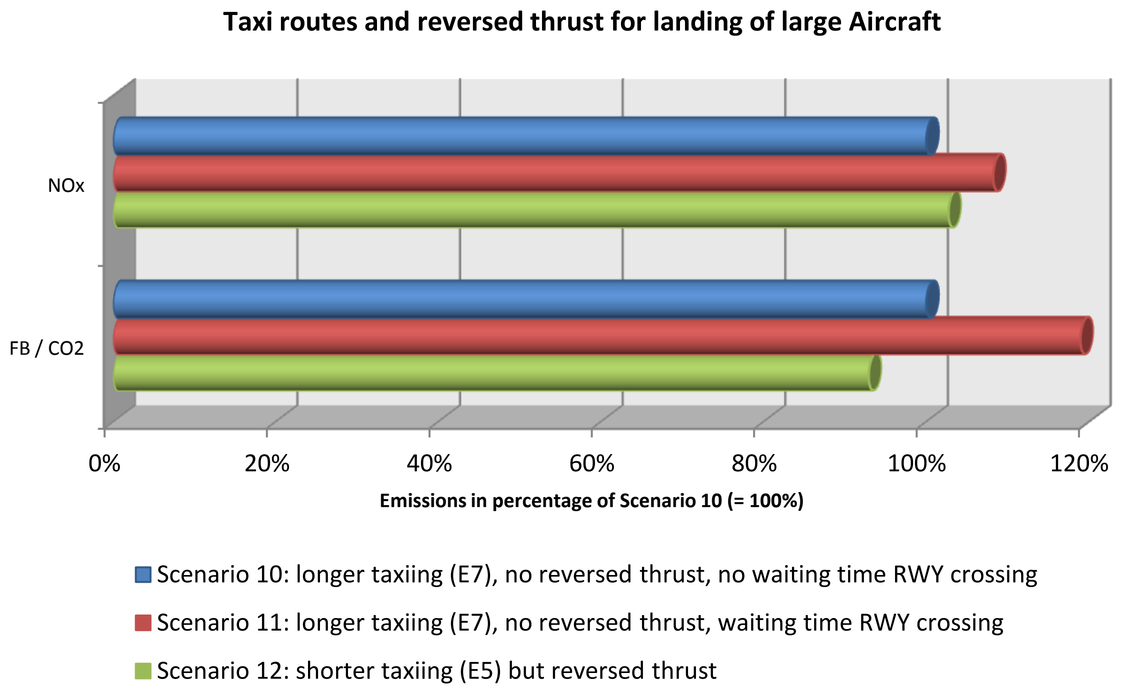
Case	Scenario 11
Calculation mode	Monitor Calculation
Arrivals	5'531
Departures	0
Total Movements	5'531
Details	Only arrival of aircraft of group 'Large' on Runway 16. Taxi via TWY E7 to pier E (figure 2). Taxi times: no mean values, but modeled from taxi route runway/aircraft stand (from digital airport map) and taxi velocity: 8.3 m/s. 2 minutes waiting time for crossing RWY 10/28.
Changes to Case	Scenario 10: 2 minutes waiting time for crossing RWY 10/28.

Emissions arrival (t)

	Scenario 10	Scenario 11	Δ (t)	Δ (%)
NO_x	**30.65**	**33.17**	2.52	+8.2%
FB	**2'879**	**3'424**	546	+19.0%
CO_2	**9'082**	**10'804**	1'722	+19.0%

Case	Scenario 12
Calculation mode	Monitor Calculation
Arrivals	5'531
Departures	0
Total Movements	5'531
Details	Only arrival of aircraft of group 'Large' on Runway 16 with reversed thrust. Taxi via TWY E5 to pier E (figure 3). Taxi times: no mean values, but modeled from taxi route runway/aircraft stand (from digital airport map) and Idle velocity: 8.3 m/s.

