The Costs of Environmental Constraints for Business Aircraft Operators

Business Aviation for a Sustainable Economy (BASE)

A CleanSky Project

Work Package 5

T 5.1

Contents

List of Figures

List of Tables

List of Abbreviations

ACNUSA	Autorité de Contrôle des Nuisances Sonores Aéroportuaires
ANCAT	Abatement of Nuisances caused by Air Transport
ARN	Stockholm Airport
ATM	Air Traffic Management
BASE	Business Aviation for a Sustainable Economy
BF	Block fuel
BPR	Bypass ratio
CAC	Command and control
CAEP	Committee on Aviation Environmental Protection
CAGR	Compound Annual Growth Rate
CDA	Continuous descent approach
CDM	Clean Development Mechanism
CO	Carbon monoxide
CO_2	Carbon dioxide
CP	Correlation parameter
DP/F_{00}	Ratio of DP (mass of emissions) and F_{00} (engine's sea level static maximum rated thrust)
EC	European Commission
ECAC	European Civil Aviation Conference
EEA	European Economic Area
EEC	Engine emission charge
EFTA	European Free Trade Association
EPNL	Effective Perceived Noise Level
EU	European Union
EU ETS	European Union Emissions Trading Scheme
EUA	European Union Allowance
EUAA	European Union Aviation Allowance
EUROCONTROL	European Organization for the Safety of Air Navigation
FOCA (also FOI)	Swiss Federal Office of Civil Aviation
GAMA	General Aviation Manufacturers Association
GHG	Greenhouse gas
H_2O	Water vapor
HC	Unburned hydrocarbons
IATA	International Air Transport Association
IBAC	International Business Aviation Council
ICAO	International Civil Aviation Organization
IFR	Instrumental flight rules
JI	Joint Implementation
kN	Kilonewtons
L/D	Lift-to-drag ratio
LPLD	Low power low drag approach
LTO	Landing and take-off
M	Metric
MRG	Monitoring and reporting guidelines
MRV	Monitoring reporting and verification
MSP	Maximum structure payload
MTOW	Maximum take-off weight
MZFW	Maximum zero fuel weight

NADP	Noise abatement departure procedures
NO_x	Nitrogen oxides
NPR	Noise preferential routeing
OEW	Operating empty weight
OPR	Overall pressure ratio
PM	Particulate matter
R&D	Research and Development
SAR	Specific air range
SO_2	Sulfur dioxide
TNSA	French tax on air noise pollution
TSFC	Thrust specific fuel consumption
UK EA	UK Environmental Agency
VAT	Value added tax

Introduction

While the bulk of economic literature analyzes the impact of environmental constraints on airlines, only little work has been done so far in the field of business aviation. The present paper analyzes existing and near-future environmental constraints and estimates compliance costs for business aircraft operators. After the release of the first paper entitled "Introduction into Business Aviation- Operating Cost Analysis", this paper focuses on environmental aspects. It presents the results obtained under BASE (Business Aviation for a Sustainable Economy). BASE is part of the CleanSky initiative- the largest European R&D project on the future of an environmental friendly aviation.

1 Structure and Approach

This paper sets out to provide a comprehensive overview of existing environmental constraints. It integrates the findings obtained during research conducted in the scope of CleanSky BASE. Around 150 business aircraft operators primarily based in the United States contributed to BASE through the completion of an online survey. It contained questions on environmental costs and their impact on operator best practices. To better understand and ensure the validity of the answers obtained in the survey, we interviewed business aviation experts and discussed the same questions in more detail. Environmental costs reported in the survey were compared with our own cost calculations. Just to list some of them, we modeled the size of emissions charges, noise charges and the cost burden faced by business aircraft operators under the European Union Emissions Trading Scheme (EU ETS). The BASE results may support the planning and decision making process of flight department managers, or simply, help the interested reader to better understand the regulatory framework in which business jets operate.

The paper is structured in Chapters 1 to 9. Chapter 2 provides a brief description on how business aviation contributes to anthropogenic climate change and other environmental damage. Chapter 3 gives an overview of existing environmental instruments which can be used for the mitigation of external effects related to the operation of aircraft. It also describes the characteristics of business aviation and clarifies why some environmental measures affect business aircraft operators differently than commercial airlines. Chapter 4 to 8 analyzes noise and emissions type certification, airport charges, taxation and emissions trading. We demonstrate how these regulatory interventions affect business jet operators. Chapter 9 summarizes all findings and compares environmental costs from different instruments.

2 Environmental Footprint of Business Aviation

The combustion of jet fuel (hydrocarbons) produces emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2), water vapor (H_2O), nitrogen oxides (NO_x) and soot. These direct emissions change the composition of the atmosphere through physical and chemical processes and thereby alter its energy balance (the so called radiative forcing). It translates into increases of the global mean surface temperature. All this is known under the name global warming. The substance which contributes the most to global climate change is CO_2. It is the most emitted greenhouse gas (GHG) and it has a longer resistance time in the atmosphere. Transport accounts for 13 percent of global man-made carbon emissions. Aviation CO_2 emissions represent two percent, whereas business aviation only accounts for 0.04 percent of global CO_2 emissions[1]. Figure 1 visualizes the distribution of global man-mad CO_2 emissions of the transport sector (=100 %).

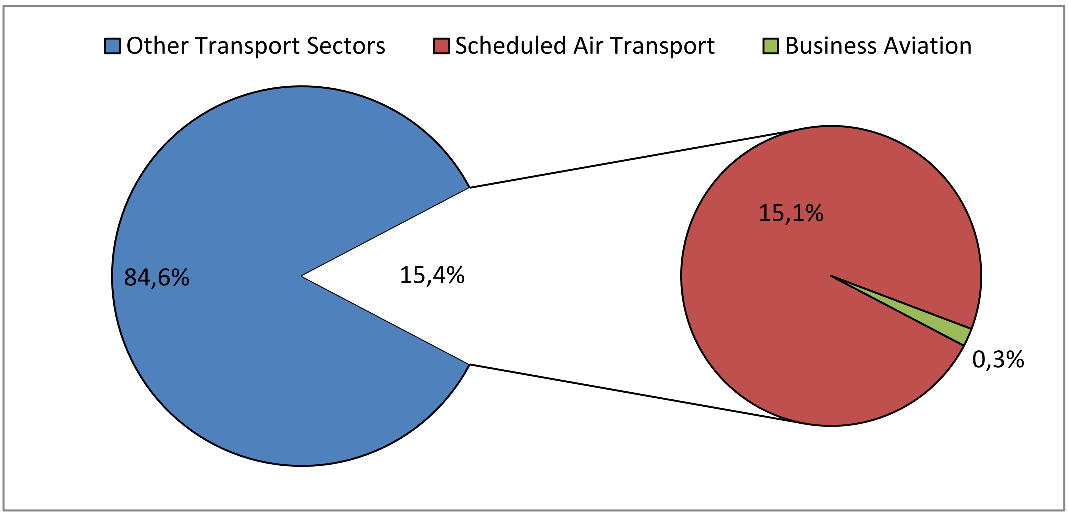

Figure 1: Global CO2 Emissions by Transport Sector

Source: EBAA (2010), 3.

But if one considers all other GHGs, it turns out that aviation accounts for 4.9 percent of anthropogenic climate change[2]. Accordingly, the share of global CO_2 emissions understates the total impact of business aviation on climate change. Besides the impact on climate change, business aircraft are also responsible for the degradation

[1] EBAA (2010), 3.

[2] Aviation and global climate change in the 21st century, David Lee et al, Atmospheric Environment, July 2009, tinyurl.com/opk8nc

of air quality in the vicinity of airports. The production of NO_x, unburned hydrocarbons (HC) and fine particulate matter (PM) present a risk to the environment and public health. Noise from overflying aircraft adds to the environmental footprint of business aircraft.

3 Business Aviation and Environmental Regulation

The objective of this chapter is threefold: First, we provide a definition for business aviation. Second, we give an overview of environmental constraints. Third, we explain in which regard business aviation differs from commercial airlines and why existing environmental constraints are rather unsuited for the regulation of business aircraft operators.

3.1 Working Definition of Business Aviation

According to the definition provided by the International Business Aviation Council (IBAC), business aviation is defined as “the sector of aviation which concerns the operation or use of aircraft by companies for the carriage of passengers or goods as an aid to the conduct of their business, flown for purposes generally considered not for public hire and piloted by individuals having, at the minimum, a valid commercial pilot license with an instrument rating”[3]. This definition does not exclude the operation of business aircraft for commercial purposes. The IBAC further subdivides business aviation in three categories. One of them refers to the transportation of passengers and goods against remuneration.

3.2 Call for Environmental Regulation

The worldwide business jet fleet is expected to continue its historical growth path. Bombardier forecasts a four percent increase of the Compound Annual Growth Rate (CAGR) for the next 20 years[4]. The growth of the business aircraft fleet pushes global CO_2 emissions to a higher level unless improvements in technology, infrastructure and operations offset traffic induced emissions growth. The reality looks something different. The General Aviation Manufacturers Association (GAMA) and the International Business Aviation Council (IBAC), both representatives of the business aviation industry, published a statement according to which business aviation strives to achieve the same carbon emissions ‘reduction’ targets as set by

[3] ICAO (2005), 3.

[4] Bombardier (2011)

the International Air Transport Association (IATA)[5]. Starting from 2020, net CO_2 emissions from business aviation shall remain flat even as demand for air transport grows. This concept is known under the name *carbon neutral growth*. GAMA and IBAC also agree on annual fuel efficiency improvements of two percent (in average) until 2020 and a reduction of total carbon emissions of 50 percent by 2050 relative to 2005 levels. Figure 2 shows by which means GAMA/IBAC seek to achieve aspirational emissions reduction targets.

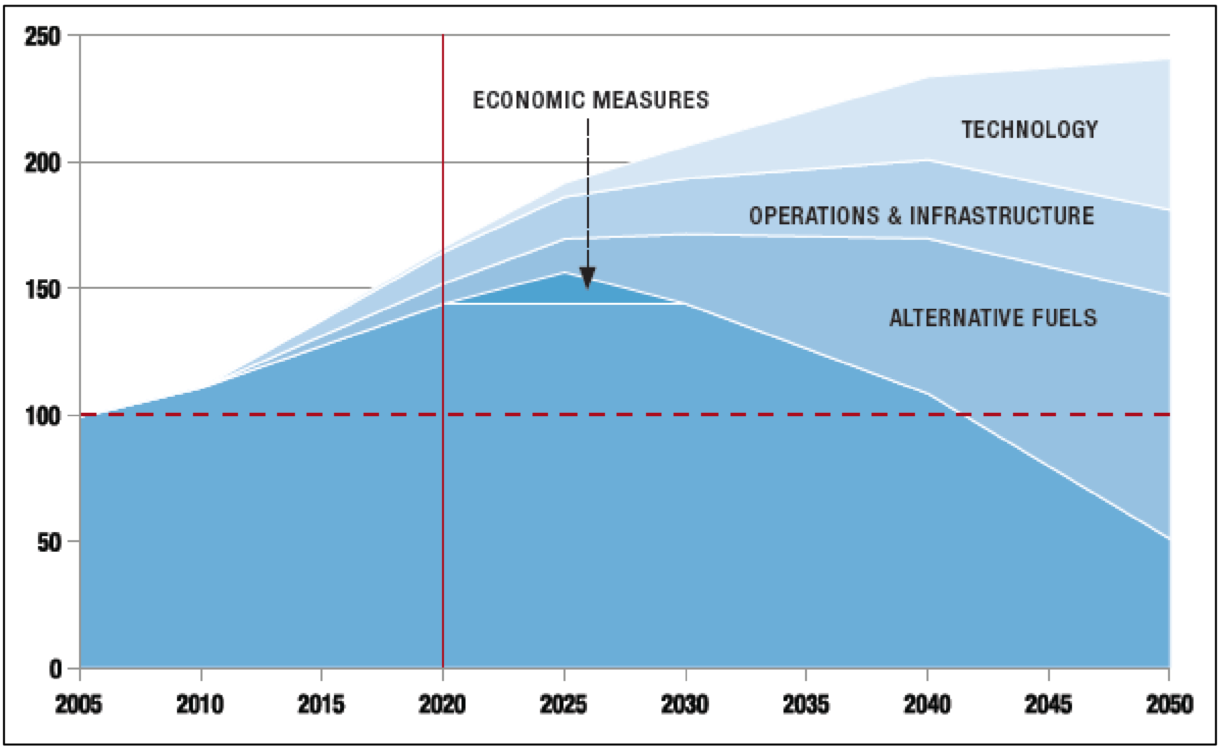

Figure 2: Business Aviation CO2 Emissions Forecast

Source: GAMA/IBAC (online)

The vertical axis measures the carbon emissions level as percent of the 2005 level. “Technology” refers to the gain in aircraft fuel efficiency. “Operations” stands for the implementation of best practices to exploit operational fuel saving potentials. As to what regards “Infrastructure”, more efficient air traffic management (ATM) systems are currently in design (SESAR in Europe and NextGen in the US). They promise more direct routing through national airspace and a higher use of fuel saving procedures, such as continuous descent approach (CDA). According to GAMA/IBAC,

[5] Online: http://www.gama.aero/media-center/press-releases/content/global-business-aviation-community-announces-commitment-climate-

alternative fuels hold the highest carbon reduction potential. Tailpipe carbon emissions from biofuel are not lower than those produced from fossil fuels. Besides emissions produced during the production of biofuel and feedstock cultivation, biofuel does add no emissions to the atmosphere. Biofuel feedstock absorb carbon from the atmosphere which is released when biofuel is burnt. But this is only one part of the truth. Emissions related to direct and indirect land use change further lower the appeal of biofuel for the use in transportation[6]. Biofuel may also face economic restrictions. Its production requires massive investments into the refinery infrastructure[7]. It is not sure when prices of new generation biofuel become competitive. Production costs are higher than for fossil fuel. Taking all these concerns into account, the contribution of biofuels to carbon reductions from business aviation can be regarded as highly uncertain.

Environmental regulation could fill the gap if emissions do not follow the trend forecasted by GAMA/IBAC. Regulators are offered a diversity of environmental instruments, as presented in Figure 3.

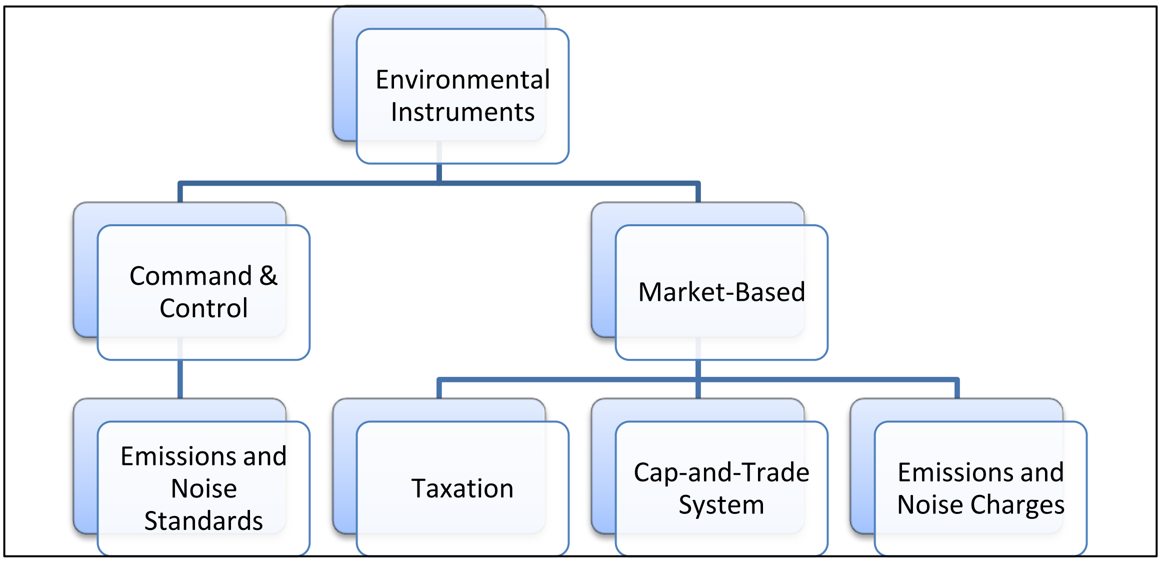

Figure 3: Overview of Environmental Instruments

Figure 3 distinguishes between command and control (CAC) instruments and market-based instruments. The difference is that the latter put a price on pollution, whereas CAC instruments define (for instance) a maximum pollution level (command) and

[6] CE Delft (2010)

[7] BIZAV (2011)

check whether the limit is not exceeded (control). Noise and emissions standards are performance-based CAC instruments used for the certification of aircraft[8]. Low stringency of standards (level of the pollution limit and the frequency of its revision), the missing incentive to reduce pollution beyond the standard, risk of dilution[9] and cost inefficiencies (of a 'one-fits-it-all' standard) are the most important disadvantages of CAC instruments. Market-based instruments leave the reduction of emissions to the discretion of the emissions source. Aircraft operators have an incentive to reduce pollution as long as abatement comes cheaper. Taxation, cap and trade system and emissions/noise charges are the most prominent market-based measures. Cap and trade systems, as the name implies, set an industry wide emissions cap and allow the trade of emissions allowances. One emissions allowance gives regulated entity the right to emit one tonne of pollutant. In contrast to taxation, the price of emissions allowances is determined by the interaction of supply and demand for tradable permits on a regulated market. Regulators using taxes to control emissions don't know by how much industry emissions will decrease, whereas cap and trade systems fix the amount of emissions reductions ex ante. Emissions and noise charges (as we will explain in greater detail later in this paper) levy a fee on aircraft movements (landing and take-off) which size depends on the environmental performance of aircraft engines (case: engine emissions charges) and aircraft-engine combinations (case: noise charges). Accordingly, aircraft operators can only decrease the cost burden by replacing or retrofitting the old aircraft.

