egts™

EGTS Environmental Benefits

Based on independent research and
analysis conducted by Envisa

envisa

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Introduction to Envisa

Established in 2004, Envisa is a global environmental consulting company specializing in sustainable aviation. Their team of experts provide support to the industry's biggest companies and influential research projects in such topics as environmental impact and trade off assessment, local air quality, global emissions, emissions trading scheme, noise modelling, aircraft recycling research & LCA, forecasting, and environmental management.

Acronyms

APU	Auxiliary Power Unit
CAEP	ICAO Committee on Aviation Environmental Protection
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DET	Dual Engine Taxi
EASA	European Aviation Safety Agency
ECS	Environmental Control System mode for APU
EI	Emissions Index (grams of pollutant per kilogram of fuel)
EPA	US Environmental Protection Agency
FAA	US Federal Aviation Administration
GSE	Ground Support Equipment
ICAO	International Civil Aviation Organization
LTO	ICAO Landing/Take-off cycle
MES	Main Engine Start mode for APU
NOx	Nitrogen Oxides
PM	Particulate Matter
SET	Single Engine Taxi
UHC	Unburned Hydrocarbons

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1.0 Executive Summary

There is significant interest in abating aviation emissions for both local air quality and global climate change concerns.

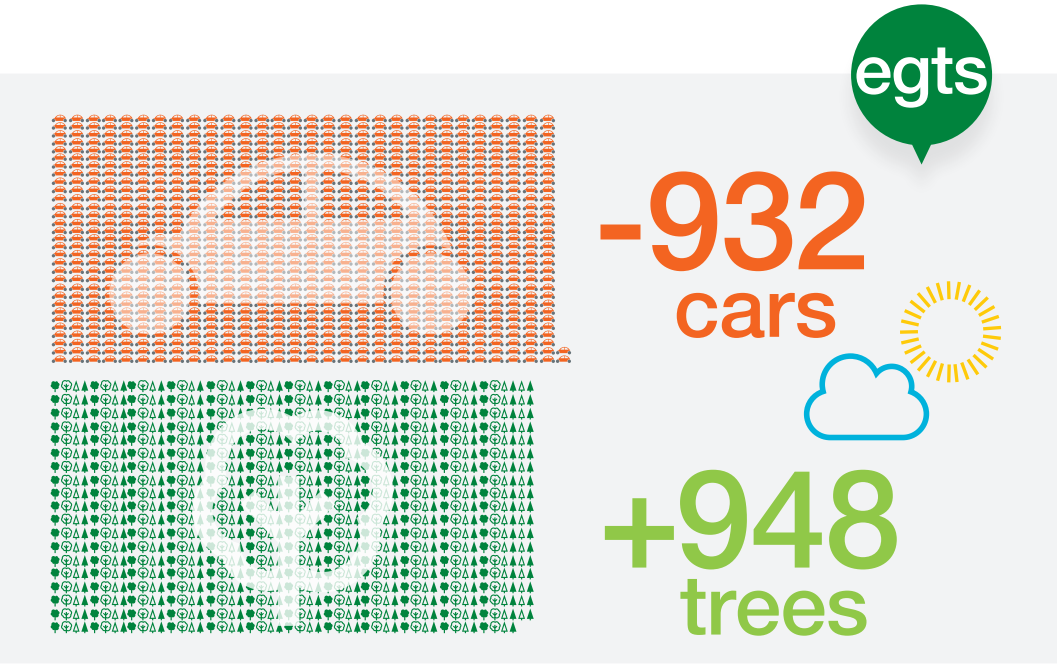
There are global and national targets to reduce CO_2 for climate change concerns – but for local air quality issues – there is nothing regulated at the global level. Most often, health impact pollutants such as NOx or Particulate Matter are controlled by regional and state regulations which dictate air quality thresholds.

As air quality is a multi-source phenomenon – any airport in a given location may be expected to respond to questions regarding its contribution to ambient air quality levels.

Airlines desire to be perceived as “greener” but also need to be more cost efficient, so this drives them to seek innovative ways to reduce fuel burn and associated emissions.

The benefits published in this white paper are based on independent research and analysis conducted by Envisa – a Paris based expert consultancy in the field of aviation and the environment. Internationally recognized models, methods and databases have been used to assess the benefits of both Single Engine taxiing (SET) and EGTS compared to Dual Engine taxiing (DET) in both single movement operations and typical airport implementation scenarios. The content of this white paper is primarily addressing narrow body twin engine jets which can most benefit from the EGTS™ technology.

This paper demonstrates that EGTS can form a useful and important component to abating aircraft ground roll emissions by introducing cleaner electric taxiing operations. Typical use of EGTS annually with an A320 aircraft at American airports is predicted to be equivalent of planting up to 948 trees for CO_2 savings, or eliminating 932 automobiles for NOx reductions. Furthermore, it can deliver significantly greater savings due to optimized ground operations – not relying on push back tractors, increasing safety of ground personnel by reducing jet blast hazard etc.



2.0 Introduction to EGTS™

Today's turbofan engines are optimized for flying, not for powering aircraft on the ground. Every time an airliner taxis, it burns a disproportionate amount of fuel between the gate and the runway. This becomes even more of an issue for short and medium-haul aircraft, which spend a relatively long time taxiing between runway and gate, compared to the actual length of the flight.

With electric motors located on the main landing gear and powered by the Auxiliary Power Unit (APU) generator, EGTS allows aircraft to pushback from the gate without a tug tractor, and taxi without the use of engines. In other words, the aircraft taxis using only electric power until just a few minutes before take off – and then again a few minutes after landing, respecting the necessary warm up and cool down time of the engines.