Changes to Case	Scenario 10: Reversed thrust, taxi via TWY E5.			
Emissions arrival (t)				
	Scenario 10	Scenario 12	Δ (t)	Δ (%)
NO_x	**30.65**	**31.49**	0.84	+2.7%
FB	**2'879**	**2'675**	-204	-7.1%
CO_2	**9'082**	**8'439**	-643	-7.1%



3.2.2. Modeling different taxi routes for departure

Emission calculation of large aircraft taxiing for departure from Pier E to either Runway 16 or to Runway 34. The average taxi time is the mean from all flights from E to 16/34 for the year 2010 (only large aircraft). Queuing time is the average taxi time minus the modeled taxi time (8.3 m/s) minus 2 minutes for push back from Pier E (estimation). Scenario 13 and scenario 14 is a calculation with the real average taxi time for both runways. Then we calculate the emissions if we cut the queuing time in half. For RWY 16 this would be a reduction of queuing time of 5:44 minutes. To RWY 34 the aircraft have to cross runway 10/28. If we model this queuing time to 2 minutes and divide in half that time too, then the total reduction sums up to 6:47 minutes for departure runway 34. This calculation is done in scenario 15 and 16.

	Runway 16	Runway 34
% of Starts from RWY (only large)	58%	33%
Taxiing distance from Pier E	2390 m	2266 m
Average taxi time	18:17 Minutes	18:08 Minutes
Modeled taxi time (8.3 m/s)	4:48 Minutes	4:33 Minutes
Queuing time (calculated, minus 2 Minutes for pushback)	11:29 Minutes	11:35 Minutes (incl. crossing RWY 10/28)

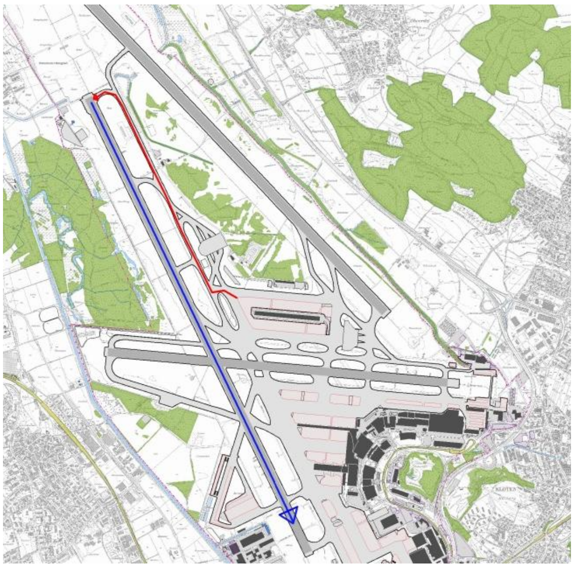


Figure 4 Departure RWY 16.