3.3 Comparing Business and Commercial Aviation

The air transport market can be segmented by the degree of personalized service. The business model of commercial airlines is to offer scheduled air service. The cabin is split into classes (such as economy, business, first class) to serve different customer needs. Business and first class passengers benefit from superior service and higher flexibility when choosing the flight. But commercial airline service lacks in many other aspects when compared with the flexibility and degree of convenience

[8] To be distinguished from technology-based CAD instruments. They prescribe the use of a 'best available technology' (BAC), 'best commercially available technology' (BACT) or 'BAT not involving excessive costs' (BAT-NEC).

[9] The risk of output related metrics (called ratios) to improve the environmental performance by increasing the output rather than decreasing pollution.

offered by business aviation. The most obvious advantage of business aviation is that flights operate on the passenger's schedule. But business aviation offers many other advantages to its users which commercial airlines cannot provide. Table 1 gives an overview of various benefits linked to business aviation.

Benefits of Business Aviation	Description
Saving Employee Time	Business aviation brings passengers to smaller airfields that are closer to the traveler's destination. Time spent before departure and after landing for security and customs is kept to a minimum.
Increasing Traveler productivity and Ensuring Confidentiality	Passengers use the cabin (equipped with internet and phone access) as work place. Meetings can be held without fearing leakage of sensitive information.
Reaching more Destinations	Business jets can start and land on 10 times more US airports than commercial airlines. Business aircraft give access to remote communities or less congested airports. It also brings the passenger closer to his destination.
Allowing scheduling Flexibility and Predictability	Business aviation allows the user to plan his business trip according to his agenda and other travel needs. The destination can even be changed en route. Concerns over delays and cancellations are virtually nonexistent on business aircraft.
Moving Vital Equipment	Business aircraft allow the transportation of ship sensitive, critical or outsized equipment.
Increasing the Reactivity	Business aircraft enable companies to quickly respond to business opportunities.

Table 1: Benefit of Business Aviation

The BASE survey was accompanied by interviews held with business aviation experts. They were asked to name the three most important benefits which business aircraft offer to their users. Time savings and scheduling flexibility were the most recurrent answers, followed by comfort, productivity, accessibility to smaller airfields and confidentiality.

As mentioned in the previous chapter, business aviation only accounts for a relatively small part of aviation carbon emissions. Environmental constraints were primarily designed to tackle emissions and noise from commercial aviation. They were extended to business aviation because of equity reasons and to strengthen the environmental integrity. Much research was done to better understand the impact of environmental constraints on commercial aviation. But only little is known about how existing regulation affects business aircraft operators. Regulators are recommended to consider the specifications of business aviation when analyzing the impact of environmental instruments, such as emissions trading or engine emissions charges.

4 Emissions and Noise Standards

Regulators have the task to correct the market performance if it does not match with a socially optimal outcome. This happens when negative externalities occur and third parties who were not involved in the production process defray the costs of e.g. atmospheric pollution. In our concrete case, policy makers introduced instruments to limit noise and emissions related to aircraft operations in the absence of self-regulating market forces or because they considered prevailing noise and emissions levels unacceptable high. Whereas carbon dioxide emissions decrease with higher fuel efficiency, the same fuel savings do not translate into lower NOx emissions or noise. Emissions standards shall provide an incentive for manufacturers to develop airframe and engine designs which reduce the output of GHG gases or noise. Figure 4 shows components of certification standards.

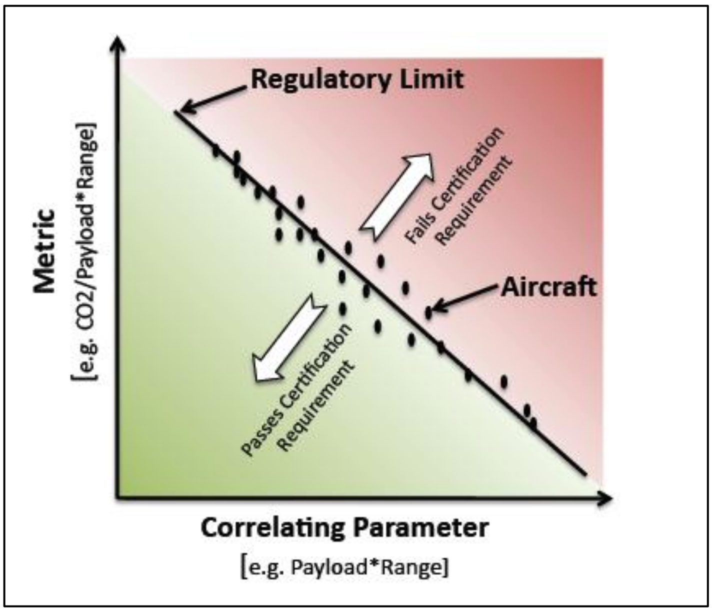

Figure 4: Emissions Standards Components

Source: Yutko, B (2011).

A certification standard consists of three elements: (1) a metric, correlating parameter and evaluation conditions, (2) a scope of applicability, and (3) a regulatory limit.

Table 2 describes the three elements of a certification standard in greater detail.

		Definition
Certification Requirement	**Metric**	The metric (M) measures noise or emissions performance. It can neutralize performance deviations related to differences in the productivity (e.g. aircraft size or range) when writing the respective variable in the denominator. Figure 3 example: The metric of the CO2 emissions standard (written on the vertical axis) is $CO_2/Payload \times Range$. Carbon emissions are normalized by dividing them by payload (as proxy for aircraft size) and range to eliminate the bias effect of both productivity variables.
Certification Requirement	**Correlation Parameter**	The correlation parameter (CP) plays the same role as the denominator of a metric and is not a necessary part of the standard. In case of correlation between metric and productivity variable, the comparison of metric values from different productivity levels might be inappropriate. This can be remedied by expressing the metric as a function of the productivity variable. Figure 3 example: The correlating parameter $Payload \times Range$ ensures that the metric remains comparable across different aircraft size and range capabilities.
Certification Requirement	**Evaluation Conditions**	The evaluation conditions refer to the conditions under which variables (especially metric and correlating parameter) are measured. Evaluation conditions are not captured in Figure 2. Range and aircraft weight have to be defined for flight tests to ensure a level playing field.
Scope of Applicability		The scope of applicability defines which type and size of aircraft are covered by the emissions or noise standard.
Regulatory Limit		The regulatory limit sets a stringent threshold of compliance. Aircraft situated to the left of the M-CP function meet a pre-defined performance minimum while aircraft on the right site of the M-CP function are not compliant.

Table 2: Core Elements of Emissions and Noise Standards

4.1 Engine Certification Standards

Engine certification standards were adopted by the Council of the International Civil Aviation Organization (ICAO[10]) in 1981 on the recommendation of the second

[10] The ICAO was created in 1944 during the Convention of International Aviation (also known as Chicago Convention) to promote the safe and orderly development of civil aviation throughout the world. It comprises 190 member states that cooperate on international level in all fields of civil aviation.

meeting of CAEP (CAEP/2). They set limits for emissions of oxides of nitrogen (NO_x), carbon monoxide (CO), unburned hydrocarbons (HC) and smoke. Since that time they were made more stringent in 1993, 1999 and 2005. The next adjustment becomes effective in 2014. The standards are contained in Annex 16, Volume II, to the Convention of International Civil Aviation. Originally, the NO_x emissions standard was designed to lower the emissions inventory in the vicinity of the airport, but it also curbs the production of ozone at high altitudes. Ozone is a greenhouse gas (GHG) which contributes to climate change.

4.1.1 Principles

Engine prototypes need to be certified for airworthiness. Standards for NO_x, CO, HC emissions and smoke only apply to turbojet and turbofan engines with rated output higher than 26.7 kilonewtons (kN; engine maximum rated thrust). These engines are tested under constant certification conditions and gathered data is consolidated in the Engine Exhaust Emissions Data Bank (DOC 9646) and on individual engine datasheets. The database is regularly updated with entire new engines or derivatives[11]. Turboprop, piston, gas turbine engines and turbojet/turbofan with maximum thrust lower than 26.7 kN are not regulated under ICAO, Annex 16, Volume II. If no ICAO information is available, engine emissions charges (see Chapter 5.1) are often calculated based on engine emissions data provided by the Swedish Aeronautical Research Agency (FOI). Jet engines exceeding the de minimis threshold of 26.7 kN are tested under the following described evaluation conditions. The certification testing is carried out on uninstalled engines. Emissions are measured for a large number of power settings, but only communicated for a set of four reference power settings, representative for typical thrust ratings during take-off, climb, approach and taxi/ground idle[12]. The four phases define the standardized landing and take-off (LTO) cycle, as shown in Figure 5. Emissions are only calculated for the four operating modes from the ground up to an altitude of 915 metres (3000 ft).

[11] Databank publicly available on: http://www.caa.co.uk/default.aspx?catid=702&pagetype=90

[12] ICAO (2007), 30.

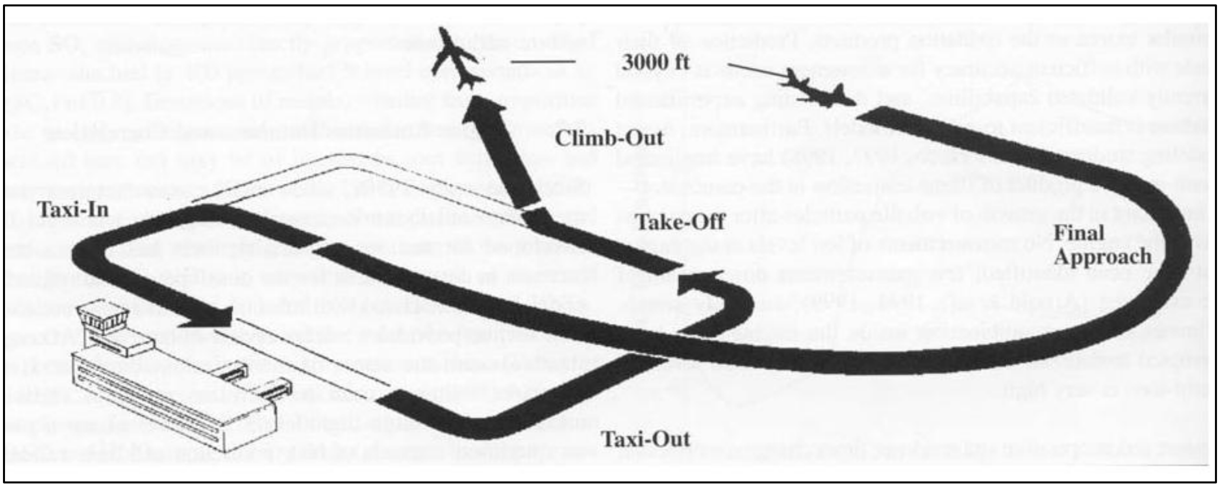

Figure 5: ICAO Reference LTO Cycle

Source: Unique/Swiss (2004), 4.

A time span is assigned to each operating mode (see Table 3). It should be noted that the time-in-mode does not necessarily reflect actual operations, but is still used by the ICAO for certification purposes. The time-in-mode is based on survey results obtained in the 1970s from large metropolitan airports at peak traffic.

Operating Mode	**Thrust Setting** (in percent of rated output)	**Time-in-Mode** (in minutes)
Take-Off	100	0.7
Climb Out	85	2.2
Approach	30	4.0
Taxi/Idle	7	26.0

Table 3: ICAO Documentations

The LTO cycle and the prescribed time-in-mode set the evaluation conditions and guarantee that all engines are tested the same way.

For the sack of simplicity, we will concentrate hereafter on the certification of NO_x emissions. As mentioned above, ICAO engine tests provide emissions indices (mass of NO_x emissions per one kg fuel) for all four operating modes together with fuel flow values (kg fuel consumed per second). In order to calculate the metric DP/F_{00}, we use information on thrust setting and time-in-mode as provided in Table 3. DP denotes the mass of NO_x emissions produced over all four phases of the ICAO reference LTO cycle. F_{00} stands for the engine's sea level static maximum rated thrust and measures the useful capability of the engine. The formula for the calculation of DP/F_{00} for one engine is stated below:

$$DP/F_{00} = \sum_{LTO\ modes} (60 \times time \times fuel\ flow \times NO_x\ emissions\ index)$$

F_{00} is written in the denominator of the metric to normalize DP because both variables are correlated. The NO_x standard uses the engine overall pressure ratio (OPR) as correlating parameter. It is the total pressure at compressor delivery divided by that of the engine inlet[13]. Figure 6 depicts the relation between the metric and the correlating parameter of in-production engines.

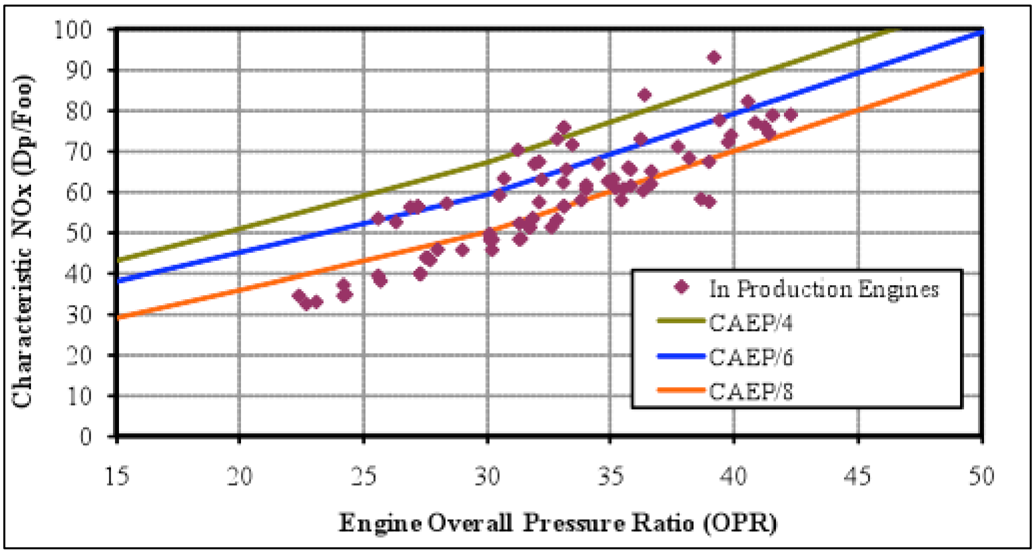

Figure 6: NOx Metric, Correlation Parameter and Regulatory Limits

Source: Yutko, B (2011), 81.

There is a correlation between DP/F_{00} and OPR. It underlines the usefulness of OPR as correlating parameter. Figure 6 also contains the regulatory limits decided on the forth, sixth and eight meeting of the Committee on Aviation Environmental Protection (CAEP/4, CAEP/6, CAEP/8). The downward adjustment of the NO_x limit shall incentivize manufacturers to invest more in research and development. To complement the standard setting process, the CAEP/7 defined medium and long term NO_x technology goals. NOx emissions shall be reduced by 45 percent (60 percent) of current levels by 2016 (2026)[14].

[13] Soares, C. (2008), 703.

[14] ICAO (2007), 64.

4.1.2 Implications for Business Aviation

As mentioned above, only jet engines with maximum thrust higher than 26.7 kN fall under the scope of the NO_x emissions standard. Figure 7 shows to which aircraft segments the standard applies. The 2012 Pocket Guide to Business Aircraft from Flightglobal served as basis for the assignment of engines to aircraft plotted in Figure 7.

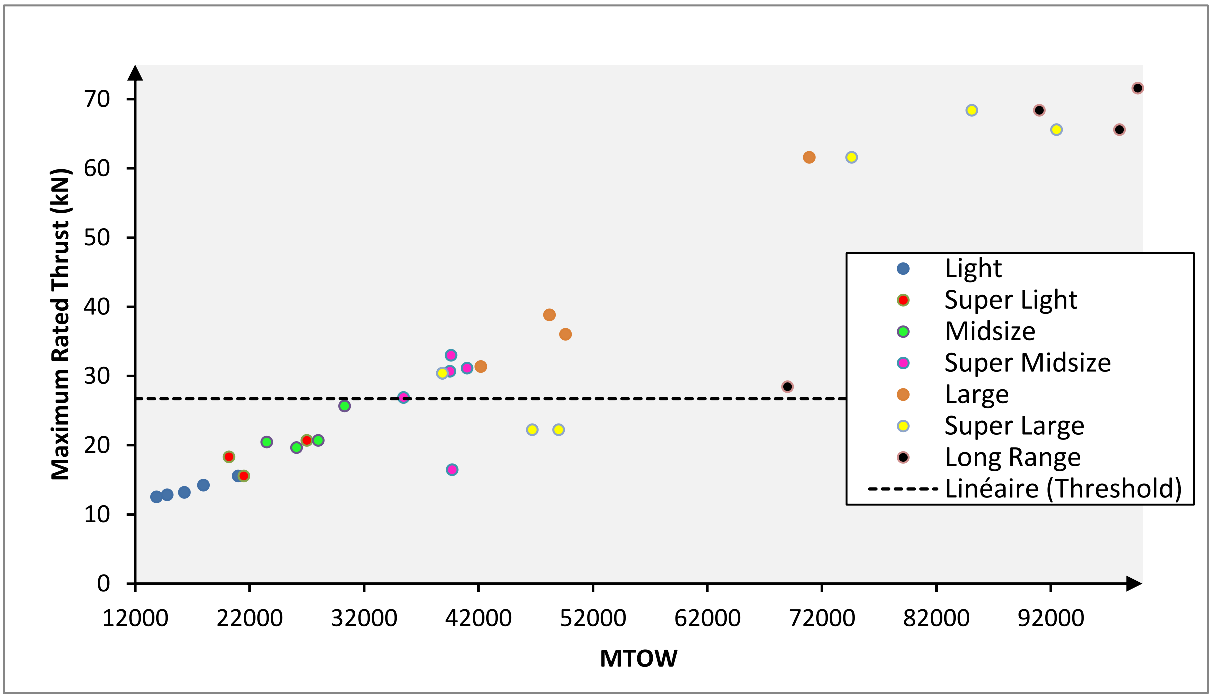

Figure 7: Scope of NOx Emissions Standard

Source: Calculations based on data from Flightglobal (2011)

The line which separates business aircraft is difficult to draw since some business aircraft segments, especially the 'midsize' segment, cover aircraft to both sides of the 26.7 kN threshold. Broadly spoken, engines from (super) large and long range business aircraft are covered by the standard, whereas NO_x emissions from engines installed on (super) light business aircraft are not regulated. However, aircraft manufacturers are likely to pass on technology advances from larger jet engines to unregulated smaller engines. In other words, the certification standard may indirectly improve the NO_x performance of smaller unregulated engines.