3.0 Regulatory & Environment Drivers

3.1 Criteria Pollutants

There are a number of criteria pollutants considered to be noxious to human health or impact climate change, and which are thus either currently controlled or in the process of being controlled for aviation The criteria pollutants for aviation are: Carbon Dioxide (CO_2), Nitrogen Oxides (NOx), Particulate Matter (PM), Carbon Monoxide (CO) and Unburned Hydrocarbons (UHC's).

Carbon Dioxide (CO_2), a direct product of burning fossil fuels, is a greenhouse gas associated with climate change. This pollutant is under intense scrutiny both as a regulated emission in certification and subject to market-based measures (i.e. emissions trading schemes).

Nitrogen Oxides (NOx) emissions cause ground level ozone and have been controlled for main propulsion engines since 1981, and continue to be the subject of ever more stringent regulations.

Particulate Matter (PM) is classified as having an impact on human health, and has recently become a focus for regulation. Current plans suggest that PM could be regulated in aviation as early as 2016.

Other pollutants including CO and UHC's are required to meet threshold levels, but there is little pressure to significantly abate. The following sections describe the pollutants and their background in more detail.

3.1.1 Carbon Dioxide (CO_2)

Carbon Dioxide (CO_2) is the most significant and longest lived of the green house gases (GHG). There are initiatives dating back to the Kyoto Protocol in 1997 which calls for all anthropogenic (ie man-made) CO_2 to be reduced, most especially for power generation and transportation. Political pressure, especially from Europe, is intense to reduce the "carbon footprint" or CO_2 emissions of aviation. Carbon Dioxide is a direct product of combustion, generated at approximately 3.16kg of CO_2 per kg of Jet-A fuel burned, as described in ICAO document 9889[1].

Since CO_2 is directly proportional to fuel burn, and fuel consumption is a direct operating cost, then it follows that this pollutant is a prime consideration for abatement, both economically and environmentally. The main way to reduce CO_2 is by reducing fuel burn through improved product efficiency or operational efficiency.

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[1] ICAO document 9889, attachment B to Appendix 1, footnote 3 to Table B-1 http://www.icao.int/publications/Documents/9889_cons_en.pdf

3.1.2 Nitrogen Oxides (NOx)

Nitrogen Oxides (NOx) emissions have been the traditional focus for control and abatement on account of the impact of this pollutant on both local air quality and on global climate change. From a local air quality standpoint, NOx emissions chemically react to form ozone/smog at ground level which is a human health concern. From a climate change standpoint, NOx emissions emitted during high-altitude operation can interact with the ozone layer thereby changing the balance of incident radiation and contributing to warming. This pollutant is controlled on almost all mobile and stationary power sources, including aviation.

Since 1981, the International Civil Aviation Organization (ICAO) , the US EPA and national departments of transportation (FAA, EASA, Transport Canada, etc.) have limited the level of pollutants from civil aviation aircraft, focusing on airport operations for local air quality considerations. The regulatory framework for aircraft is demonstrated in Figure 1.

The Landing/Take-off (LTO) cycle aggregates emissions over a cycle comprising of approach, taxi, take-off and climb-out modes up to a ceiling of 3,000 feet. The allowable level of NOx emissions has been revised downwards 4 times since 1981, most recently on December 31, 2013, thereby reducing the allowable NOx by 50%. There is clearly a great deal of regulatory interest in abating NOx, which tends to be the pollutant most quoted and studied for local air quality concerns.

3.1.3 Particulate Matter (PM)

Particulate Matter (PM) in the atmosphere influences visibility, ecological systems, surface deposition, atmospheric composition, cloud formation, precipitation and climate, and when inhaled, has serious health effects (see, for example, EPA's website http://www.epa.gov/pm/). Particulate Matter is generated by a number of sources, and are comprised of elemental carbon (or soot), soil dust, organic compositions, Ammonium Sulphate and Ammonium Nitrate, mineral components, and metals. Gas Turbine Engines tend to emit ultra-fine particulate matter (20 to 500 nanometers), 1000 times smaller than human hair but which is currently not directly controlled by regulatory agencies. The international Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP) has indicated a high priority on controlling this pollutant, and is working towards a new certification standard at the 10th meeting of CAEP in 2016.

Current methods to model and assess PM emissions are not for the moment considered robust enough to allow comparison within this study, due to the limited engine and APU certification data available today (based on smoke number).