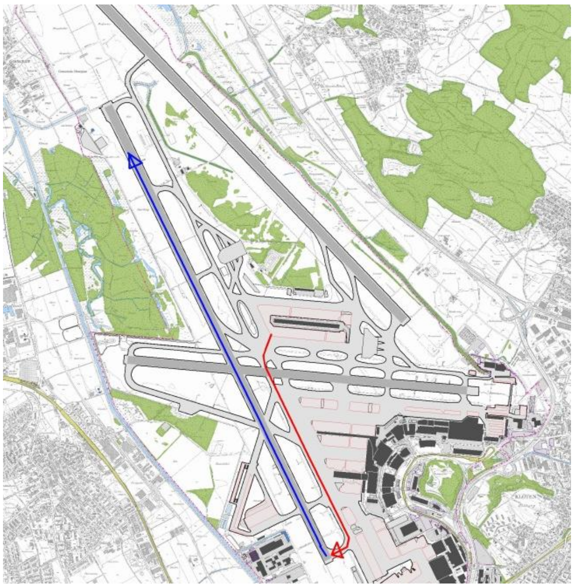


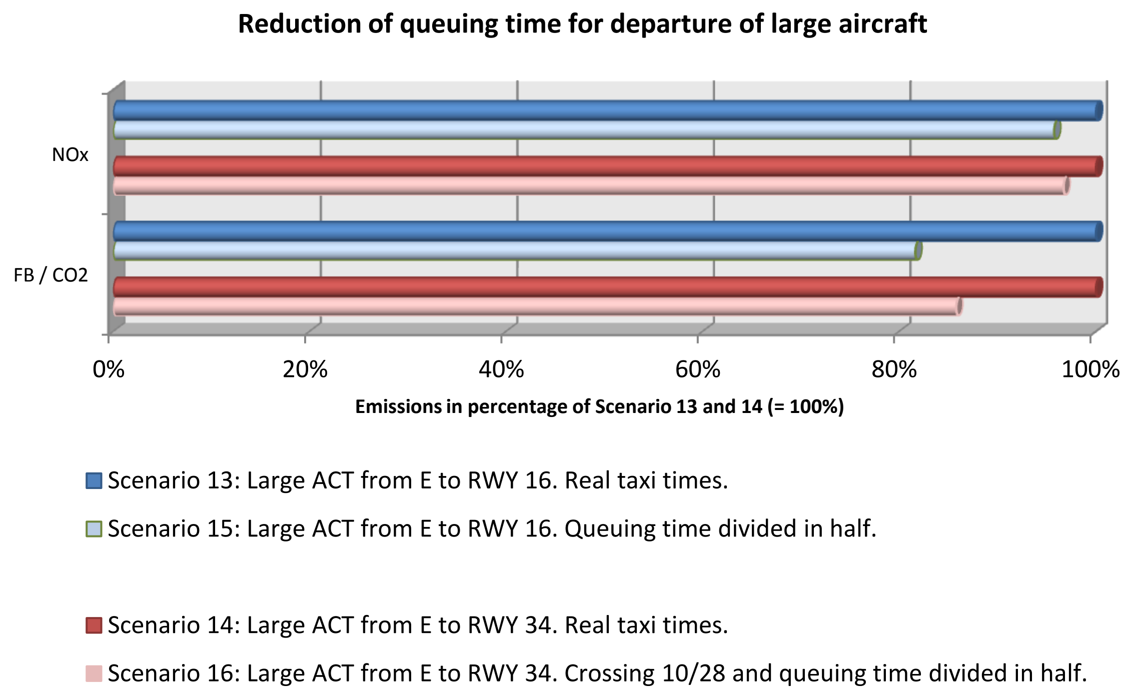
Figure 5 Departure RWY 34.

Case	Scenario 13
Calculation mode	Monitor Calculation
Arrivals	5'533
Departures	0
Total Movements	5'533
Details	Only starts of aircraft of group 'Large' on Runway 16. Taxi from pier E to RWY 16. Taxi times: real mean total taxi times for 'large' aircraft from pier E-RWY16: **18:17 minutes**. Estimation: push back: 2 Min, taxi: 4:48 Min, queuing time: 11:29 Min.
Changes to Case	
Emissions Departure (t)	
	Scenario 13
NO_x	**167.90**
FB	**8'399**
CO_2	**26'500**

Case	Scenario 14
Calculation mode	Monitor Calculation
Arrivals	5'533
Departures	0
Total Movements	5'533
Details	Only starts of aircraft of group 'Large' on Runway 34. Taxi from pier E to RWY 34. Taxi times: real mean taxi times for 'large' aircraft from pier E-RWY 34 incl. queuing: **18:08 minutes**. Estimation: push back: 2 Min, taxi: 4:33 Min, crossing RWY 10/28: 2 Min, queuing time: 09:35 Min.
Changes to Case	
Emissions Departure (t)	
	Scenario 14
NO_x	**167.67**
FB	**8'351**
CO_2	**26'346**

Case	Scenario 15			
Calculation mode	Monitor Calculation			
Arrivals	5'533			
Departures	0			
Total Movements	5'533			
Details	Only starts of aircraft of group 'Large' on Runway 16. Divide queuing time in half: **05:44** **Total taxing: 10:32**			
Changes to Case	Scenario 13: Divide in half queuing time.			
Emissions Departure (t)				
	Scenario 13	Scenario 15	Δ (t)	Δ (%)
NO_x	**167.90**	**160.75**	-7.15	-4.3%
FB	**8'399**	**6'855**	-1'544	-18.4%
CO_2	**26'500**	**21'629**	-4'871	-18.4%

Case	Scenario 16			
Calculation mode	Monitor Calculation			
Arrivals	0			
Departures	5'533			
Total Movements	5'533			
Details	Only departures of aircraft of group 'Large' on Runway 34. Taxi from pier E to RWY 34. Divide queuing time in half and crossing 10/28: **05:47** **Total taxing: 12.20 Min.**			
Changes to Case	Scenario 15: Divide queuing time in half and wait for crossing 10/28.			
Emissions Departure (t)				
	Scenario 14	Scenario 16	Δ (t)	Δ (%)
NO_x	**167.67**	**162.37**	-5.30	-3.2%
FB	**8'351**	**7'205**	-1'146	-13.7%
CO_2	**26'346**	**22'732**	-3'615	-13.7%