4.2 CO_2 Emissions Standards

The ICAO currently works on the development of the first carbon dioxide certification standard. After having ruled out the implementation of a global fuel tax or emissions trading scheme, carbon emissions growth related to increasing air traffic shall be neutralized or reduced by means of a CO_2 emissions standard. The eight meeting of the Committee on Aviation Environmental Protection (CAEP/8) agreed on a plan for the development of a CO_2 emissions standard. The adoption of the standard was scheduled for 2013, but recent disagreements are likely to delay the process. ICAO workgroups seek to define a consistent and practicable certification requirement which forces manufacturers to build more fuel efficient aircraft. This section presents the two most promising emissions standards. We evaluate the performance of both candidates and investigate their impact on business aviation.

The carbon standard of ICAO seeks to reduce carbon dioxide emissions. It is often referred to as fuel efficiency standard since fuel and carbon dioxide emissions are linked by a constant fuel-specific emissions factor. For instance the combustion of one tonne Jet A fuel produces 3.15 tonnes carbon dioxide. Fuel savings translate directly into lower CO_2 emissions. We can therefore focus on how well aircraft do on fuel consumption.

The Breguet-Range equation shows what parameters affect aircraft fuel consumption and thus identifies through which channels fuel and emissions could be reduced.

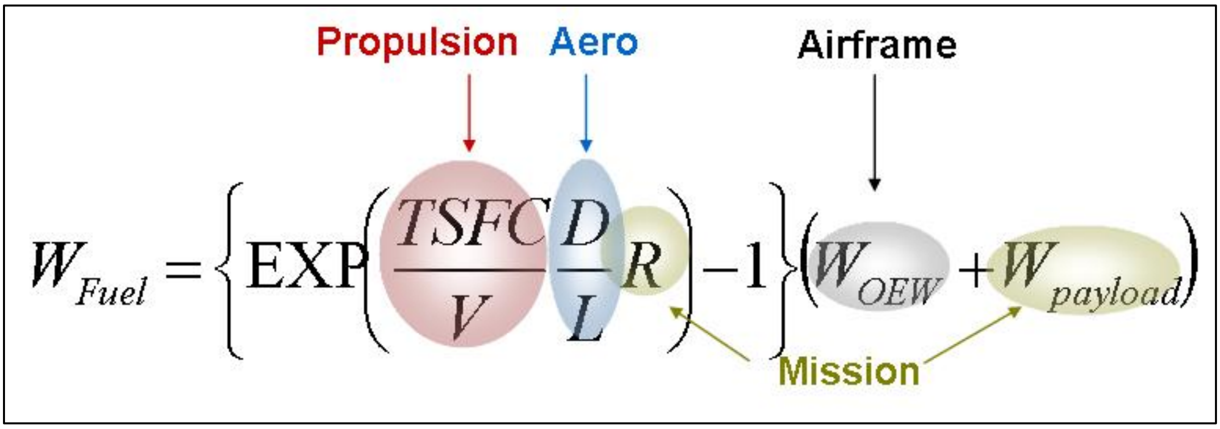

Figure 8: Breguet-Range Equation

Source: PARTNER Project 30 (2010), 9.

The mass of fuel burned during a particular mission (W_{Fuel}) depends on aircraft specific factors (propulsion, aerodynamics and airframe weight) and operational parameters (range (R) and payload ($W_{payload}$)). The thrust specific fuel consumption (TSFC) measures the mass of fuel consumed per unit of thrust. The lift-to-drag ratio (L/D) describes the aerodynamic characteristics of fuselage and wings. Streamlined shapes reduce drag and increase the lift-to-drag ratio. The airframe operating empty weight (W_{OEW}) denotes the mass of the aircraft structure. The use of light-weight materials can contribute to the reduction of aircraft fuel consumption. A carbon dioxide emissions standard shall incentivize manufacturers to push technical progress in the field of propulsion, aerodynamics and aircraft weight beyond what market forces can do.

The CO_2 standard complements already existing certification standards of nitrogen oxides and noise. As Figure 8 shows, propulsion is not the only parameter affecting aircraft fuel consumption. The design and weight of fuselage and wings also affect aircraft performance. Engine fuel efficiency does not necessarily correlate with aircraft fuel efficiency[15]. That is the reason why the type certification has to include the measurement of carbon dioxide emissions from aircraft-engine *combinations* contrary to the certification of NO_x emissions which concentrates on engines only. The idea of an emissions standard is to issue positive type certificates to aircraft which certified performance lies above a stringent fuel efficiency minimum. The threshold is set externally by policy makers. Manufacturers will have to respond on tightened criteria and make an effort to increase the fuel efficiency of new generation aircraft. Certified emissions data could also serve as basis for the calculation of CO_2 emissions charges. Operators might have an additional incentive to invest in more fuel efficient aircraft. The ICAO CAEP workgroup tries to design the CO_2 emissions standard in a way that fuel efficiency is measured accurately while keeping the certification process as simple as possible.

Table 1 defines the three elements of the certification requirement. It was said that the metric can be normalized either by writing the productivity variable in the denominator of the metric itself or by expressing the metric as function of a

[15] PARTNER Project 30 (2010), 10.

correlation parameter. The fuel consumption of different aircraft is hardly comparable without normalization.

4.2.1 Design Requirements

Emissions standards can be tested against a number of criteria. They have to satisfy several design requirements before being retained as candidates for a CO_2 emissions standard. Table 4 provides a list of conditions potential candidates should fulfill.

	Description
Measurement of fuel efficiency	A CO_2 emissions standard shall accurately measure aircraft fuel efficiency and guarantee that the variety of aircraft capabilities is taken into account.
Aviation Fuel Neutrality	Aircraft CO_2 emissions depend on (1) fuel CO_2 content and (2) aircraft energy intensity. A CO_2 emissions standard shall allow the integration of alternative fuels or blends with different CO_2 contents.
Independence of Utilization	Emissions standards should not discriminate between different aircraft utilizations (e.g. cargo vs. passenger transportation).
Ability to differentiate aircraft technology levels	A CO_2 emissions standard shall clearly distinguish between different aircraft technology levels (e.g. out-of production vs. in-production aircraft).
Limited unintended consequences	Emissions standards shall be designed such as to avoid unintended consequences. Apart from the intended reduction of aircraft fleet carbon emissions, all other conditions should remain similar to business-as-usual.
Simple certification and measurement	Simple certification process refers to the simplicity of implementing the certification requirement. A simple approach means no or only little certification work to set up a standard test environment. The measurement of fuel performance can be done through test flights and/or using powerful simulator software. The time spent for measuring fuel efficiency should be limited to a minimum.
Fairness	Fairness refers to the treatment of different stockholders. The waste majority of aviation professionals agree that the certification requirement should account for different levels of aircraft capability. For the purpose of research performed in the scope of PARTNER Project 30 (2010), a “fair” certification requirement minimizes the spread of fuel performance across different aircraft types, aircraft size and business model.

Table 4: Design Requirements for Emissions Standards

Source: PARTNER Project 30 (2010), 19.

The next section presents the two most promising certification standards. They will be tested against the above listed attributes.

4.2.2 Full Mission vs. Instantaneous Performance

A variety of metrics were discussed by stakeholders involved in the ICAO process. They can be regrouped under the following to subsets:

Full mission performance: All variables describing the aircraft performance are measured for the entire mission. Mission fuel equates fuel burn during taxi, departure, climb, cruise, approach and landing (from block off to block on).

Instantaneous performance: Aircraft performance is only measured at one point during cruise under particular flight conditions (speed, altitude, aircraft weight and atmospheric conditions). As widely used by manufacturers to specify the fuel performance of aircraft, the Specific Air Range (SAR) measures the range aircraft can fly on the next incremental amount of fuel burned.

Two metrics were retained as candidates for the CO_2 emission standard because they perform best under the design requirements listed in Table 4. Table 5 and 6 describe both metrics in greater detail.

			Characteristics
Full Mission Performance	Metric	$\frac{Block\ Fuel}{Range}$	A promising full mission performance approach is the ratio of block fuel (BF) and range. Block fuel is defined as the fuel consumed during all ground and flight phases from block-off to block-on. The mission range stands in the denominator and eliminates the effect of range on block fuel.
	Correlation Parameter	*MTOW*	It appears inappropriate to compare the fuel efficiency metric without considering aircraft payload capabilities. Under equal capacity utilization, the absolute take-off weight of wide body aircraft is higher than the one of business aircraft. Hence, more fuel per nautical mile (nm) is burned by wide body aircraft. The normalization can be done by relating the fuel efficiency measure to Maximum Take-Off Weight (MTOW). The regulatory limit is a function of MTOW.
	Evaluation Conditions		Aircraft performance models, such as Piano, were used to analyze the performance of metric-correlation parameter combinations under different evaluation conditions. Research conducted in the scope of PARTNER project 30 found out that all three elements have to be considered simultaneously, because different evaluation conditions lead to different fuel efficiency pattern of the same metric-correlation parameter combination. After having tested diverse certification requirements, it turns out that aircraft shall be tested flying with MSP (Maximum Structural Payload) and sufficient fuel in tanks to reach 40 percent of the maximum achievable range (maximum achievable range denotes the range aircraft would fly under MSP and MTOW). The range length is expressed in relative terms, because aircraft range varies considerably amongst aircraft and so does the range for which least fuel is consumed. 40 percent of maximal achievable range was chosen because it describes real-life operational pattern the best. The metric was weighted with the frequency of ranges flown in real-life operations and compared to the unweighted metric. Using an unweighted metric, 40 percent of maximal achievable range (as defined above) does not discriminate between aircraft types, whereas relative ranges higher than 40 percent overstate the fuel efficiency of short-haul aircraft and understate fuel performance of long-haul aircraft. The reason is that the fuel optimal range of long-haul aircraft is lower than the maximal achievable range. Besides the definition of range and payload, around 150 other parameters need to be defined for measuring block fuel of diverse aircraft types under equal conditions.

Table 5: Characteristics of Full Mission Performance

Source: Yutko, B. (2011)

			Characteristics
Instantaneous Performance	Metric	$^{1}/_{SAR}$	Inverse specific air range $(1/SAR)$ denotes the mass of fuel burned over one nautical mile in cruise mode (i.e. in steady-level conditions). The metric measures instantaneous performance at a single point in time. SAR can be calculated using the following formula: $SAR = (V/TSFC) \times (L/D) \times (1/W)$ SAR is positively related to aircraft speed (*V*) and lift-to-drag ratio (*L/D*) and negatively related to thrust specific fuel consumption (*TSFC*) and weight (*W*).
	Correlation Parameter	$\frac{(MTOW + MZFW)}{2}$	The question that arises is under which evaluation conditions aircraft should be tested. According to the SAR formula, $(1/SAR)$ goes up with increasing weight (weight of aircraft structure, transported payload or fuel load). An appropriate weight measure is $(MTOW + MZFW)/2$. Maximum zero fuel weight (*MZFW*) is the sum of operating empty weight (*OEW*) and maximum structure payload (*MSP*). The metric is equivalent to MZFW + 50 percent of maximum fuel load. As mentioned in Table 4, weight is measured in relative terms, because aircraft have different payload capabilities. MTOW was confirmed as appropriate weight measure because the average take-off weight (as measured as percentage of MTOW) of real-life operations does not differ between aircraft types. MZFW is integrated to account for differences in the mission design philosophy of aircraft. In general, business jets are designed to carry less payload. The payload fraction, measured as share of MTOW, is thus relatively lower than for aircraft designed to carry passenger and freight, such as narrow body aircraft. Compared to MTOW as CP, business aircraft display lower productivity under $(MTOW + MZFW)/2$ and face more stringent regulatory limits.
	Evaluation Conditions		The instantaneous performance approach brings the advantage that flight tests only require the definition of four variables: weight (already defined above), altitude, speed and atmospheric conditions. Manufacturers can choose the level of altitude and speed that minimize $1/SAR$ because fuel efficient speed and altitude optima vary widely between aircraft models. Atmospheric conditions (temperature, pressure) are derived from ISA (International Standard Atmosphere) at the chosen altitude with zero wind speed.

Table 6: Characteristics of Instantaneous Performance

After having presented the certification requirement of $1/_{SAR}$ and $^{BF}/_{range}$, Table 7 sets out to evaluate both approaches on the basis of the design requirements listed in Table 4.

Metric (M)	$1/_{SAR}$	$^{BF}/_{range}$
Correlation Parameter (CP)	$\frac{(MTOW + MZFW)}{2}$	$MTOW$
Measurement of fuel efficiency	**Reasonably well** Fuel consumption is measured in steady-level flight.	**Yes** Fuel consumption is measured from block-off to block-on.
Measure of Productivity	**Proxy** Available seats and payload would better reflect "true" productivity.	**Proxy** Available seats and payload would better reflect "true" productivity.
Aviation Fuel Neutrality	**Yes** Fuel efficiency is measured. Fuel CO_2 content has no impact on certification.	**Yes** Fuel efficiency is measured. Fuel CO_2 content has no impact on certification.
Independence of Utilization	**Reasonably well** Freighter aircraft tend to allow lower maximum fuel load. CP favors passenger aircraft.	**Yes** MTOW of freighter and passenger aircraft is the same.
Ability to differentiate aircraft technology levels	**Reasonably well** CP may not reward structural weight reduction technologies, but does reflect other technological progress. CP does not separate in- and out-of-production aircraft as well as MTOW alone. The metric does not explicitly reward fuel efficiency improvements in non-cruise.	**Yes** CP may not reward structural weight reduction technologies, but does reflect other technological progress.
Simple certification	**Yes** 1/SAR is not certified, but relative easy to certify. MTOW & MZFW are certified. Definition of 3 other variables only (speed, altitude and atmospheric conditions).	**No** Block fuel and range are not certified and relative difficult to certify (around 150 variables have to be defined) MTOW is certified.
Fairness	**Yes**	**Yes**

Table 7: Evaluation 1/SAR vs. BF/range Certification Requirement

Source: PARTNER Project 30 (2010)
Yutko, B. (2011)
Notes: Fairness was defined as minimal performance spread between different aircraft types.

Table 7 compares both certification requirements using a choice of design requirements for which results were available. The comparison of specific air range (SAR) and block fuel (also called mission fuel) revealed some pros and cons. It was said that SAR only focuses on the cruise phase and thereby does not measure fuel efficiency during all other phases. However, SAR and block fuel are highly correlated which proves that aircraft performing well in cruise are just as fuel efficient in all other flight stages. The popularity of SAR can also be explained by its simplicity and ease of certification. It is commonly used by the industry to provide information on fuel performance in the aircraft operations manual.

4.2.3 Implications for Business Aviation

The CO_2 emissions standard introduced above covers turbine powered engine aircraft of different size. Aircraft are designed to satisfy a variety of market needs. They reflect different design philosophies. As illustrated in Figure 9, aircraft are assigned to five categories.

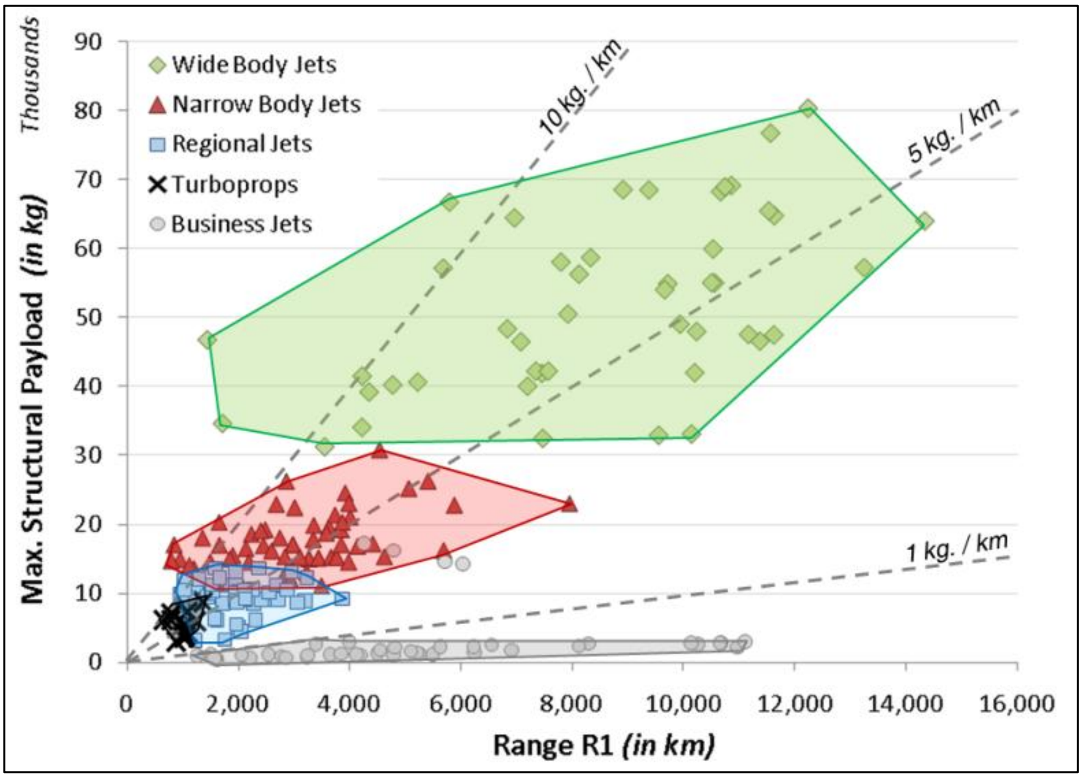

Figure 9: Aircraft Design Philosophies by Payload-Range Combination

Source: PARTNER Project 30 (2010), 55.