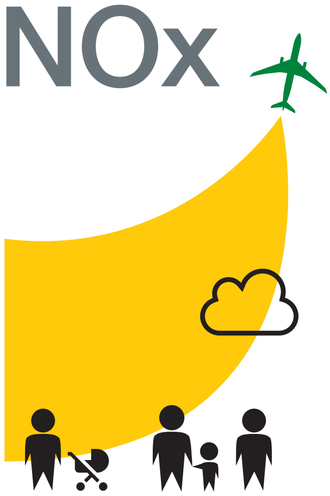
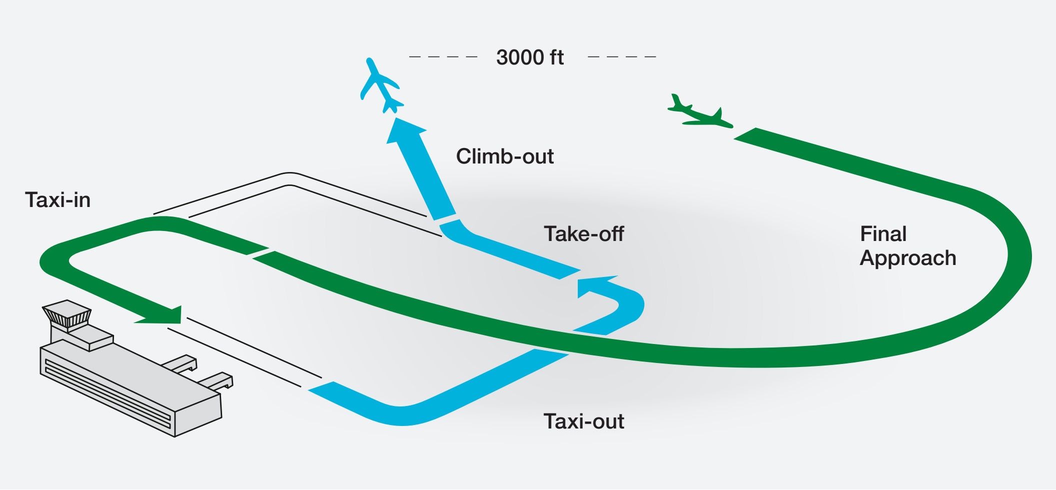


Figure 1. The ICAO Landing/Take-Off (LTO) Cycle



3.1.4 Other Pollutants

The other criteria pollutants for aviation are Carbon Monoxide (CO) and Unburned Hydrocarbons (UHC). Both pollutants are controlled for turbofan engines, using the same aggregate Landing/Take-off cycle as for the NOx emissions. Generally, these pollutants are required to be below a threshold level, but there has been no overt pressure to increase stringency or to reduce the allowable levels. CO is hazardous in large quantities, but modern engines in an open space do not produce high levels. UHC emissions may become more regulated, especially if these are implicated as gaseous particulate precursors (as part of a future volatile particulate matter standard).

3.2 Airline Perspective

Airlines are extremely motivated to address climate change issues. As an industry they have published[2] very challenging goals both for the near future in 2020 and beyond.

- a global annual average fuel efficiency improvement of 2% until 2020 and an aspirational global fuel efficiency improvement rate of 2% per annum from 2021 to 2050;
- a collective medium-term global aspirational goal of keeping the global net carbon emissions from international aviation from 2020 at the same level (CNG2020).

But not only playing their part in tackling climate change, airlines of course do intuitively strive to reduce fuel costs as these form a significant part of its operating costs.

3.3 Airport Perspective

From an airport perspective, there are two main influencing factors that should be considered when looking at the benefits that EGTS can bring. Firstly, airports must deal with managing their emissions from all sources of their activity and be able to demonstrate the contribution this has to the ambient air quality.

Secondly, more and more now, airports are managing their "carbon footprint" – or in other words – the amount of CO_2 that is generated by the airport activity. Local Air Quality is being scrutinized closely by residents around airports backed by recognized associations.

3.3.1 Airport Emissions Inventories

Airports in many regions of the world are required to perform detailed modeling and maintain inventories of emissions to comply with regional or national regulations. Under the US Clean Air Act, Airports that are in Environmental Protection Agency (EPA) designated National Ambient Air Quality Standard (NAAQS) emissions non-attainment areas are required to produce and maintain an emissions inventory and take steps to reduce emissions. In such cases, Federal funding is made available, ie through the Voluntary Airport Low Emissions program[3]. Typically, large city centers are in emissions non-attainment areas, as such, most large US airports make yearly emissions inventories.

These inventories are developed in the US through the Emissions Dispersion Modeling System (EDMS[4]) created and managed by the Federal Aviation Administration. The EDMS software incorporates all airport area emissions sources, including aircraft, ground support equipment, transportation and local road traffic. EDMS also incorporates APU emissions data provided by manufacturers, including Honeywell (data provided to EPA in 2000[5]). In Europe, there are several airports (including Heathrow and Zurich) that are required to demonstrate emissions inventories because of local air quality concerns in their respective regions. In Europe, there are a number of modelling tools available including LASPORT[6], ALAQS[7] and ADMS[8].

3.3.2 Airport Carbon Footprint

More and more airports are now aware of their carbon footprint resulting from all the activities of the site. Airport Carbon Accreditation (ACA) is a carbon management certification standard for airports developed by ACI Europe. The program independently assesses and recognizes the efforts of airports to manage and reduce their carbon emissions. The independent program has four levels: 'Mapping' (Level 1), 'Reduction' (Level 2), 'Optimization'(Level 3) and 'Neutrality' (Level 3+). At the mature levels (3 and 3+) the airport requires third party engagement in carbon footprint reduction so this is where airlines with CO_2 saving taxiing procedures and technologies can make a significant contribution.

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[2] https://www.iata.org/policy/environment/Documents/atag-paper-on-cng2020-july2013.pdf

[3] FAA VALE website http://www.faa.gov/airports/environmental/vale/

[4] FAA EDMS website http://www.faa.gov/about/office_org/headquarters_offices/apl/research/models/edms_model/

[5] "APU Emissions", Randy Williams author, Honeywell correspondence to US EPA, Sept 29, 2000

[6] LASPORT website http://www.janicke.de/en/home.html

[7] https://www.eurocontrol.int/services/airport-local-air-quality-studies

[8] http://www.cerc.co.uk/environmental-software/ADMS-Airport-model.html

4.0 Emission Sources Analysed

This section pertains to quantifying the reduction in criteria pollutants from the implementation of the EGTS taxiing system relative to the current status quo (dual or single engine taxi). The section will describe several scenarios for comparison and the associated assumptions. Fuel burn and emissions have been compared on the basis of a single aircraft movement (section 4.1) and at an airport level (section 4.2). The main engine, APU and tug emissions will be described for background. Finally the emissions will be calculated for EGTS vs status-quo and the emissions savings compared to other measures.