3.2.3. Takeoff weight

The emission strengths and profiles according to the performance model ADAECAM are based on local temperature, pressure, humidity and the actual take-off weight. ADAECAM accounts for the effects of ambient conditions and forward-speed effects on fuel flow (departure) and emission indices for each LTO phase. It incorporates detailed turbine knowledge, the so-called Boeing Fuel Flow Method 2 (BFFM2), and detailed climb profiles derived by the performance model PIANO.
The individual climb profile is applied by Lasport according to the aircraft group. An individual profile is defined by the profile name and the maximum range. The range specific sub-profile is automatically selected from the given great circle distance to the destination airport. The range is applied for the profile selection instead of the actual take-off weight because the latter is usually a sensible parameter that may not be available.

For scenario 17 the emissions of all aircraft of the group ‘Large’ are modeled, taxiing from Pier E to RWY 16 and departing to Frankfurt (EDDF, GCD 284 km). So all aircraft are supposed to be ‘light’. For scenario 18 the destination of all aircraft is changed to Buenos Aires (SAEZ, GCD 11’320 km). The ATOW of those Aircraft is supposed to be high.

Case	Scenario 17
Calculation mode	Monitor Calculation
Arrivals	0
Departures	5'533
Total Movements	5'533
Details	Only departures of aircraft of group ‘Large’ on Runway 16. Taxi from pier E to RWY 16. Real mean taxi time: 18:29 Min. All aircraft to Frankfurt (EDDF). Measured ambient conditions for each movement.
Changes to Case	

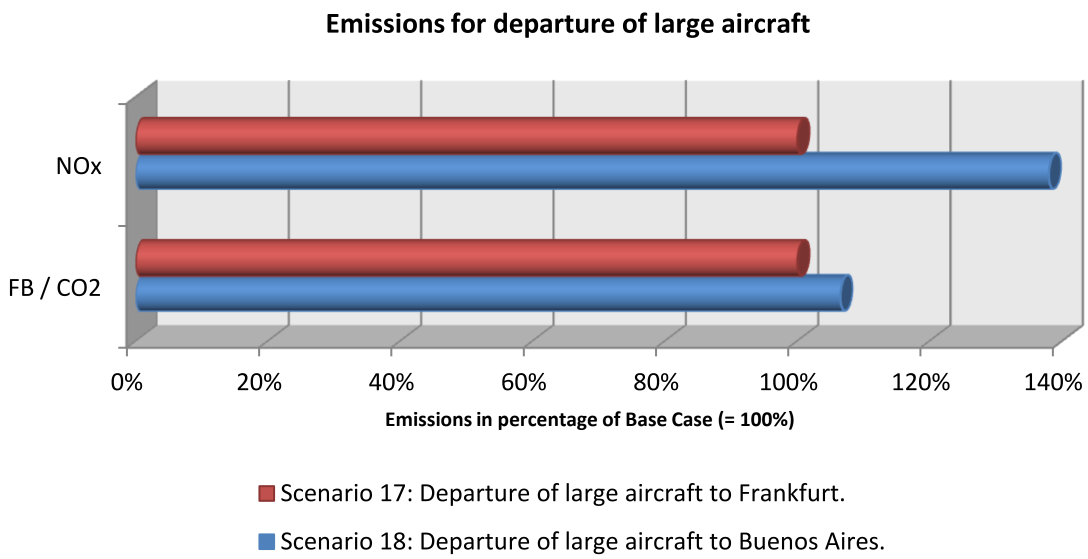
Emissions Departure(t)

	Scenario 17
NO_x	**144.02**
FB	**8'174**
CO_2	**25'790**

Case	Scenario 18
Calculation mode	Monitor Calculation
Arrivals	0
Departures	5'533
Total Movements	5'533
Details	Only departures of aircraft of group ‘Large’ on Runway 16. Taxi from pier E to RWY 16. Real mean taxi time: 18:29 Min. All aircraft to Buenos Aires (SAEZ). Measured ambient conditions for each movement.
Changes to Case	Scenario 17: Aircraft to Buenos Aires.

Emissions Departure (t)

	Scenario 17	Scenario 18	Δ (t)	Δ (%)
NO_x	**144.02**	**198.76**	54.73	+38.0%
FB	**8'174**	**8'705**	531	+6.5%
CO_2	**25'790**	**27'464**	1'674	+6.5%


Emissions for departure of large aircraft
NOx
FB / CO2
0%
20%
40%
60%
80%
100%
120%
140%
Emissions in percentage of Base Case (= 100%)
Scenario 17: Departure of large aircraft to Frankfurt.
Scenario 18: Departure of large aircraft to Buenos Aires.