Wide body, narrow body, regional, business jets and turboprop aircraft are segmented based on MSP and range R1. R1 denotes the range that can be flown with MSP and limited fuel uplift equivalent to MTOW minus MSP. Figure 9 reveals different payload and range capabilities. For instance the design of business aircraft prioritizes range over payload, whereas narrow body aircraft rather trade payload against range to carry a maximum of passengers or freight. There is an ongoing discussion whether the emissions standard should rather use MTOW or payload for the normalization. We are going to discuss the MTOW-payload controversy in greater detail in chapter 8.1.2. It should be noted that payload is less suitable as correlating parameter for CO_2 emissions standards because it poorly performs under the criteria 'separation of aircraft technologies' and 'unintended consequences'. MTOW based emissions standards have the potential to distort aircraft from the same market segment. They may penalize more fuel efficient aircraft for better aerodynamics and lighter aircraft structures. Take for example the Falcon F900 and the Bombardier Global 5000. Both manufacturers compete on the market of large and long range business jets. Interviews held with business aviation professionals under BASE revealed that both aircraft primarily seek to increase mission range. One reason why the Global 5000 almost doubles MTOW of the F900 is because of more fuel must be carried to reach the same mission range than the F900 does. Higher fuel load requires a more robust airframe which adds to aircraft weight and, in turn, increases the necessary amount of fuel.

Another, more general, discussion refers to the justification of regulating CO_2 emissions. Business aircraft manufacturers argue that the market puts sufficient pressure on them to increase aircraft fuel efficiency. In the past, manufacturers improved the fuel efficiency of their jets rather to increase the maximum mission range than for cost savings associated with a reduction in fuel consumption.

4.3 Noise Certification

In 1971, ICAO introduced a noise certification standard to limit noise at the source in order to lower the number of people exposed to aircraft noise. Annex 16, Volume I, to the Convention of International Civil Aviation regulates aircraft noise from aeroplanes and helicopters. The noise standard is only one mean of reducing noise. The ICAO promotes a balanced approach including three other channels through which noise exposure can be reduced. Land use planning and management, noise abatement operational procedures and operating restrictions are part of the noise mitigation strategy. Operating restrictions refer to the withdrawal of older aircraft which certified noise levels exceed today aircraft noise limits. We will come back to noise abatement operational procedures and operating restrictions at a later stage of the paper.

4.3.1 Principles

In contrast to a NO_x emissions standard, the noise certification addresses both airframe and engine manufacturers. Noise is produced by both engines and airframe. Airframe noise occurs when the aircraft moves through the air. Take for instance landing gear which directly creates drag and noise of higher levels [16]. But aerodynamics also contribute indirectly to noise production if you bear in mind that additional drag has to be compensated by more thrust. Engine thrust ratings, noise respectively, are higher if air flows less smoothly around fuselage and wings. It is the airframe-engine combination that determines the noise performance. The metric of the noise certification standard is the Effective Perceived Noise Level (EPNL), as measured in EPNdB. It measures human annoyance to aircraft noise by accounting for noise intensity, tonal content and the duration of the noise from an aircraft[17]. Aircraft noise correlates with MTOW. That's why it was decided to use MTOW as correlation parameter. The weight of an aircraft determines how much power and thrust is needed to move the aircraft and to keep it in motion. The evaluation conditions were defined to present actual aircraft operations at an airport. Aircraft noise is measured at three well-specified locations (approach, lateral and flyover), as shown in Figure 10. During certification of the aircraft prototype, pilots have to fly the aircraft following detailed procedures. The measured noise level under test conditions is higher than actual noise of real-life operations because aircraft are not in a "clean" configuration, but rather in a louder "dirty" configuration with landing gear, flaps and other surfaces exposed[18].

[16] ICAO (2007), 26.

[17] ICAO (2010), 26.

[18] PARTNER Project 30 (2010), 10.

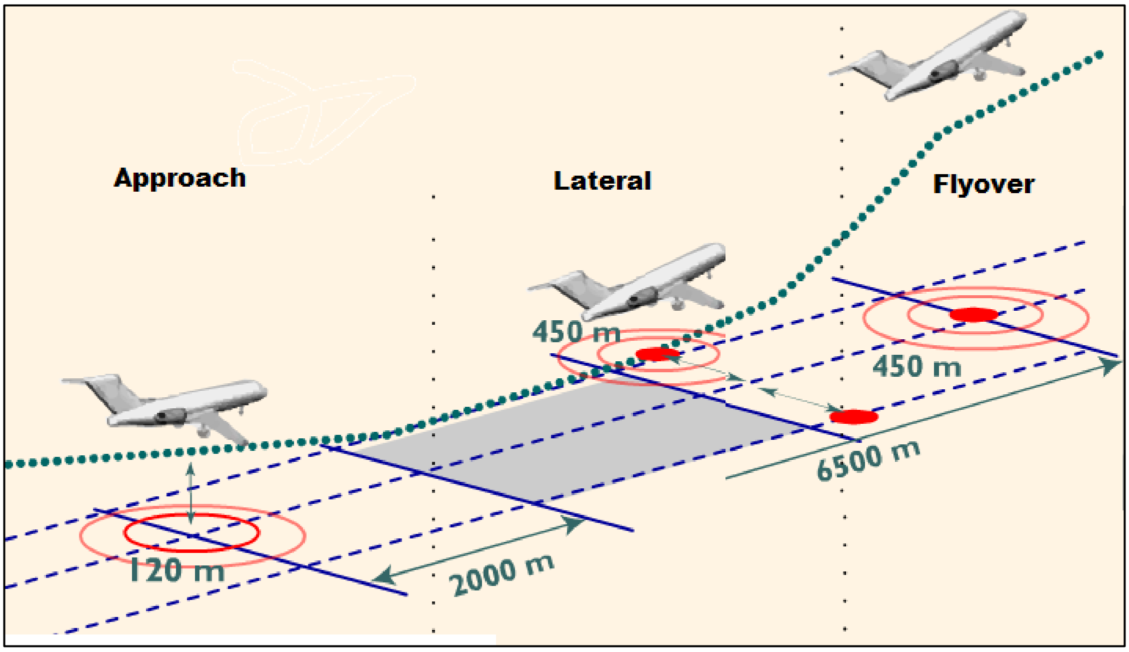

Figure 10: Reference Noise Measurement Points

Source: NoisedB (online)

Aircraft-engine combinations receive a positive certification opinion if they comply with prescribed noise levels. The ICAO tightens noise limits according to technological advances achieved in research and development. Manufacturers are incentivized to continue on this track because more stringent noise limits are expected to be adopted on CAEP meetings in the near future.

Table 8 provides information on the applicability of aircraft under Chapters 2, 3 and 4 of Annex 16, Volume I.

Chapter	Aircraft	Application accepted
2	Supersonic jet aeroplanes	Until 1977
3	Supersonic jet aeroplanes	From 1977 until 2006
	Propeller-driven aeroplanes over 5700 kg (MTOW)	From 1985 until 1988
	Propeller-driven aeroplanes over 8618 kg (MTOW)	From 1988 until 2006
4	Supersonic jet aeroplanes	From 2006
	Propeller-driven aeroplanes over 8618 kg (MTOW)	From 2006

Table 8: Annex 16, Volume I Chapters

Source: NoisedB (online)

Noise limits are the most stringent under Chapter 4. Maximum noise levels are set for single measurement points and for the cumulated noise level. Whereas Chapter 2 and 3 allowed non-compliance at single measurement points under certain conditions, Chapter 4 prohibits any trade between noise levels at single measurement points[19]. The calculation of aircraft noise levels accounts for the number of engines. The noise limit for aircraft equipped with four engines is less stringent than for two-engine aircraft.

Figure 11 displays the stringency of aircraft noise standards and the progress made in noise reductions largely due to the development of engines with higher bypass ratios (BPR). The BPR measures the relation between the mass bypassing the engine core and the mass passing through the engine core.

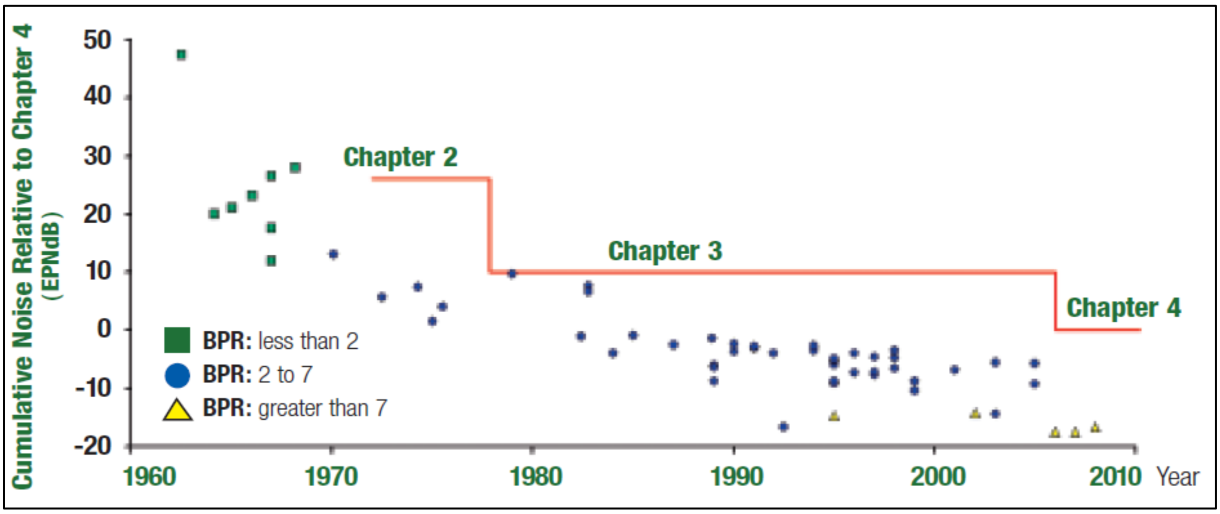

Figure 11: Reduction of Cumulative Noise

Source: ICAO (2010), 22.

Figure 11 shows how noise performance improved in the past. The engine bypass ratio played a significant role in the reduction of aircraft noise levels. Engine noise arises from different engine sources. Fan, compressor, turbine and jet exhaust noise contribute to the engine noise. Higher BPRs means that more bypassing air is available to slow down the air which goes through the engine core. Lower exhaust speed causes less noise. Figure 11 displays the cumulated noise limits as defined in Chapter 2, 3 and 4 of Annex 16, Volume I.

Noise standards push manufacturers to invest more money in research and development to keep pace with tightening noise limits. However, regulators are unlikely to tighten noise limits in the absence of noise reducing airframe and engine advances. This is true because prohibiting operations of average performing aircraft

19 Boeing (2009)

would cut the supply of business aircraft and cause tremendous costs for the whole industry.

4.3.2 Implications for Business Aviation

Figure 12 shows the development of the cumulative noise level (expressed in EPNdB) for the Falcon F50/F900 series. It also contains the maximum noise level defined in Chapter 3 and 4 of Annex 16, Volume I.

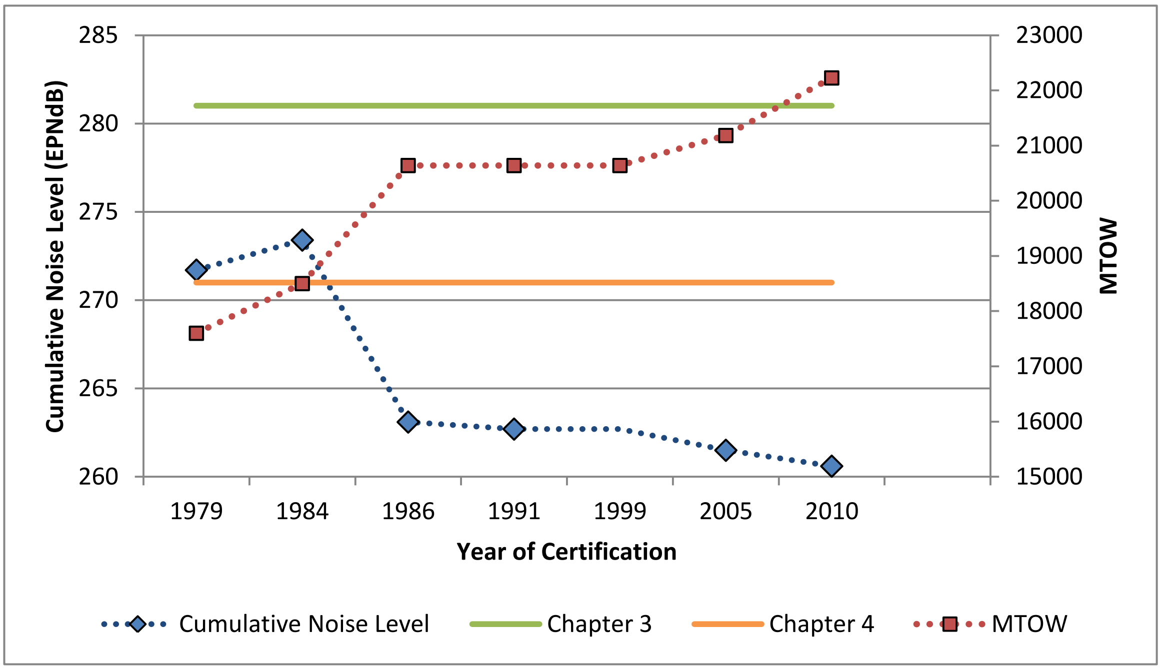

Figure 12: Cumulative Noise Level for Dassault Falcon F50/F900

Source: NoisedB (online)

Dassault constantly improved the noise performance of Falcon F900 aircraft. Cumulative noise levels decreased although MTOW went up by around 30 percent over the last 30 years. The downward trend of the cumulative noise level goes along with increasing bypass ratios. This may (at least partially) explain the achieved noise reduction. Figure 12 also shows that Falcon F50 aircraft would not be certified airworthy under the Chapter 4 noise limit.

It should be noted that the gap between certified noise levels of midsize or light business jets and Chapter 3 or 4 noise limits is much higher than observed for larger business aircraft, such as Falcon F900. Smaller jets create less noise because of their weight.

5 Emissions and Noise Charges

This chapter describes the design of emissions and noise charges and models the cost burden incurred by business aircraft operators. Business aircraft operators are often not aware of the existence of emissions and noise charges because they are added as surcharge to the regular weight based landing fee.

5.1 Engine Emissions Charges

Engine emissions charges (also known as emissions landing charges) are levied on aircraft arrivals and departures and address emissions of nitrogen oxides (NO_x) and unburned hydrocarbons (HC) produced in the vicinity of airports. The amount due is related to the quantity of emissions released during the standardized landing and take-off (LTO) cycle, as originally designed by ICAO for certification purposes. But some airports slightly modified assumptions of the ICAO LTO cycle to better reflect today operations[20]. Landing emissions charges were introduced at airports in Sweden and Switzerland in the nineties of the last century. Engines were assigned to emissions classes which led to situations where engines with similar emissions values were treated differently[21]. The bias was corrected as the European Civil Aviation Conference (ECAC) harmonized existing approaches by introducing a new classification scheme for NO_x emissions[22]. Since then, airports in Sweden, Switzerland, UK and Germany base the emissions calculation on the so called ECAC model.

5.1.1 Description of the ECAC Model

The ECAC model specifies the methodology of measuring and calculating engine emissions charges. The following explanation ties in with Chapter 4.1.1 which discusses the certification of NO_x emissions. As a reminder, the mass of NO_x emissions per unit of thrust (DP/F_{00}) from one engine was obtained by multiplying the emissions output per second with the time spent during each phase of the ICAO LTO cycle. The mass of NO_x emissions for the entire aircraft is the product of DP/F_{00} and

[20] For instance time for taxi is lower than specified by ICAO at Stockholm Arlander airport.

[21] FOCA (2005)

[22] ECAC Recommendation 27/4

the number of engines. Box 1 shows how unburned hydrocarbons are integrated into the calculation.

Calculation of aircraft NO_x value:

$$NO_{x,aircraft}[kg] = No. of\ engines \times \sum_{LTO\ modes} (60 \times time\ [s] \times fuel\ flow\ [g/s] \times NO_x\ emissions\ index\ [g/kg])\ /1000$$

A factor a has to be included to account for HC emissions:

$$If\ DP_{HC}/F_{00} \leq 19.6\ g/kN, then\ a = 1, else\ a = \frac{DP_{HC}/F_{00}[g/kN]}{19.6[g/kN]}$$

Calculation of aircraft emissions value:

$$Aircraft_{Emissions\ Value}[kg] = NO_{x,aircraft}[kg] \times a$$

Box 1: Calculation of the Aircraft Emissions Value

Factor a can take a maximum value of 4, but remains unconsidered if DP/F_{00} of HC remains under 19.6 g/kN. In most cases, a equals 1 because only some rare old engines with lower combustion efficiency exceed 19.6 g/kN. If no fuel and emissions data is available from the ICAO database, other sources have to be used. As mentioned earlier, only turbofan and turbojet engines with maximum thrust above 26.7 kN are covered by the NO_x certification standard. For instance Swiss airports obtain information of unregulated aircraft engines from a database maintained by the Swiss Federal Office of Civil Aviation (FOCA or FOI). Aircraft emissions values are estimated using the *Matrix* of Table 9 if both the ICAO and FOCA database fail to provide requested information.