4.1 Scenarios & Duty Cycles

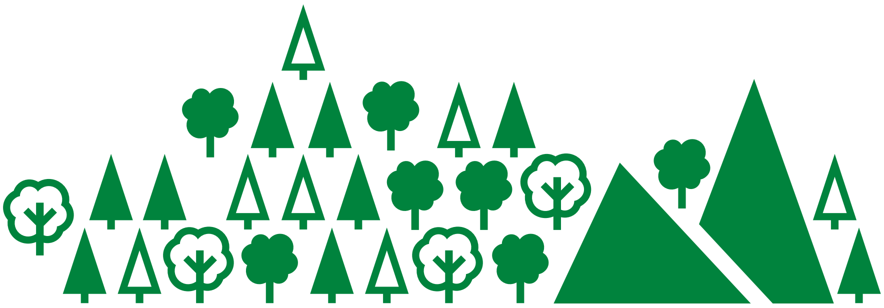
For the purpose of assessing the benefits of EGTS on emissions, two scenarios were studied. Two sets of taxi-time were considered: European averages and US averages. In Europe, based on the CODA database, the average taxi-in time is 6 minutes and average taxi-out time is 12 minutes. Whereas in the US, the average taxi-in time is 7 minutes and average taxi-out time is 17 minutes for narrow-bodied aircraft (based on the US Bureau of Transportation Statistics T-100 database – 2011 figures).

For each of the taxi-time sets, EGTS benefits were compared with Dual Engine and Single-Engine taxiing. The input parameters of the case-studies are summarized in Table 1.

The fuel burn and emissions were calculated through a model developed by Envisa based on FDR data. For all scenarios the emissions were compared after gate push-back. The main engine startup and APU operation in main engine start mode are included in this sequence. Emission calculations for departures start with the aircraft pushback (off-block) and end at the runway threshold. An engine warm up of 3 minutes is considered. Emissions for arrivals are modeled between runway exit and aircraft stand. An engine shut down of 3 minutes is considered, in which one minute corresponds to the landing roll on the runway (cool down begins as soon as engines are at idle, so at touchdown when landing with no reverse, which is the most commonly used practice now).

Case #1 is the case of comparing Dual Engine Taxi (DET) to EGTS. In this scenario, the status-quo case is that the aircraft uses DET for both taxi-in and taxi-out operation. It is assumed that a tug is used for 4 minutes to push-back the aircraft, including the time to transport the tug to/from the gate. The EGTS alternative would use 100% taxi operation with EGTS for both taxi-in and taxi-out, net of 3 minutes of the main engines for warm-up and cool-down. (ie for European airports taxi-in 3 minutes Dual Engine Taxi + 3 minutes EGTS and for taxi-out, 9 minutes of EGTS + 3 minutes Dual Engine Taxi). This case is expected to be the most optimistic comparison of EGTS to the status quo.

Case #2 is the case of comparing Single Engine Taxi (SET) to EGTS. In this scenario, the status-quo case is that the aircraft uses SET for both taxi-in and taxi-out operation. For SET operation, it is assumed that the APU is running at ECS conditions and that Dual Engine Taxi is required for 3 minutes for main engines warm-up and cool-down. It is assumed that a tug is used for 4 minutes to push-back the aircraft, including the time to transport the tug to/from the gate. The EGTS alternative would use 100% taxi operation with EGTS for both taxi-in and taxi-out, net of 3 minutes of the main engines for warm-up/cool-down time (ie for European airports taxi-in 3 minutes Dual Engine Taxi + 3 minutes EGTS and for taxi-out, 9 minutes of EGTS + 3 minutes Dual Engine Taxi). This case is expected to be somewhat more realistic comparison of EGTS to the status quo, given that Single Engine Taxi is becoming the norm.



	Case #1 **Dual Engine Taxi vs EGTS**	**Case #2** **Single Engine Taxi vs EGTS**
Aircraft	A320	A320
Engines	CFM56-5B4/3	CFM56-5B4/3
APU	ICAO, APU (100 – 200) seats newer type	ICAO, APU (100 – 200) seats newer type
Taxi-in Engine Operation	100% Dual Engine Taxi	100% Single Engine Taxi
Gross Taxi-in time	6 minutes (EU) / 7 minutes (US)	6 minutes (EU) / 7 minutes (US)
Taxi-out Engine Operation	100% Dual Engine Taxi	100% Single Engine Taxi
Gross Taxi-out time	12 minutes (EU) / 17 minutes (US)	12 minutes (EU) / 17 minutes (US)
APU operation during taxi with main engines:	Off with Dual Engine Taxi	ECS with Single Engine Taxi
Engine Warm-up time	3 minutes	3 minutes
Engine Cool-down time	3 minutes	3 minutes
Tractor time for gate pushback	4 minutes	4 minutes
Alternative EGTS Operation Taxi-in	100% EGTS only	100% EGTS only
Alternative EGTS Operation Taxi-out	100% EGTS only	100% EGTS only
Alternative EGTS tractor Operation Taxi-out	None (no pushback)	None (no pushback)
Alternative EGTS operation APU	100% APU MES load	100% APU MES load