4. Results and Conclusions

The highest impact on NOx emissions for LTO procedures is observed for the change of the ambient parameters and the MTOW of the aircraft. Those two parameters can hardly be influenced. The limitation in modeling the emissions of the ambient parameters is the lack of thrust adjustments for different ambient parameters. This would allow to model the fuel flow and the CO_2 emissions.

With an emission reduction of 7% for NOx and 18% for fuel flow and CO_2 (compared to the LTO cycle), all engine taxi in and out have a large potential for pollutant reduction. However, it is not clear that this scenario is realistic because of the necessary warm-up of the aircraft engine. Single engine taxi in still has a reduction potential of 2% for NOx and 4% for CO_2.

Very important with regard to emission reduction is to prevent queuing time. The addition of 4 minutes queuing of every aircraft at Zurich Airport leads to 4% more NOx and 12% CO_2 emissions. The limitation of the model in this case is that only one taxi-mode is selectable. This means that a rolling aircraft is equal to a queuing aircraft. It would be nice to be able to segment taxi time into queuing (aircraft with running engines but not moving), to accelerate the aircraft, and real taxiing. This would allow to model the typical stop-and-go taxi procedure.

Scenario 3 shows that a longer roll-off with no thrust reverser leads to a 2% emission reduction compared to a shorter roll-off with reversed thrust. To simulate reversed thrust with Lasport the LTO phase approach ground is replaced by the emission and turbulence values of phase approach ground to account in a rather conservative form for reversed thrust events.

All Aircraft			**Emission difference of total LTO**	
Case	**normal procedure**	**modelled procedure**	**NO_x**	**CO_2**
Scenario 1	all engine taxi in & out	single engine taxi in	-1.6%	-4.3%
Scenario 2	all engine taxi in & out	single engine taxi in & out	-6.7%	-18.4%
Scenario 3	roll off 1800 m	reversed thrust, roll off 1400m	+2.1%	+1.9%
Scenario 4	mean taxi times	mean taxi times +2 minutes	+1.3%	+3.9%
Scenario 5 & 6	4 minutes queuing time	8 minutes queuing time	+3.7%	+12.2%
Scenario 8	measured ambient parameters	warm, sunny weather for all flights	+38.9%	0.0%
Scenario 9	measured ambient parameters	cold, rainy weather for all flights	-14.2%	0.0%

Only large Aircraft			**Emission difference of total LTO**	
Case	**normal procedure**	**modelled procedure**	**NO_x**	**CO_2**
Scenario 10 & 11	Arrival RWY 16 via E7 to E	plus 2 Ms queuing crs 10/28	+8.2%	+19.0%
Scenario 12	Arrival RWY 16 via E7 to E	Rev. Thrust, via E5 to E	+2.7%	-7.1%
Scenario 13 & 15	Dep RWY 16 normal queuing	Dep RWY 16 divide queuing in half	-4.3%	-18.4%
Scenario 14 &16	Dep RWY 34 normal queuing	Dep RWY 34 divide queuing in half	-3.2%	-13.7%
Scenario 17 & 18	Departures low MTOW	departures high MTOW	+38.0%	+6.5%

This study shows the need for a sophisticated tool for emission calculation at airports. Without reliable simulation of the different processes it is nearly impossible to discuss the appropriate solutions for the desired emission reduction. The following elements are recommended to be considered in future model enhancements:

- Stop-and-go taxi procedure
- Influence of ambient parameters on thrust level (and hence fuel burn)
- Simple possibility to model single engine taxi
- More detailed modeling of reversed thrust

5. Appendix

5.1. Abbreviations

ADAECAM	Advanced method for calculating the emissions from aircraft engines
AF	Approach final
AG	Approach ground
ATOW	Actual take-off weight
CF	Climb final
CI	Climb initial
FB	Fuel burn
GCD	Great circle distance
ID	Idle
ISA	International standard atmosphere
LAQ	Local air quality
LTO	Landing take-off cycle
MTOW	Maximum take-off weight
RWY	Runway
TG	Take-off ground
UID	Unique identification number

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