No. of Engines	Piston: Turbo-diesel Microlight Ecolight	Piston: Conventional			Helicopter		Business Jets		Turbo props
		≥200hp	200-400hp	>400hp	<1000 shp	>1000 shp	<16kN	16-26.7 kN	
1	0.1	0.2	0.4	0.5	0.2	0.7	0.5	1	0.8
2	0.2	0.4	0.8	1	0.4	1.4	1	2	1.6
3	-	0.6	1.2	1.5	-	2.1	1.5	3	2.4
4	-	0.8	1.6	2	-	2.8	-	-	3.2

Table 9: FOCA Aircraft Emissions Value Matrix

Source: FOCA (2005)

For instance a business jet equipped with two engines, each rated at 18kN thrust, is given an aircraft emissions value of 2 provided no emissions data was available. The

EUR amount to be paid by the aircraft operator corresponds to the product of aircraft emissions value [kg] and pre-defined emissions charge [EUR/kg]. The ECAC model recommends that the emissions charge should rise continuously with increasing aircraft emissions values. Accordingly, those who emit more, pay more. This rule would respect the polluter-pays-principle.

5.1.2 Costs of European Engine Emissions Charges

This section provides information on the cost impact of the engine emissions charge at Zurich International airport (ZRH), Stockholm (ARN), Munich (MUC) and at London Gatwick (LGW). The calculation of the surcharge was described in the previous chapter. Table 10 lists associated costs for a choice of business aircraft.

Aircraft Type Name	Engine Type Name	No. of Engines	Engine Emissions Value	Emissions Charge (EUR* per landing and kg NOx emissions)**			
				ZRH	ARN***	MUC	LGW
Falcon 50 EX	TFE731-40-1C	3	0.9	5.48	14.58	8.10	14.18
Falcon 900 EX	TFE731-60-1C	3	1.6	9.74	25.92	14.40	25.20
Falcon 2000	TFE738-1-1B	2	2	8.12	21.60	12.00	21.00
Falcon 7X	PW307A	3	1.2	7.31	19.44	10.80	18.90
G100	TFE731-40	2	1.2	4.87	12.96	7.20	12.60
G450	TAY MK611-8	2	2.8	11.37	30.24	16.80	29.40
G550	BR710 C4-11	2	2.8	11.37	30.24	16.80	29.40
Learjet 45	TFE731-20	2	0.8	3.25	8.64	4.80	8.40
Challenger 605	CF34-3B	2	1.1	4.47	11.88	6.60	11.55

Table 10: Swiss Emissions Landing Charge at Zurich Airport

Source: Calculations are based on FOCA emissions database and 2011 emissions charges
*Notes: *Currencies were converted in EUR using http://www.xe.com/ [25/11/2011]*
***The charge per kg NO_x emissions amounts to 2.03 EUR (ZRH), 5.40 EUR (ARN), 3.00 EUR (MUC) and 5.25 EUR (LGW).*
****Table 9 slightly overestimates the emissions charge at Stockholm Arlander airport because time spent in the taxi phase is lower than specified by ICAO.*

Figure 13 plots data from Table 10 to facilitate its interpretation.

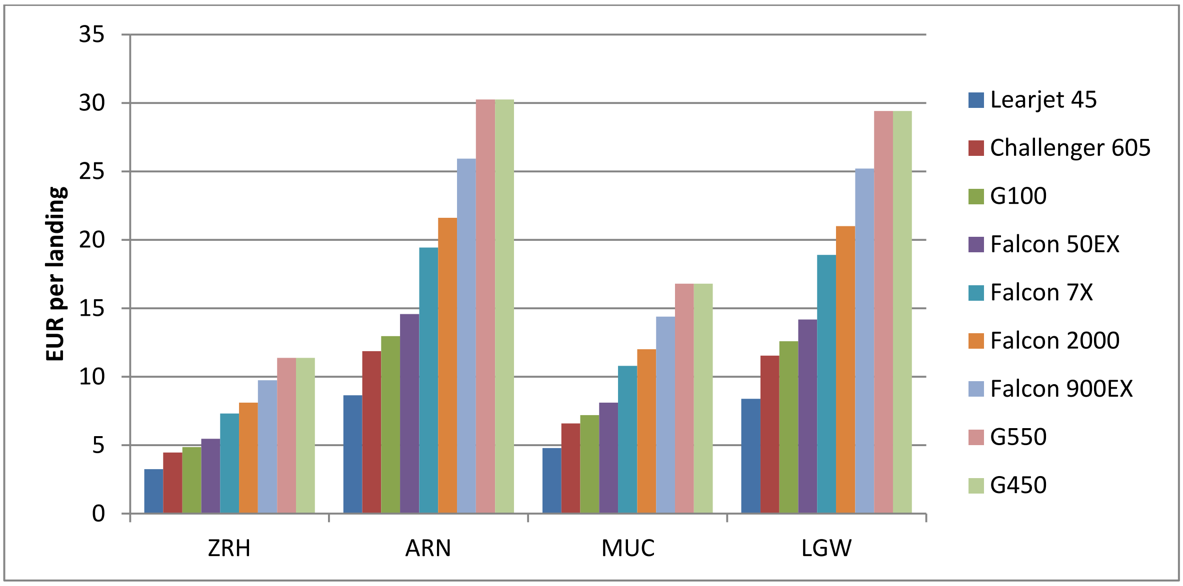

Figure 13: Engine Emissions Charges

It comes out that Stockholm Arlander and London Gatwick airport have the highest rates. Figure 13 also shows that all four airports sort aircraft in the same way. Gulfstream 450 and 550 operators pay higher engine emissions charges than Bombardier Learjet and Challenger 605 operators. Both Bombardier aircraft display lower emissions values. As measured in absolute terms, the cost burden related to engine emissions charges is relatively low. As interviews held under BASE have revealed, most operators don't even know that NO_x emissions charges exist. Chapter 5.2.1 gives an idea on the relative size of engine emissions charges. They are compared with landing, noise and other charges (de-icing, parking).

We asked business aircraft operators how many percent of their operations are affected by European engine emissions charges (EECs). Figure 14 shows how non-EU business aircraft operators answered this question.

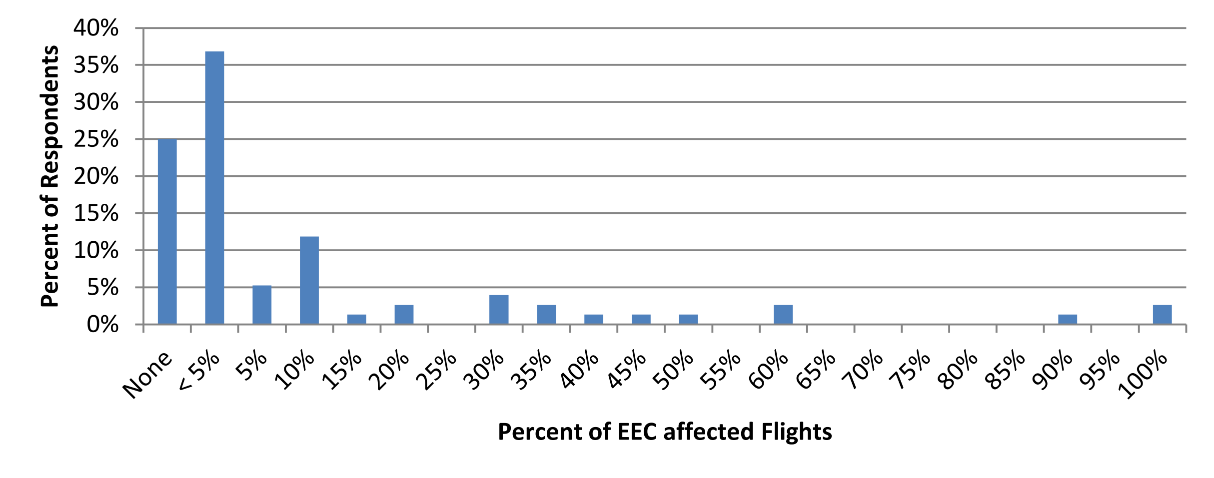

Figure 14: Exposure of non-EU Business Aircraft Operators to European EECs

Source: BASE survey results
Question: How many percent of your operations are affected by Engine Emissions Charges (EECs) levied at airports in Denmark, Germany, Sweden, Switzerland and UK?
Number of respondents: 76

Figure 14 shows that 80 percent of respondents state that European engine emissions charges affect less than 10 percent of their operations. The survey results from European operators are not robust enough to draw any conclusions because only 12 European operators referred to the question.

5.2 Noise Charges

It is common practice at European airports to charge aircraft for noise produced during landing and take-off. However, globally, only 126 airports (20 percent) listed in the Boeing database (covering 17 percent of global IFR traffic) make use of noise charges[23]. Revenue from noise charges shall allow people who live around airports to better adapt to aircraft noise. The noise mitigation strategy may include, for example, investments into sound insulation of houses. The ICAO recommends charging no more than the costs applied to alleviation and prevention. Noise charges are updated in case of divergence of generated revenue and planned expenses.

Noise charging schemes all reward quitter aircraft, but differ in the way they do. Airport operators can either calculate noise charges based on certified (ICAO) and uncertified (FOCA, FOI) aircraft noise levels, or monitor the noise footprint of real-life operations at measurement points around the airport (as done by airports in

[23] Clean Sky CARING (2010), 28.

Germany and Switzerland). The later approach allocates aircraft to noise categories and assigns a fixed charge to each group. Noise charges are not always reported separately as surcharge, but combined with other airport fees. For instance London Gatwick airport reports weight based landing charges and noise related charges as aggregate. Both elements cannot be separated by aircraft operators or other interested readers. Paris airports follow a similar approach. Landing charges are multiplied with a noise level coefficient which size depends on the cumulative margin of the certified noise level. When comparing noise charges from different airports, one should also keep in mind that most airports apply different rates depending on the season and time of the day. In general, take-off and landing becomes more expensive at night time if not already stopped by curfews[24].

5.2.1 Cost and Impact Analysis

This Chapter sets out to analyze the cost burden associated with noise charges. Figure 15 compares the amount of noise surcharges levied on different aircraft at Munich, Stockholm and Zurich airport. London Gatwick is not considered because it was not possible to separate the noise related charge from the weight based landing charge.

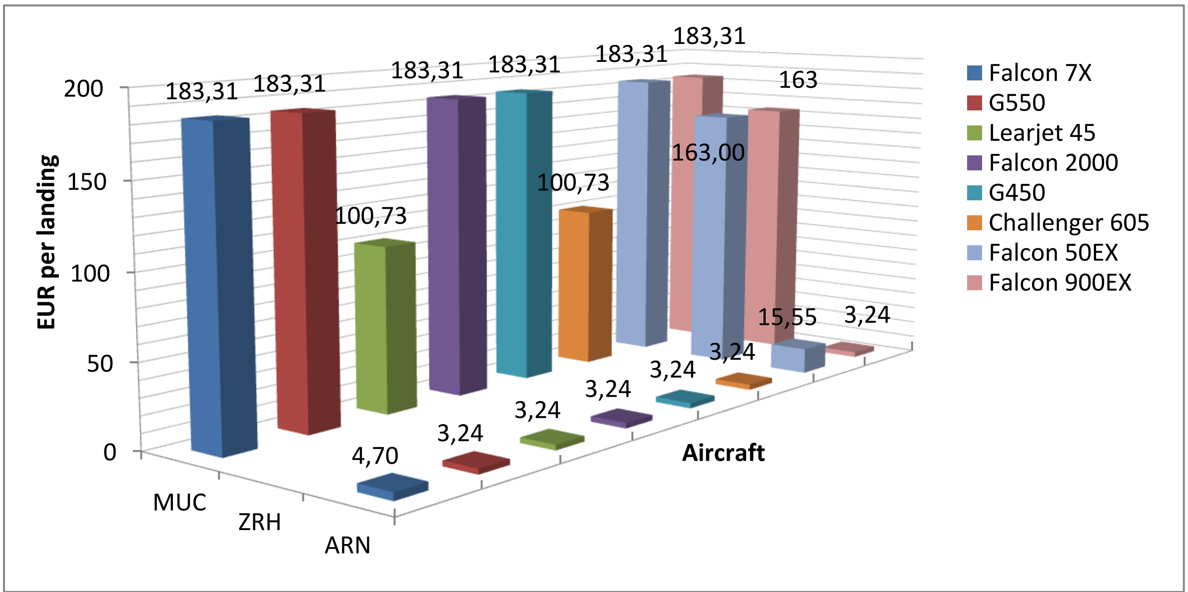

Figure 15: Noise Charges at MUC, ZRH and ARN

Source: Information on 2011 Airport Charges is publicly available on the respective airport homepage

[24] For a detailed overview of major noise charging schemes, see Clean Sky CARING (2010).

At Munich (MUC) and Zurich (ZRH) airport, aircraft are assigned to noise groups depending on the average noise level. Whereas Zurich airport exempts aircraft that are allocated to the quietest noise category, Munich levies a fixed surcharge on every noise group. The noise charging scheme of Stockholm Arlander airport is based on aircraft emissions values from certified or uncertified aircraft. The noise charge increases continuously with aircraft noise levels. EUR 3.24 is the minimum noise charge. This explains why almost all aircraft display the same noise charge.

Figure 16 models airport and air navigation service charges for a Gulfstream 450 on a flight from Paris Le Bourget (LBG) to Munich International airport (MUC).

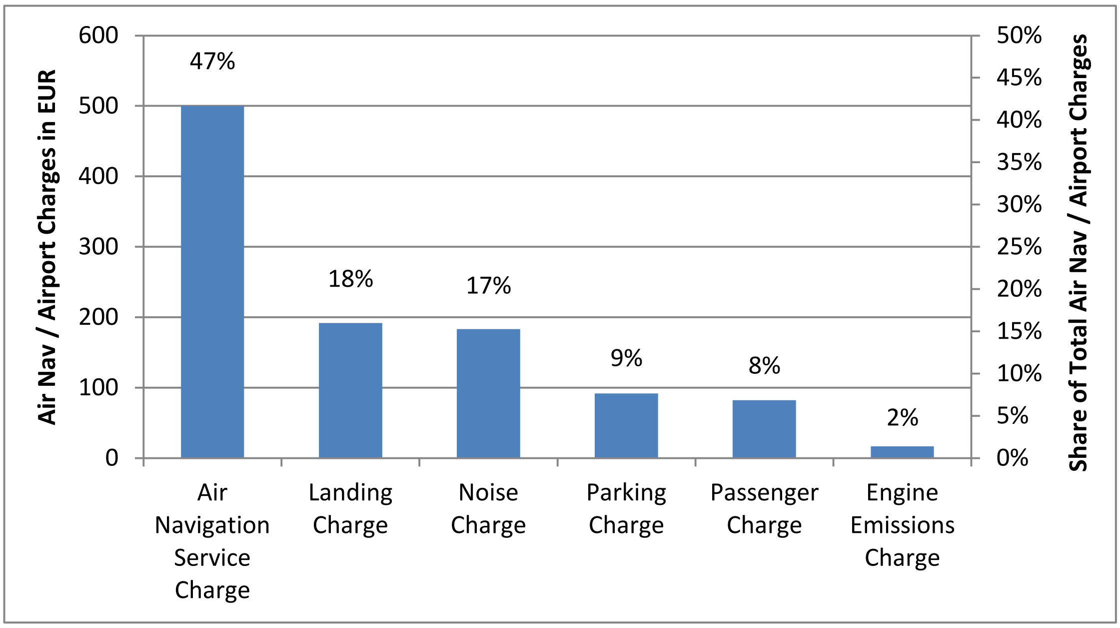

Figure 16: Air Navigation and Airport Charges at Munich International Airport

Source: Airport Charges publicly available on homepage

Assumptions: *<u>Air Navigation Service Charge</u> from 2010 estimated for 1 hour flight from LBG to MUC*
<u>Parking Charge</u> if parking time > 4 h and < 24 h (without counting 2200:0600)
<u>Passenger Charge</u> calculation based on 5 passengers

Figure 16 provides information on the absolute and relative size of different airport charges applicable at Munich International airport for a Gulfstream 450. Engine emissions charges account for 2 percent and noise charges for 17 percent of air navigation and airport charges. Both charges sum up to EUR 200 at Munich airport. The absolute EUR amount due at Stockholm Arlander (EUR 34) and Zurich airport (EUR 12) is even lower. While the cost impact of noise charges is amongst the highest, engine emission charges are negligible. We detected significant variations in the design of charging schemes and between different aircraft. Whereas landing and noise charges for a Gulfstream G450 at Munich airport amount to EUR 375, London Gatwick charges between zero (winter off-peak) and EUR 1845 (summer peak)[25].

Figure 17 compares air navigation service and airport charges at Munich and London Gatwick airport during summer season and peak time.

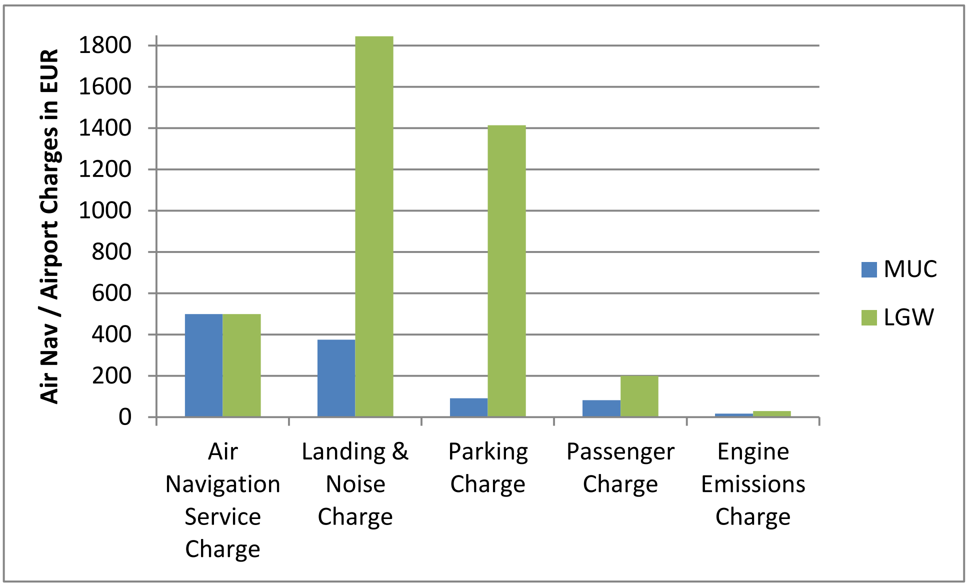

Figure 17: Air Navigation and Airport Charges at LGW and MUC

Source: Airport Charges publicly available on homepage
Notes: The calculation based on assumption made in Figure 16

[25] Peak Period 0600-1159 UTC (GMT) and 1700-1859 UTC (GMT); Summer Period 01st April to 31st October.