Table 1. Input parameters for EGTS™ Taxiing Operation

4.2 Main Engine Emissions

CFM56-5B4/3 emissions were extracted directly from the ICAO engine exhaust emissions databank[9], which is publicly available. The engine exhaust emissions databank lists the emissions for all Turbofan engines with rated thrust greater than 6000 lbs. The emissions are tabulated for the Landing/Take-off cycle points (see section 3.2.1), at 7%, 30%, 85% and 100% of the rated thrust. Germane to the calculations of the emissions benefits is the 7% thrust point which is designated as the "taxi" point and according to the engine exhaust emissions databank, the fuel flow and emissions at 7% thrust are:

Fuel flow = 0.102kg/s
NOx Emissions Index = 4.22g NOx per kg of fuel
CO Emissions Index = 32.07g CO per kg of fuel
UHC Emissions Index = 1.92g UHC per kg of fuel
Smoke Number = 2.1

It is assumed that the main engine operates at 7% of rated thrust for taxi operation. For Single Engine Taxi, but it is assumed that the main engine's fuel flow is 28% higher than for dual engine taxiing.

4.4 APU emissions

The APU studied corresponds to the generic APU provided by the ICAO local air quality manual (9889) for small aircraft (between 100 and 200 seats, newer type). For dual and single engine taxiing, the APU is assumed to be operated in "no load" mode for one minute until it is started-up and stabilized. After start-up, the APU switches into the ECS mode operated at "normal load". For main-engine start-up, the APU is operated at "high load".

It is assumed that when operating in the EGTS mode to provide motive force for the aircraft and to supply electrical power and Environmental Control Systems (ECS) support, is operating at the equivalent of Main Engine Start (MES) mode, approximately 25% higher fuel flow than the ECS mode alone.

	Start-up no load (kg/h)	Normal running (ECS) (kg/h)	Maximum load (kg/h)
NOx	0.364	0.805	1.016
UHC	2.662	0.094	0.091
CO	3.734	0.419	0.495

APU emissions

4.3 Tractor Emissions

It is assumed that, normally, a diesel tractor is required to push the aircraft back from the gate and that the EGTS system would enable the aircraft to push back without this tractor. The pushback-tractor emissions depend on the tractor type, its power, and the load of the engine. The tractor type corresponds to a diesel engine fitting narrow-type aircraft with a net power of 95kW. It is assumed that the market placement date of the tractor is after January 1999. An old pushback tractor was considered to evaluate a conservative scenario.

Three main phases are identified in which the tractors are used at either high or normal load:

- "Tractor arrival": Tractor movement from parking stand to aircraft and connecting to the aircraft (normal load)
- "Tractor pushback": Pushing the aircraft (high load)
- "Tractor departure": Disconnecting the tractor from the aircraft and going back to the parking stand (normal load)

Fuel flow = 6 L/Hours
NOx Emissions Index = 9.2g Nox per kg of fuel
CO Emissions Index = 5g CO per kg of fuel
UHC Emissions Index = 1.3g UHC per kg of fuel

The fuel flow was extracted from a study conducted by Zurich airport[10] and the emission indexes from the EU Non-road mobile machine emissions. 2004 directive. (http://transportpolicy.net/index.php?title=EU:_Nonroad:_Emissions. EU Directive 2004/26/EC).

[9] EASA Engine Exhaust Emissions Databank http://www.easa.europa.eu/environment/edb/aircraft-engine-emissions.php

[10] Fleuti, Emanuel. Aircraft Ground Handling Emissions at Zurich Airport. 2004

This section provides an overview of the benefits of EGTS based on a single movement basis. This will be of most interest to aircraft operators.

This calculation excludes the APU operation at the gate before pushback, the emissions generated during take-off and climb-out (i.e. on the runway). It analyses only the ground movements. It is assumed that a tractor/tug would not be required to push back from the gate with EGTS.

Examples are given here for typical taxi times at European and US airports.

5.1. European airports

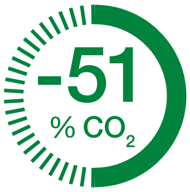
5.1.1 Taxi-in

The fuel consumption for taxi-in movements with six minutes taxi time is 73kg for the dual engine taxiing technique.

Case 1: EGTS VS DET

The fuel consumption for taxi-in movements is reduced if the EGTS instead of the main engines are used for taxiing. The fuel consumption for taxi-in movements with the EGTS technique is 36kg, which is less than half of the fuel burnt compared to dual engine taxiing.

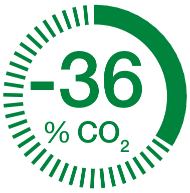
Overall, for case #1, the EGTS system provides the opportunity to reduce fuel burn and CO_2 emissions by 51%, NOx emissions by 41%, UHC by 29% and CO by 62%.



Case 2: EGTS VS SET

The fuel consumption is reduced by 24% to 56kg if one main engine is switched off during taxiing compared to dual engine taxiing. The fuel consumption for taxi-in movements with the EGTS technique is 36kg, which is 36% less than the fuel burnt with the single-engine technique.

Overall, for case #2, the EGTS system provides the opportunity to reduce NOx emissions by 22%, CO by 50% and UHC by 7%. In addition, the amount of CO_2 is estimated to be reduced by 36%.