6 Noise Restrictions and Operating Procedures

Noise from landing and departing aircraft is one of the major preoccupations of regulators and airport authorities. Developed countries have done many efforts to tackle noise in the vicinity of airports. The International Civil Aviation Association (ICAO) plays an important role in the co-ordination of national policy measures. In the nineties of the last decade, the ICAO initialized a global phase-out of aircraft certified before 1977 (chapter 2). The ICAO states that 97 percent of chapter 2 aircraft were progressively banned from airports in North America, Europe, Japan, Australia, New Zealand and parts of Asia and Central and South America by 2007[26]. The Committee on Aviation Environmental Protection (CAEP) performed a cost benefit analysis on the phase-out of chapter 3 aircraft (subsonic jets certified between 1977 and 2006). The proposition of a gradual phase-out of chapter 3 aircraft was rejected during the ICAO Assembly in 2001 because its implementation would cause extreme high costs for the industry, but bring only little environmental benefit. The ICAO decided instead to tap the potential of reducing noise by means of four principle elements which are part of the ICAO Balanced Approach (see Table 11).

Elements	**Reduction of Noise at Source**	**Land-Use Planning and Management**	**Noise Abatement Operational Procedures**	**Operating Restrictions**
Brief Description	Aircraft obtain the airworthiness certificate only if they comply with the applicable noise certification standard.	Land use planers seek to minimize the population affected by aircraft noise.	Use of noise abatement procedures during LTO phase. Preferential runways and routing to minimize noise impact.	Restriction of chapter 2 or marginally compliant chapter 3 aircraft at noise-sensitive airports.

Table 11: The ICAO Balanced Approach

Source: http://www.icao.int/env/noise.html

The ICAO wants to make sure that contracting States reduce noise in the most cost-effective way. According to them, regulators shall tap the potential of the first three elements (in Table 11) before restricting operations of chapter 3 aircraft.

[26] Clean Sky CARING (2010), 11.

The European Union adopted several Directives to regulate noise at European airports[27]. Directive 2002/30/EC allows noise-sensitive airports to restrict operations of marginally compliant 'minus 5' aircraft, provided the measure is part of a Balanced Approach. It means that chapter 3 aircraft with cumulative noise margins of lower than 5 are required to reduce the number of movements.

Airport authorities should use less costly noise abatement operational procedures to mitigate the noise exposure of local residents before restricting aircraft operations. They can specify procedures for every phase of the LTO cycle. In absence of mandatory noise abatement techniques, aircraft operators can voluntarily use noise abatement programs from aircraft manufacturers or aviation associations. For instance the National Business Aviation Association (NBAA) designed a generic noise abatement program to complement established noise abatement procedures.

6.1 Aircraft Operating Restrictions

Table 12 presents commonly used aircraft operating restrictions.

	Operating Limits	**Chapter 3 Restrictions**	**Noise Quotas**	**Noise Level Limits**	**Curfews**
Airports / Global IFR Traffic (%)	9/10	10/12	2/4	13/13	37/27
Definition	Restriction of the number of aircraft movements	Restriction of marginally-compliant chapter 3 aircraft types	Limitation of total noise level from all aircraft operations	Maximum noise limit during single events (take-off or landing)	Prohibition of take-off and/or landing during a certain time period

Table 12: Aircraft Operating Restrictions

Source: Clean Sky CARING (2010)

The second row of Table 12 refers to the number of airports making use of the respective operating restriction. 'Airports/Global IFR Traffic' measures the percentage share of airports (traffic) of the total number of airports (of global IFR traffic) listed in the Boeing database. Boeing monitors environmental constraints of about 630 airports from around the globe.

[27] More detailed information on noise regulation are available in the report Clean Sky CARING (2010).

Figure 18 shows the geographical distribution of these 630 airports.

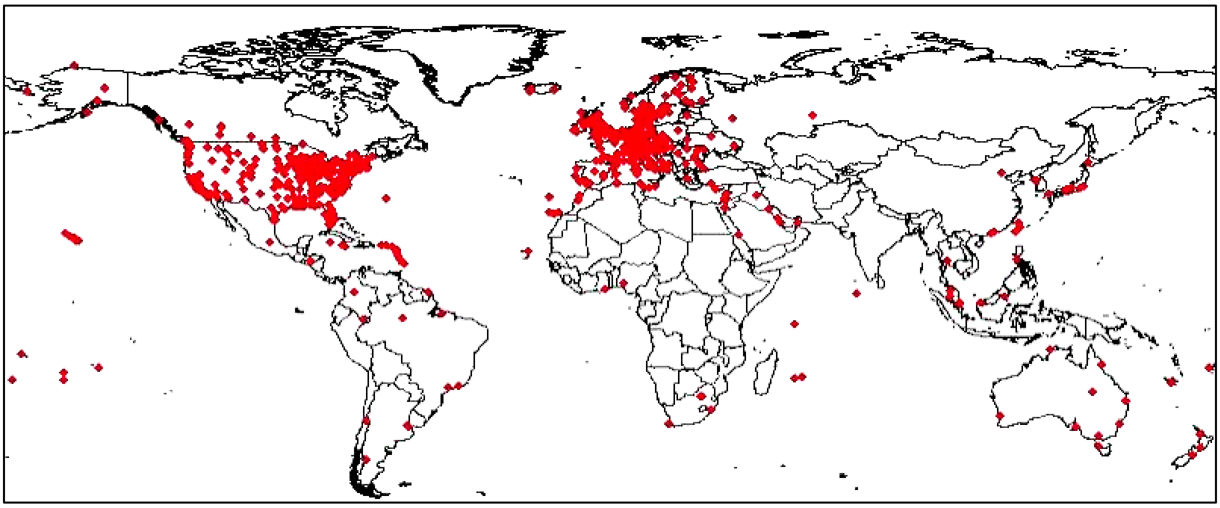

Figure 18: Map of Airports covered by the Boeing Database
Source: Clean Sky CARING (2010)

Table 12 reveals that only less than one-third of all airports covered by the Boeing database use aircraft operating restrictions to reduce noise pollution. Possible explanations are that a part of airports may not be considered noise-sensitive (no or small local community around the airport) or other more cost effective noise abatement measures suffice to reduce the noise to an acceptable level. Table 12 shows that curfews are relatively often used amongst airport operators, whereas noise quotas are less common.

We asked, predominantly, US business aircraft operators in the BASE survey whether they face any kind of aircraft operating restrictions.

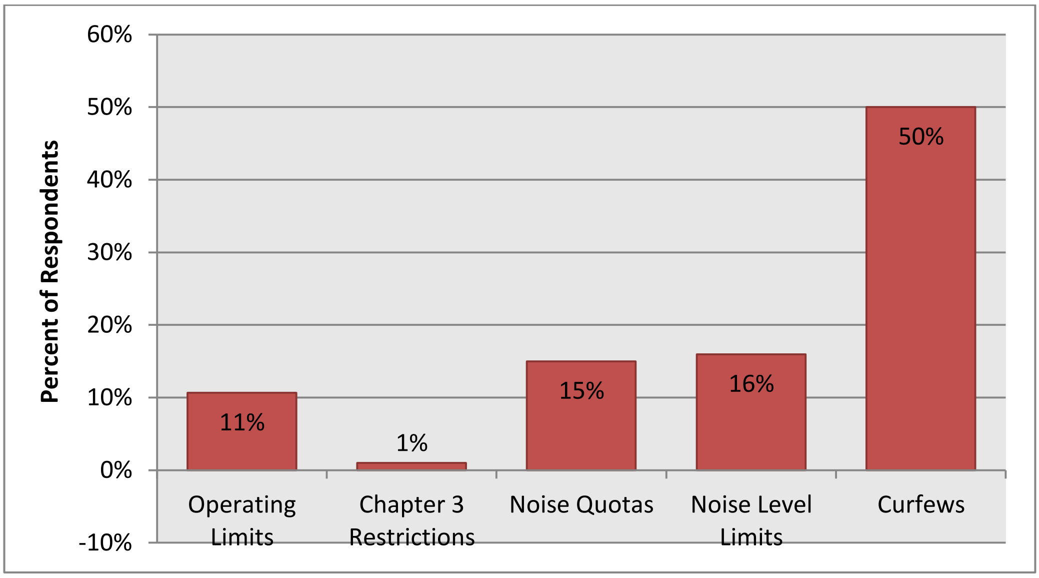

Figure 19: Impact of Aircraft Operating Restrictions on Business Aircraft Operators

Source: BASE online survey
Question: Are your operations limited by the following noise restrictions?
Number of respondents = 95

Figure 19 confirms the preferred use of curfews to limit or stop aircraft noise at night time. Between 10 and 20 percent of questioned business aircraft operators state that their operations are affected by operating limits, noise quotas and noise level limits. Chapter 3 restrictions are quasi nonexistent for surveyed business aircraft operators.

6.2 Noise Abatement Operational Procedures

Noise abatement operational procedures are in place at 77 percent of airports listed in the Boeing database, and representing 57 percent of global air traffic. Table 20 gives an overview of existing noise abatement operational procedures.

Operation Procedures	Definition
Noise Abatement Departure Procedures (NADP)	It describes how pilots shall fly the aircraft until 3000 ft by giving standard settings for engine thrust rating and flap/slat retraction.
Noise Preferential Routeing (NPR)	It constraints the departure path of an aircraft until 3000 or 5000 ft.
Continuous Descent Approach (CDA)	The aircraft descends towards the airport from its cruising height in a gradual and continuous approach.
Increased Glide Slope	Steeper glide path than 3 degree.
Low Power Low Drag Approach (LPLD)	The LPLD approach reduces engine thrust and airframe noise through later extension of flaps and gear.
Preferential Runways	This measure either concentrates traffic over less populated areas or spreads aircraft noise evenly over the residential area.
Idle instead of Max Reverse Thrust	Reverse thrust is used to relieve breaks during landing, but leads to additional noise. Pilots may slow down the aircraft by using less reverse thrust.

Figure 20: Noise Abatement Operational Procedures

Source: Clean Sky CARING (2010)

We asked, predominantly, US business aircraft operators in the BASE survey if they consider using reduced thrust take-offs, CDAs and idle reverse thrust (for the landing) to lower fuel consumption and carbon emissions. All three measures also contribute to lower noise pollution. Figure 21 presents the survey results.

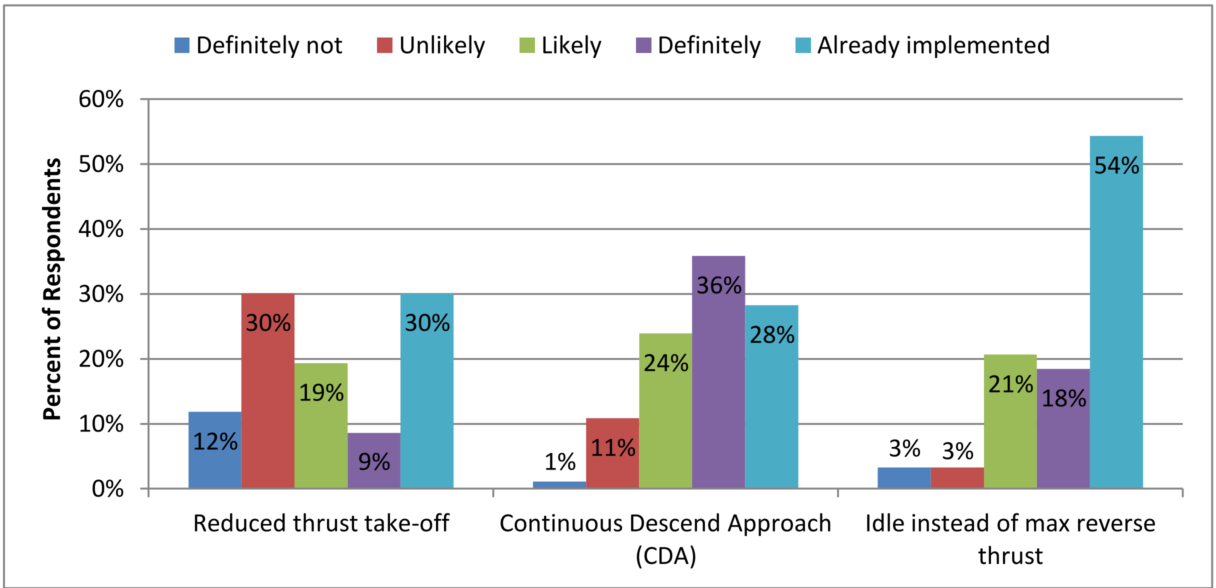

Figure 21: Noise Abatement Operational Procedures

Source: BASE survey results
Question: Which of the following fuel (and CO2) saving measures are likely to be taken in the near future?
Number of respondents = 93

The use of idle reverse thrust is largely implemented by business aircraft operators. Further noise reductions can be expected if air traffic control (ATC) allows business aircraft operators to fly CDAs more often. Operators were found to be less favorable for reduced thrust take-offs. However, one-third of pilots have already implemented this measure. Reduced thrust take-offs are usually applied to keep down engine temperatures and lower maintenance costs.

6.3 Noise Fines

Noise fines occur if operators breach with noise abatement operational procedures specified by airport operator authorities. We asked the question how often business aircraft operators are confronted with noise fines that are related to non-respect of curfews, exceeding of noise limits or deviation from Noise Preferential Routeing (NPR). Figure 22 presents the BASE survey results.

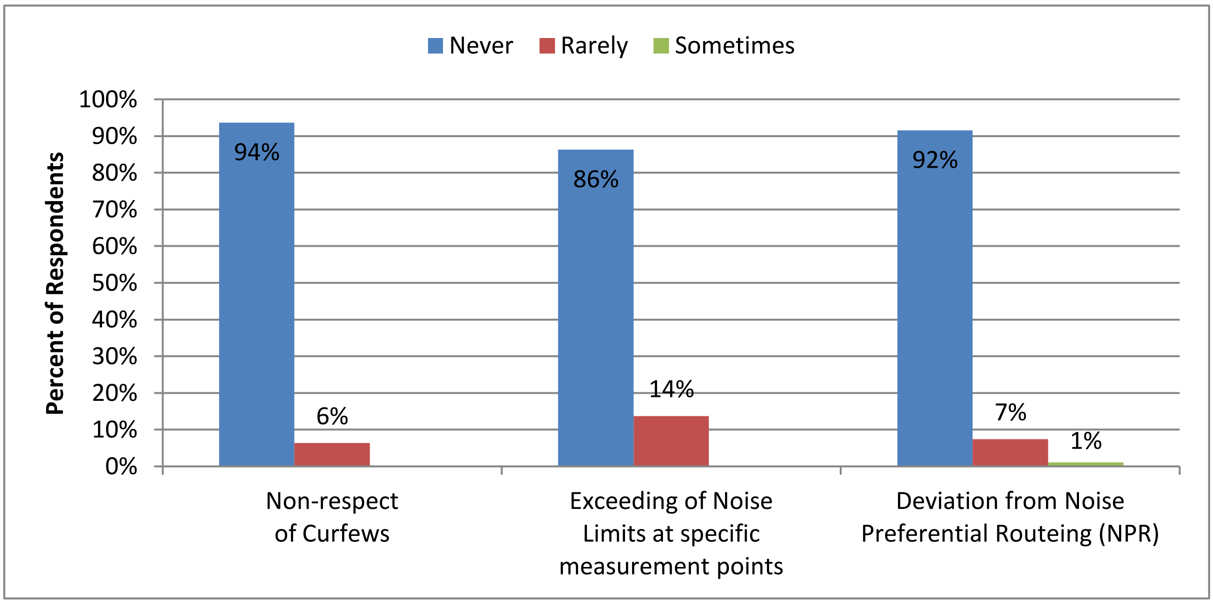

Figure 22: Noise Fines

Source: BASE survey results
Question: How frequently do you face noise fines that are due to …?
Number of respondents: 95

As it comes out very clearly, business aircraft operators never or rarely face noise fines related to the violation of compulsive noise abatement procedures.

7 Taxation

The environmental impact of aviation can be reduced through taxation. As mentioned earlier, aircraft emissions and noise impose costs on society that are not wholly borne by those who fly. The regulator can make use of a Pigouvian tax (named after the economist Arthur Pigou) which increases the price for air travel and leads to a fall in demand. According to the theory, the tax rate shall be chosen such that air service demand finds its new equilibrium at the socially desirable level (this is where marginal social costs equal marginal benefit). Two types of taxes can be distinguished. The tax may correspond to a fixed monetary amount per gallon (excise tax on aviation fuel), or be expressed as percent of the ticket price (ticket tax). The ticket tax is an ad valorem tax. It differs from the value added tax (VAT) because it cannot be claimed by business users[28]. As to what regards commercial aviation, both tax types can be used as environmental tax because they make air transport services more expensive and (depending on the price responsiveness of passengers) reduce the demand if costs are passed through. Lower demand results in lower emissions compared to business as usual. However, a ticket tax is not applicable to non-commercial operations. Only charter services fly for remuneration. A fuel excise tax imposes a levy on fuel and so incentivizes aircraft operators to fly a given leg by consuming less fuel. Ticket taxes are better suited if the regulator seeks to generate a maximum of income.

Aviation is largely exempt from fuel taxation. This is a result of Article 24 of the 1944 Convention on International Civil Aviation (also called Chicago Convention) and bilateral air service agreements[29]. The 190 contracting States of the Chicago Convention agreed to mutually exempt international aviation from taxation (principle of reciprocity) to avoid double taxation of international airline operations. Article 24 requires that “fuel, lubricating oils [and other items] on board an aircraft of a contracting State, on an arrival in the territory of another contracting State and retained on board on leaving the territory of that State, shall be exempt from customs

[28] Keen, M., Strand, J. (2006), 6.