	Fuel consumption (kg):Total	Emission of CO (kg):Total	Emission of CO_2 (kg):Total	Emission of UHC (kg):Total	Emission of NOx (kg):Total
DET	73.44	2.36	231.34	0.14	0.31
SET	55.81	1.79	175.82	0.11	0.24
EGTS	35.82	0.89	112.83	0.10	0.18
SET VS DET	**-24%**	**-24%**	**-24%**	**-24%**	**-24%**
EGTS VS DET	**-51%**	**-62%**	**-51%**	**-29%**	**-41%**
EGTS VS SET	**-36%**	**-50%**	**-36%**	**-7%**	**-22%**

European airports taxi-in

5.1.2 Taxi-out

The total fuel consumption with dual engine taxiing technique is 143kg for taxi-out movements in the sample scenario.

Case 1: EGTS VS DET

The fuel consumption for taxi-out movements is reduced if the EGTS is used instead of the main engines for taxiing. The fuel consumption for taxi-out movements with the EGTS technique is 69kg, which is less than half of the fuel burnt compared to dual engine taxiing.

Overall, for case #1, the EGTS system provides the opportunity to reduce NOx emissions by 43%, UHC by 51% and CO by 63%. In addition, the amount of CO_2 is estimated to be reduced by 52%.

Case 2: EGTS VS SET

Single-engine taxiing reduces the fuel consumption by approximately 16% compared to DET, resulting in a fuel consumption of 120kg. The fuel consumption further is significantly reduced when using EGTS. The fuel consumption with EGTS is 69kg, which corresponds to a reduction of 42% compared to single-engine taxiing.

Overall, for case #2, the EGTS system provides the opportunity to reduce NOx emissions by 37%, UHC by 40% and CO by 51%. In addition, the amount of CO_2 is estimated to be reduced by 42%.

	Fuel consumption (kg):Total	Emission of CO (kg):Total	Emission of CO_2 (kg):Total	Emission of UHC (kg):Total	Emission of NOx (kg):Total
DET	142.86	4.46	450.02	0.31	0.63
SET	119.68	3.38	376.99	0.25	0.57
EGTS	68.83	1.67	216.83	0.15	0.36
SET VS DET	**-16%**	**-24%**	**-16%**	**-18%**	**-10%**
EGTS VS DET	**-52%**	**-63%**	**-52%**	**-51%**	**-43%**
EGTS VS SET	**-42%**	**-51%**	**-42%**	**-40%**	**-37%**

5.2 US airports

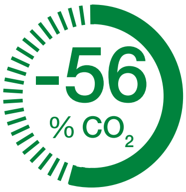
5.2.1 Taxi-in

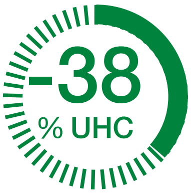
The fuel consumption for taxi-in movements with seven minutes taxi time is 86kg for the dual engine taxiing technique.

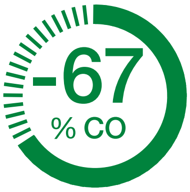
Case 1: EGTS VS DET

The fuel consumption for taxi-in movements is reduced if the EGTS is used instead of the main engines for taxiing. The fuel consumption for taxi-in movements with the EGTS technique is 38kg, which is less than half of the fuel burnt compared to dual engine taxiing.

Overall, for case #1, the EGTS system provides the opportunity to reduce fuel burn and CO_2 emissions by 56%, NOx emissions by 45%, UHC by 38% and CO by 67%.



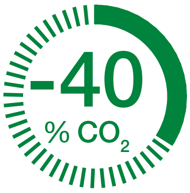


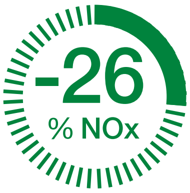


Case 2: EGTS VS SET

The fuel consumption is reduced by 26% to 64kg if one main engine is switched off during taxiing compared to dual engine taxiing. The fuel consumption for taxi-in movements with the EGTS technique is 38kg, which is 40% less than the fuel burnt with the single-engine technique.

Overall, for case #2, the EGTS system provides the opportunity to reduce NOx emissions by 26%, CO by 56% and UHC by 17%. In addition, the amount of CO_2 is estimated to be reduced by 40%.





	Fuel consumption (kg):Total	Emission of CO (kg):Total	Emission of CO_2 (kg):Total	Emission of UHC (kg):Total	Emission of NOx (kg):Total
DET	85.68	2.75	269.89	0.16	0.36
SET	63.65	2.04	200.49	0.12	0.27
EGTS	37.89	0.89	119.35	0.10	0.20
SET VS DET	**-26%**	**-26%**	**-26%**	**-26%**	**-26%**
EGTS VS DET	**-56%**	**-67%**	**-56%**	**-38%**	**-45%**
EGTS VS SET	**-40%**	**-56%**	**-40%**	**-17%**	**-26%**

US airports taxi-in

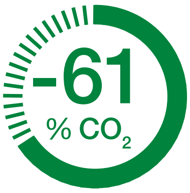
5.2.2 Taxi-out

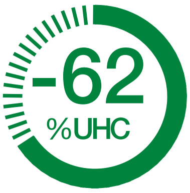
The total fuel consumption with dual engine taxiing technique is 205kg for taxi-out movements in the sample scenario.

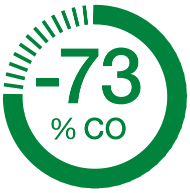
Case 1: EGTS VS DET

The fuel consumption for taxi-out movements is reduced if the EGTS is used instead of the main engines for taxiing. The fuel consumption for taxi-out movements with the EGTS technique is 79kg, which is less than half of the fuel burnt compared to dual engine taxiing.

Overall, for case #1, the EGTS system provides the opportunity to reduce NOx emissions by 51%, UHC by 62% and CO by 73%. In addition, the amount of CO_2 is estimated to be reduced by 61%.



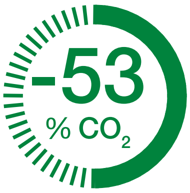


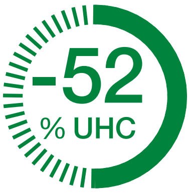


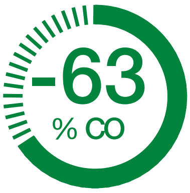
Case 2: EGTS VS SET

Single-engine taxiing reduces the fuel consumption by approximately 18% compared to DET, resulting in a fuel consumption of 168kg. The fuel consumption further is significantly reduced when using EGTS. The fuel consumption with EGTS is 79kg, which corresponds to a reduction of 53% compared to single-engine taxiing.

Overall, for case #2, the EGTS system provides the opportunity to reduce NOx emissions by 46%, UHC by 52% and CO by 63%. In addition, the amount of CO_2 is estimated to be reduced by 53%.







	Fuel consumption (kg):Total	**Emission of CO (kg):Total**	**Emission of CO_2 (kg):Total**	**Emission of UHC (kg):Total**	**Emission of NOx (kg):Total**
DET	204.06	6.43	642.80	0.43	0.89
SET	167.89	4.68	528.88	0.34	0.80
EGTS	79.18	1.71	249.43	0.16	0.43
SET VS DET	**-18%**	**-27%**	**-18%**	**-21%**	**-10%**
EGTS VS DET	**-61%**	**-73%**	**-61%**	**-62%**	**-51%**
EGTS VS SET	**-53%**	**-63%**	**-53%**	**-52%**	**-46%**

US airports taxi-out

5.3 Comparison of Emissions

It is useful to compare the emissions reductions by the EGTS system to tangible measures to improve the environment. This section pertains to estimating the number of trees planted or automobiles eliminated from the road by virtue of utilizing the EGTS system. The basis of comparison is the average usage of EGTS on an A320 with 2,000 flights per year, assuming EGTS average utilization rate of 75% for taxi-out and 90% for taxi-in.

In terms of trees planted, according to a North Carolina State Study, a tree can absorb up to 48 lbs (21.8kg) of carbon per year, or 2000lbs (908kg) over a 40 year period.

If we consider **European** airports, the amount of CO_2 saved for a single A320 airport turn with EGTS compared to DET is 351kg CO_2 (118kg saved for taxi in – 233kg saved for taxi out). Therefore, at 2,000 flights per annum, each aircraft equipped with an EGTS would save 561,900kg CO_2 (2,000 flights times (75% x 233 + 90% x 118) kg CO_2 per flight) which is the equivalent of planting roughly 619 trees (561,900kg saved divided by 908kg CO_2 per tree).

If we consider **American** airports, the amount of CO_2 saved for a single A320 airport turn with EGTS compared to DET is 543kg CO_2 (151kg saved for taxi in – 393kg saved for taxi out). Therefore, at 2,000 flights per annum, each aircraft equipped with an EGTS would save around 861,300kg CO_2 (2,000 flights times (75% x 393 + 90% x 151) kg CO_2 per flight) which is the equivalent of planting roughly 948 trees (861,300kg saved divided by 908kg CO_2 per tree).

At 2,000 flights per annum, each aircraft using EGTS would reduce CO_2 emissions equivalent to planting up to 948 trees.

According to the European Automobile Manufacturers' association, the average distance travelled by a European car is 13,000 km . The Euro 6 standard for nitrogen oxide (NOx) emissions contained in EC regulation no 715/2007 is 0.08 grams/kilometer. Therefore, the average NOx produced per annum by a European car is 1.04kg NOx (13,000 km times 0.08 grams/kilometer).

For **European** airports, the amount of NOx saved for a single A320 airport turn with EGTS compared to DET is 397g NOx (126g saved for taxi in – 271g saved for taxi out).

Therefore, at 2,000 flights per annum, each aircraft equipped with an EGTS would save 633kg NOx (2,000 flights times (75% x 271 + 90% x 126) g NOx per flight) which is the equivalent of eliminating 609 automobiles (633kg saved divided by 1.04kg NOx per automobile).

For **American** airports, the amount of NOx saved for a single A320 airport turn with EGTS is 615g NOx (162g saved for taxi in – 452g saved for taxi out).

Therefore, at 2,000 flights per annum, each aircraft equipped with an EGTS would save 970kg NOx (2,000 flights times (75% x 452 + 90% x 162) g NOx per flight) which is the equivalent of eliminating 932 automobiles (970kg saved divided by 1.04kg NOx per automobile).

At 2,000 flights per annum, each aircraft using EGTS would reduce NOx emissions equivalent to removing up to 932 cars from the road.

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[11] NCSU trees of strength, tree facts http://www.ncsu.edu/project/treesofstrength/treefact.htm

[12] European Automobile Manufacturers' association website http://www.acea.be/automobile-industry/passenger-cars

6.1 Assumptions

To evaluate the benefits of EGTS at an airport level, a study was conducted using a real medium size airport (Zurich) as a case-study. The study was based on air traffic data for two weeks data, one in June and one in January. The fuel burn and emissions were calculated for these two weeks.