[29] Keen, M., Strand, J. (2006), 10.

duty, inspection fees or similar local duties"[30]. In a 1999 resolution, the ICAO Council extended this provision to also exempt "fuel taken on board for consumption by an aircraft from a contracting State in the territory of another contracting State departing for the territory of any other State"[31]. By contrast, the Chicago Convention does not prohibit the taxation of domestic fuel.

The ICAO policy distinguishes between taxes and charges. "A charge is a levy that is designed and applied specifically to defray the costs of providing facilities and services for civil aviation, and a tax is a levy that is designed to raise national or local government revenues which are generally not applied to civil aviation in their entirety or on a cost-specific basis"[32]. The ICAO prohibits taxes on international aviation if collected funds are not 'recycled' back to the aviation sector. A fuel tax is only consistent with ICAO policy if it takes the form of a revenue neutral aircraft efficiency charge or an en-route emissions charge provided revenues are used to mitigate the environmental impact from emissions.

There is actually no fuel tax in Europe which uses tax revenue to 100 percent for emissions mitigation. Even the Norwegian CO_2 tax on mineral oil that is burned on domestic flights contributes annually by around EUR 35,000,000 to the central government tax revenue[33]. Each liter of jet fuel is taxed at NOK 0.65. Business aircraft are not exempt from this fuel exercise tax. The CO_2 tax supports the polluter pays principle, but is said to cause unfair competition. Only an international tax could remedy the risk of fuel tankering or other negative effects arising from a national fuel tax.

In absence of international co-operation, fuel taxes tend to divert traffic to countries where operators face lower fuel prices. Differences in fuel prices between different regions of the world encourage business aircraft operators to tanker fuel. All interview partners who participated in BASE confirmed that fuel tankering is a common practice of reducing the fuel bill. From an economic viewpoint, it can make sense to

[30] ICAO (2000)

[31] http://globalwarming.house.gov/files/LTTR/ACES/IntlAirTransportAsscn.pdf

[32] http://www.icao.int/HyperDocs/Display.cfm?Name=AT-WP%2F1900&Lang=E

[33] Avinor (2008)

carry additional fuel even though, as a rule of thumb, one third of tankered fuel gets burned because of the additional fuel load. Fuel tankering increases total fuel burn and thus negatively affects the environment through the production of relatively more greenhouse gases (GHGs). BASE interview partners and survey participants also confirmed that differences in fuel prices provide sufficient incentives to perform tech stops where fuel is cheaper.

Business aircraft operators can increase the fuel efficiency (and thus lower fuel costs) if they tank only a required minimum of fuel. We asked, predominantly, US business aircraft operators if they would limit excess fuel to lower the aircraft fuel consumption.

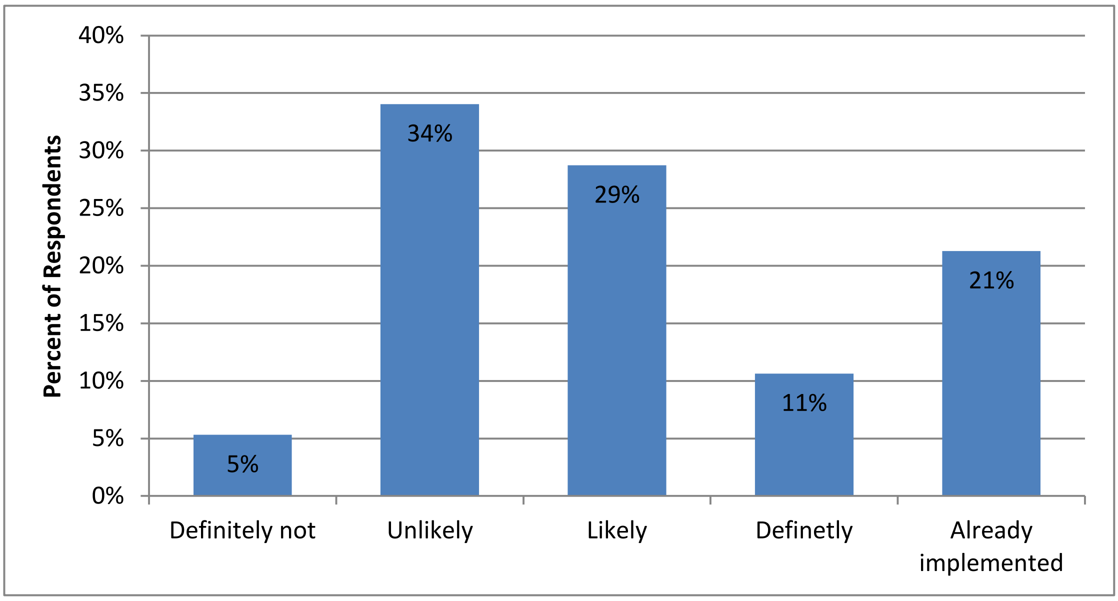

Figure 23: Limitation of Excess Fuel

Source: BASE survey results
Question: Which of the following fuel (and CO2) saving measures are likely to be taken in the near future?
Number of respondents = 94

More than one-third of questioned business aircraft operators are unlikely to (or don't) reduce excess fuel. Excess fuel is the amount of fuel that exceeds minimum required fuel (= taxi fuel + trip fuel + 5% error margin + emergency reserve). It gives operators more flexibility to react on unforeseeable obstacles without compromising passenger comfort. However, Figure 23 also shows that all other respondents consider the limitation of excess fuel as a way to reduce the fuel consumption, and carbon emissions respectively. 21 percent have already taken this measure.

7.1 French Tax on Air Noise Pollution

The French tax on air noise pollution (TNSA) puts a tax on departing aircraft from French airports. Tax revenue is used to finance insulation work around airports. According to the ICAO distinction between taxes and charges, the TNSA should better be referred to as air noise pollution *charge*. The tax burden depends on the MTOW of the aircraft, its cumulative noise margin and the time of take-off. We have modeled the costs for a Gulfstream G450 for one take-off from Paris Le Bourget airport and compared the tax to the applicable noise adjusted landing fee.

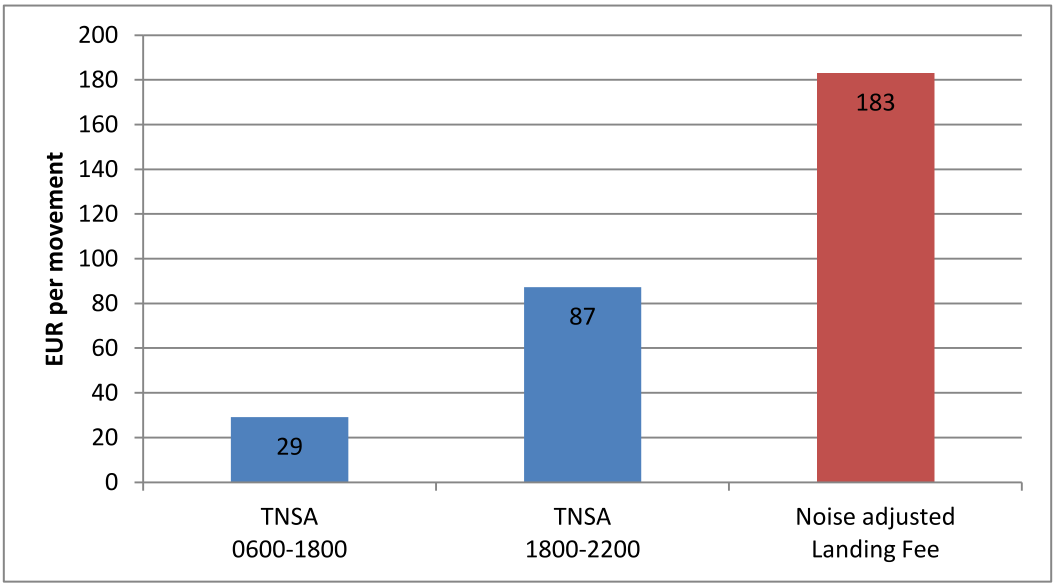

Figure 24: TNSA vs. Noise adjusted Landing Fee at Paris Le Bourget

Guidance for Calculation:
*https://www.formulaires.modernisation.gouv.fr/gf/getNotice.do?cerfaNotice=51058%2306&cerfaFormulaire=12503*06*
Notes: Tax rate at Paris Le Bourget for 2011 = EUR 19, GLF4 acoustic noise group = 5a, MTOW = 34 tonnes

The cost burden associated with the TNSA is relatively low compared to the noise adjusted landing fee. It should be noted that the tax rate has been revised several times in the past. From its entry into force in January 2005 the tax revenue of EUR 15 Million increased to EUR 54 Million EUR in 2009. Further adjustment can be expected since the *Autorité de Contrôle des Nuisances Sonores Aéroportuaires* (ACNUSA) seeks to double tax revenue. Costs for appropriate sound insulation around French airports are estimated at EUR 110 Million[34].

[34] Clean Sky CARING (2010), 30.

8 Cap and Trade System

A cap and trade system is a market-based instrument which gives pollution a price. Without such price, aircraft operators would not take into account the external costs associated with the emission of CO_2 or other pollutants. Take for instance the external costs of CO_2 emissions. They comprise all costs related to the damage caused by global climate change. External costs can be decreased by bringing down the concentration of GHG gases. 191 States agreed in the Kyoto Protocol in 1997 to mitigate GHG emissions to a level which would avoid global surface temperature to increase by more than 2 degrees of pre-industrial levels. To fulfill its commitment under the Kyoto Protocol, the European Union (EU) tackles GHG emissions using a number of regulatory instruments. The flagship of the EU climate change policy is the European Union Emissions Trading Scheme (EU ETS). It is the world largest cap and trade system regulating about 50 percent of European man-made CO_2 emissions.

Fundamentals

Under a cap and trade system, emissions sources are required to surrender emissions allowances equivalent to the number of emissions produced. One emission allowance gives regulated emissions sources the right to emit one tonne of emissions. The regulator creates scarcity of emissions allowances by limiting its number to below business as usual levels. Unused emissions allowances can be sold on a regulated market to those who need to cover their allowance shortfall. A 'carbon' price emerges from the interaction of supply and demand providing incentives to the polluter to reduce emissions if this comes cheaper than buying emissions allowances on the market.

Upstream vs. Downstream System

A cap and trade system can be designed as upstream or downstream system. The latter approach is used by the EU ETS. It requires emissions sources to surrender emissions allowances, whereas an upstream approach rather regulates fuel suppliers. The number of emissions allowances to be surrendered by the fuel supplier equals the number of emissions produced when the fuel is burned. Administrative costs related to monitoring, reporting and verification (MRV) are lower under an upstream emissions trading scheme because of the relatively low number of fuel suppliers. Mandatory national emissions trading schemes are on the way in Australia, New Zealand, USA and Canada. In contrast to Europe, these countries follow the upstream approach. Proponents of environmental actions on global level urge for the creation of a global emissions trading system. This can be achieved by linking regional schemes. But the integration of upstream and downstream schemes may come at a price of increased competitive distortion[35].

8.1 The European Union Emissions Trading Scheme

The EU ETS is the flagship of European climate change policy. It is the world largest carbon dioxide (CO_2) emission trading scheme covering CO_2 intensive installations from 27 EU member states, such as power stations, oil refineries, coke ovens, iron and steel plans and other stationary sources. It was implemented to assist member states in meeting the emissions reduction targets stipulated by the Kyoto Protocol. The EU ETS is about to be extended to include aviation emissions from virtually all flights arriving and departing at/from airports situated in the territory of the 27 EU Member States and three EEA-EFTA countries (Iceland, Liechtenstein and Norway)[36]. The following chapter provides detailed information on the design of the EU ETS.

8.1.1 Inclusion of Aviation into the EU ETS

From 2012 onwards, virtually all national and international flights arriving or departing at/from EEA[37] airports (also called Annex 1 flights) are covered by the EU ETS. Aircraft operators are required to comply with the provisions set out in the Directive 2008/101/EC, the monitoring and reporting guidelines (MRG) and national law. They have to monitor emissions from Annex 1 flights and submit a verified emissions report by 31 March of the following year to the competent authority of the assigned

[35] Scheelhaase, J. (2011)

[36] By 01 January 2014, the aviation part of the EU ETS expands to Croatia due to the country's planned accession to the EU on 01 July 2013.

[37] The European Economic Area (EEA) comprises 27 EU member states and three EEA-EFTA states (Iceland, Liechtenstein, Norway).

EEA State[38]. The Directive also requires aircraft operators to surrender emissions allowances by 30 April of each year (starting from 2013) to cover its emissions during the preceding calendar year.

Aircraft with less than 5.7 tonnes maximum take-off mass, as well as, military, training and rescue flights are, amongst a number of other exemptions, excluded from the scheme[39].

Commercial operators operating fewer than 243 Annex 1 flights per period for three consecutive 4-month periods; or emitting less than 10,000 t CO_2 per year are exempt from the EU ETS. Most air charter companies are excluded from the scheme because they fall below the threshold. As a consequence, they hold a cost advantage over non-commercial operators. We will discuss this point in greater detail in Chapter 8.1.4.

Setting the Emissions Cap

Figure 25 shows how the European Commission (EC) caps emissions to create scarcity of emissions allowances. Otherwise, there would be no demand for emissions allowances and thus no functioning carbon market.

[38] Aircraft operators reporting to Spain/ Czech Republic/Norway face the following deadlines: 28 February/15 March/20 March.

[39] See Annex 1 exemptions of Directive 2008/101/EC.

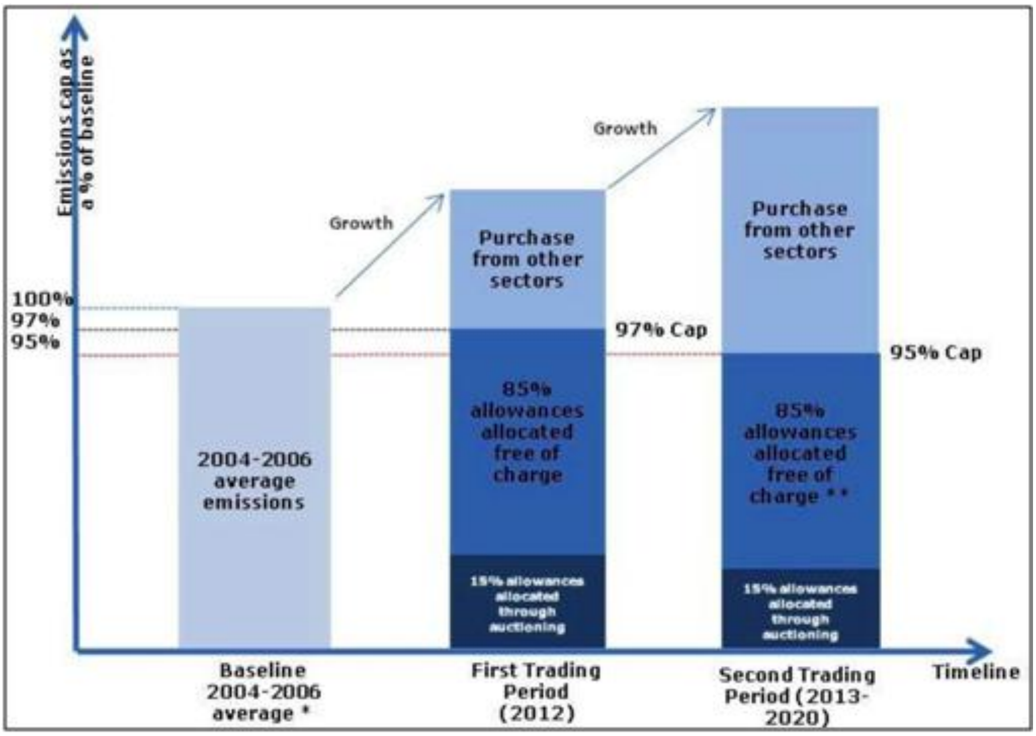

Figure 25: Cap Setting Process and Emissions Allowance Deficit

The emissions cap in 2012 corresponds to 97 percent of historical emissions, expressed as an average of emissions for 2004 to 2006 from the baseline. From 2013 to 2020, the annual number of available emissions allowances amounts to 95 percent of baseline emissions. According to Article 3 of Directive 2008/101/EC, 85 percent of the emission cap are allocated free of charge and 12 percent at auction. The missing three percent of the emissions cap are reserved for new entrants (aircraft operators with no Annex 1 flights in 2010) and those which activity expressed in tonne kilometer grows by an average of more than 18 percent annually between 2010 and 2014. As to what regards the allocation of free emissions allowances, aircraft operators were invited to report Annex 1 relevant flight activity from 2010 to apply for free emissions allowances. The distribution of free emissions allowances is based on benchmarking. An average emissions rate, expressed as tonnes CO_2 per tonne kilometer, ensures that more fuel efficient aircraft receive relatively more emissions allowances free of charge. We will describe the benchmark calculation in greater detail in Chapter 8.1.2. Figure 25 also shows the anticipated deficit of emissions allowances for the whole aviation industry for the first trading period (2012) and the second trading period (2013 to 2020). The deficit of emissions allowances results from (1) the stringency of the emissions cap and (2) is due to the forecasted traffic growth. As a consequence, the aviation industry is likely to become a net buyer of emissions allowances.

Types of Emissions Allowances

European Union Aviation Allowances (EUAAs) are allocated to aircraft operators free of charge and at auction. They are valid in the aviation sector only (semi open system) and cannot be used by stationary sources for compliance purposes. If operators are short of emissions allowances, they can purchase EUAAs/EUAs[40] or offset emissions buying carbon credits from project based Kyoto instruments, so called *flexibility mechanisms*. Industrialized countries that have taken on quantified emissions limitations under Kyoto (so called Annex 1 countries) can reduce emissions at lower costs outside national borders. The Clean Development Mechanism (CDM) allows operators to offset emissions by purchasing CERs (Certificate Emissions Reductions) which are generated by emissions reduction projects in developing countries (so called Annex 2 countries), or ERUs (Emissions Reduction Units) created under Joint Implementation (JI) by emissions reduction projects in other Annex 1 countries (most commonly former Eastern bloc States). Aircraft operators are allowed to buy such credits to up to 15 (1.5) percent of their allowances need in 2012 (from 2013 to 2012). Unused allowances can be carried over for use up to the year 2020 ("banking").