Two scenarios were analyzed: Dual Engine Taxi vs. EGTS and Single Engine Taxi vs. EGTS.

To make a conservative scenario, it has been considered that only 30% of aircraft eligible for EGTS are actually equipped with EGTS. Aircraft eligible for EGTS are A320 and B737 families.

Flights eligible for EGTS have a taxi-out time greater than 5 minutes, as a minimum time has to be planned for engines warm-up and holding before takeoff. To apply EGTS, the taxi-in time should be greater than 3 minutes. Moreover again considering a conservative approach, EGTS has not been applied to the first flight of the day, as it is preferable for engines to warm-up longer after more than 6 hours stop.

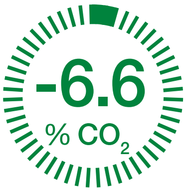
The average taxi-out time of the eligible aircraft is 14 minutes and taxi-in is 5 minutes. In January, the taxi-out time is higher because of de-icing (17 minutes).

Single-engine taxiing has also been applied to A320 and B737 families, but has been restricted to taxi-in as in practice airlines currently don't apply it for taxi-out.

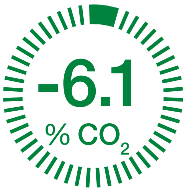
6.2 Results

	Total movements	Fuel consumption (kg):Total	Emission of CO (kg):Total	Emission of CO_2 (kg):Total	Emission of UHC (kg):Total	Emission of NOx (kg):Total
All DET	**9,778**	**1,526 399**	**43,618**	**4,808,209**	**4,932**	**6,514**
30% EGTS	**1,183.20**	**1,425 461**	**39,815**	**4,490,247**	**4,589**	**6,162**
30% SET	**708.0**	**1,517 863**	**42,709**	**4,781,322**	**4,836**	**6,495**
SET VS DET		**-0.6%**	**-2.1%**	**-0.6%**	**-2.0%**	**-0.3%**
EGTS VS DET		**-6.6%**	**-8.7%**	**-6.6%**	**-7.0%**	**-5.4%**
EGTS VS SET		**-6.1%**	**-6.8%**	**-6.1%**	**-5.1%**	**-5.1%**

EGTS VS DET



EGTS VS SET



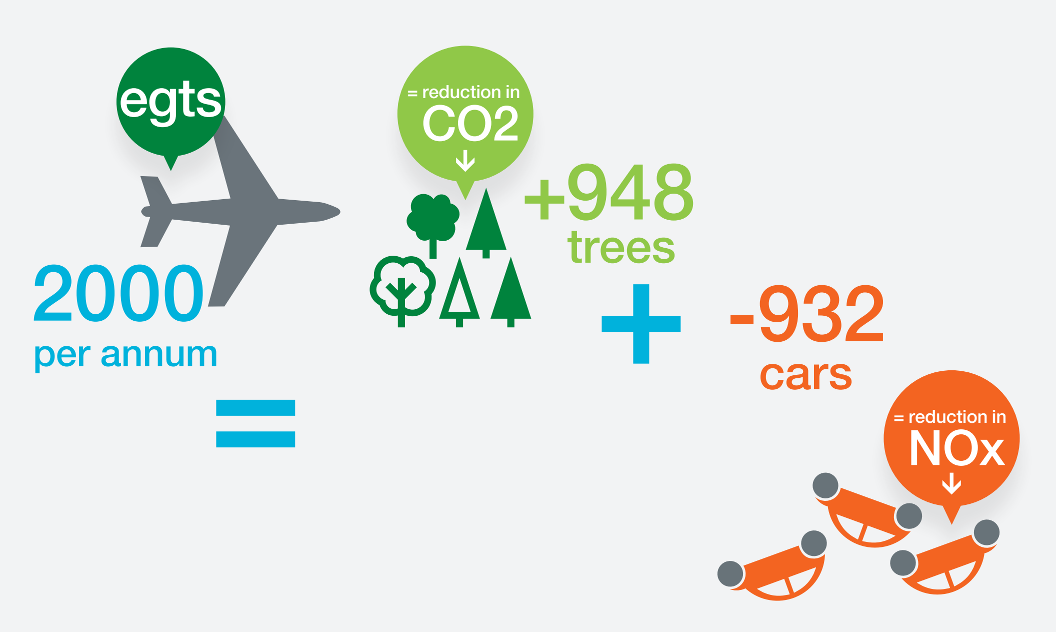
7.0 Conclusion

There is significant interest in abating emissions for both local air quality and global climate change concerns. Specific to airports, there is distinct interest in reducing NOx and CO_2 emissions while maintaining or reducing other pollutants including Unburned Hydrocarbons and Carbon Monoxide. There is a patchwork of national, regional and local regulations which seek to reduce emissions from aircraft, ground support equipment, and other source emission in the airport area through both technology and operational aspects.

This whitepaper demonstrates that EGTS can form a useful and important component to abating airport ground operations emissions by introducing cleaner electric taxiing operations.

Compared to current taxiing techniques, Dual Engine Taxi or Single Engine Taxi , EGTS is predicted to significantly reduce all criteria pollutants in the airport environment, including NOx, CO_2, UHC and CO. At a typical European airport level, a 30% EGTS adoption rate can reduce emissions by up to 9% compared to Dual Engine Taxi operations.

Each aircraft using EGTS annually on American airports will be equivalent to planting up to 948 trees for CO_2 emissions and eliminating up to 932 cars for NOx reduction.



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All estimates on performance, operational benefits and cost savings provided within this document are based on Honeywell and Safran data.

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