8.1.2 The Distribution of Emissions Allowances

The allocation methodology is an important design element of emissions trading schemes. The regulator decides whether emissions allowances are made available for free or against payment at auction. The design of the allocation methodology has financial implications for participating aircraft operators.

EU ETS Benchmark Design

As mentioned in Chapter 8.1.1, the EU ETS uses an average emissions rate as benchmark. It is nothing different than an output-related fuel efficiency standard

[40] European Union Allowances are allocated to stationary sources for free or at auction (primary market) and traded on energy exchanges (secondary market).

which compares the individual fuel efficiency of each aircraft operator with the industry average. The relative position of the operator's fuel efficiency decides over the share of free emissions allowances. The individual fuel efficiency is calculated by dividing annual emissions by the product of kilometer flown (great circle distance + 95 km) and payload (cargo, mail or passengers) carried. The resulting value is then compared with the benchmark. Aircraft operators are eligible for relatively more emissions allowances if they perform better on the benchmark. Box 2 describes the calculation of free emissions allowances in greater detail.

(1) $$TK_{total} = \sum_{i=1}^{n} TK_i$$

(2) $$E_{total} = \sum_{i=1}^{n} E_i$$

(3) $$A_i = \frac{E_{total}}{TK_{total}} \times TK_i$$

n…Total number of aircraft operators
TK_i… Tonne kilometer of aircraft operator i in the base period
E_i…Emissions produced by aircraft operator i
TK_{total}… Total tonne kilometer of all Annex 1 flights in the base period
E_{total}…Total emissions from Annex 1 flights in the base period
A_i…Number of emissions allowances allocated to aircraft operator i

Box 2: Average Emissions Rate

Equation (3) consists of two terms, the average emissions rate E_{total}/TK_{total} (also called benchmark) and the tonne kilometer value of a given aircraft operator. The benchmark was published by the European Commission. Every operator can calculate its share of free emissions allowances by multiplying the individual 2010 tonne kilometer value with the benchmark[41].

Distributional Effects

Figure 26 estimates the expected shortfall of emissions allowances for different market segments in 2012.

[41] Benchmark (2012) = 0.0006797 t CO2/TK; Benchmark (2013-2020) = 0.0006422 t CO2/TK.

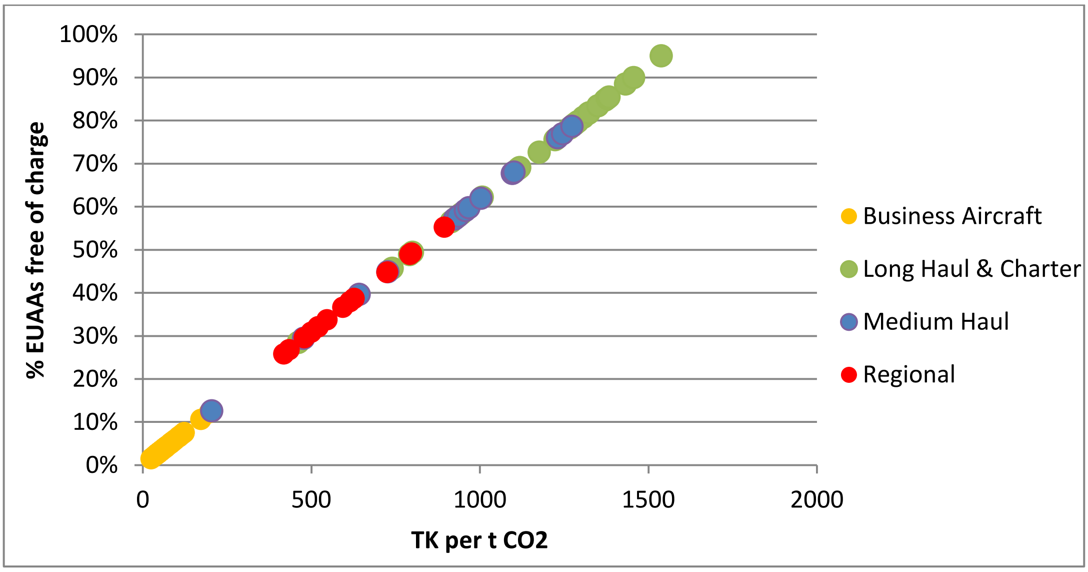

Figure 26: Share of Free EUAAs and Operator Fuel Efficiency

Source: VerifAvia
Notes: The calculation assumes an increase in emissions of 10 percent between 2010 and 2012.

Figure 26 shows that long haul and charter airlines are better off than medium haul and regional carriers. Business aircraft operators (marked yellow in Figure 26) display the lowest fuel efficiency and thus obtain a relatively small share of free emissions allowances. In average, they get around four percent of emissions allowances free of charge. The rest have to be purchased at auction or on the carbon market. Long haul and charter companies perform better because (1) the time spent in the landing and take-off (LTO) cycle represents a lower share of total flight time, and (2) aircraft are generally operated at higher load factors.

Payload vs. MTOW-based Benchmark

As Figure 27 shows, business aircraft would gain some ground if emissions were related to MTOW rather than payload.

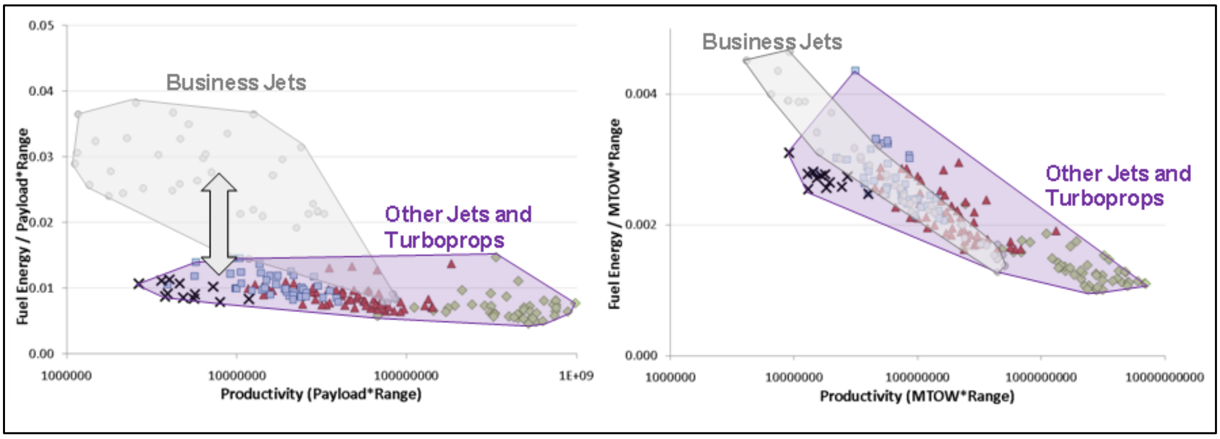

Figure 27: Business Aircraft under Payload and MTOW Fuel Efficiency Measure

Source: PARTNER Project 30 (2010)
Notes: Fuel energy means fuel burned per unit of productivity.

The right part of Figure 27 demonstrates how business aircraft would perform if fuel efficiency were measured as ratio of emissions and MTOW. Payload-based fuel efficiency measures penalize business aircraft because they carry less payload. In contrast to commercial airlines, business aircraft operators have no incentive to operate at full capacity. One reason why the EC may have decided to rather base the benchmark on payload is because it better rewards operational fuel reduction measures, such as operating aircraft at higher capacity utilization. There is an ongoing discussion on whether the benchmark should have included payload or MTOW. Business aviation professionals claim that the allocation approach should account for the specifications of business aircraft. According to them, it is in the nature of business aircraft to carry on business trips less payload. Why should business aviation be discriminated against other market segments, such as the charter or long haul sector? Two things are important to mention. First of all, it is widely accepted that fuel efficiency, as measured in emissions per unit of payload, provides the most accurate picture of real-life fuel consumption. An aircraft burns more fuel if operated with higher payload. A fuel efficiency metric based on MTOW makes no difference between the fuel consumption of a fully packed business jet or a ferry flight. A payload-based fuel efficiency measure therefore better reflects the environmental performance of daily operations.

Losing the Cost Advantage

Business aviation incurs higher costs than scheduled air services under the EU ETS because of (1) the relatively lower load factor and (2) the financial implications of the payload-based benchmark. Regarding (1), attributed emissions per passenger are lower the more people are carried. This leads to higher carbon costs per business aircraft user. This is even more true because it is common practice to reposition empty business aircraft. Regarding (2), the shortfall of emissions allowances is higher for business aircraft operators because they obtain relatively fewer emission allowances free of charge under the payload-based benchmark. As a consequence, they face higher compliance costs because more emissions allowances have to be purchased at auction or on the carbon market. Both arguments provide clear evidence that the EU ETS pursues the *Polluter Pays Principle*. Aircraft operators with higher emissions per passenger pay more. In other words, the polluter is held responsible for the climate change impact of its emissions. Since business aircraft produce relatively more emissions per passenger, the non-existence of a carbon price is an *indirect* subsidy for business aviation. Business aviation loses its relative cost advantage vis-à-vis more fuel efficient transport modes with the inclusion of aviation emissions into the EU ETS.

8.1.3 Costs for the Purchase of missing Emissions Allowances

Costs for the purchase of missing emissions allowances depend on the emissions allowances shortfall and the price at which the aircraft operator purchases emissions allowances.

We have modeled costs related to the purchase of EUAs (European Union Allowances) for a Gulfstream 450 flying on three different sector lengths (long, medium and short haul). Figure 28 estimates the costs under three different carbon price scenarios (15, 20, 30 EUR per EUA) and compares them with airport charges at Munich airport.

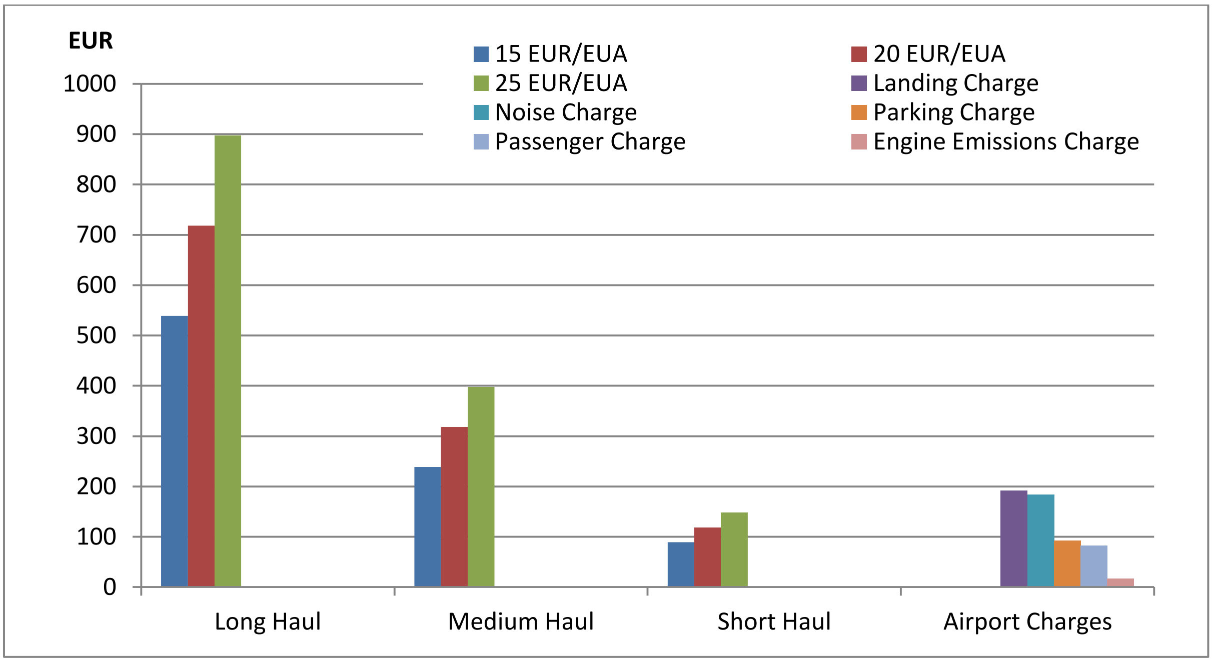

Figure 28: EU ETS related Costs and Airport Charges

Source: In house calculations

Notes: Calculations for Gulfstream 450
Long haul (GCD of KJFK EDDM), medium haul (GCD of HECA EDDM), short haul (GCD of LFPB EDDM), 2011 airport charges of EDDM
Emissions calculation based on version 2011.11.1 Eurocontrol Small Emitter tool

Figure 28 assumes that four percent of emissions allowances were distributed free of charge. The rest must be purchased at a price of 15, 20 and 25 EUR per EUA. Aircraft noise charges are higher than costs for emissions allowances when operating the G450 on short trips. By contrast, carbon costs of medium or long haul flights exceed the size of noise charges. This becomes even more true the higher the carbon price is.

Carbon Price Development

The EUA assumptions from above reflect what was observed for the last three years on the BlueNext spot market. Figure 29 shows the development of the EUA and CER spot price (2008-2012). It also contains the EUA-CER spread, defined as the difference between EUA and CER spot prices.

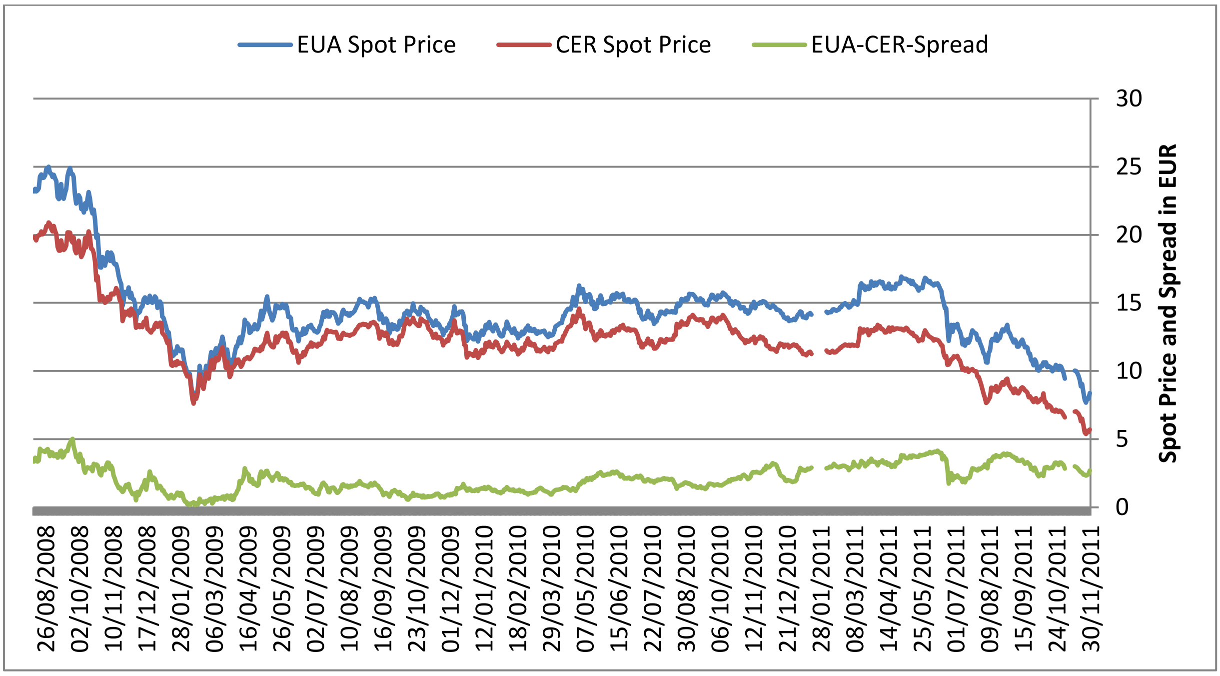

Figure 29: BlueNext Spot Market (2008-2012)

Source: http://www.bluenext.eu/statistics/downloads.php

The spot market trades standardized contracts with immediate delivery and settlement. Over the last 3 years, EUA spot prices were between 10 and 20 EUR. According to the EUA-CER spread, CERs were on average between 2 and 4 EUR cheaper than EUAs. This means that aircraft operators can reduce the costs related to the purchase of missing allowances if they use CERs to a maximum of 15 percent of the number of tonnes CO_2 produced in 2012. Under the assumption that the EC does not change the emissions cap and allocation methodology, Thomson Reuters Point Carbon forecasts an average EUA spot price of EUR 12 in the period from 2013 to 2020. It seems to us the most realistic price scenario considering the institutional framework and forecasted economic activity in Europe.

Carbon Price Factors

The long term carbon price depends primarily on economic and institutional parameters. Economic growth implies higher production in the primary and secondary sector of the economy. In times of economic recovery and boom, stationary emissions sources covered by the EU ETS, such as iron and steel production, would lift the production rate and, as a consequence, emit more CO_2 emissions. The demand for carbon credits from power generation (especially coal power plants) would increase with higher demand for electricity. Carbon price changes may also be explained with the level and development of energy prices. When prices for oil and gas are high, electricity generators may switch to relatively cheaper, but more CO_2 intensive coal. Institutional parameters refer to the design of the EU ETS and other rules affecting supply and demand of emissions allowances. Take for instance the stringency of the emissions cap, the limits to which operators can use credits from JI and CDM projects or the EC decision to gradually phase out free allocation in regulated industries other than aviation. Another factor is the shape of the abatement cost curve of regulated industries. Emissions sources abate emissions if marginal abatement costs are lower than the prevailing carbon price. They will maintain the emissions level and buy missing allowances on the carbon market if marginal abatement costs exceed the carbon price. New demand for emissions allowances pushes the carbon price upwards. Short term fluctuations of carbon prices can be triggered by political statements (unmatched expectations), one-time events (such as fraud with emissions allowances) or weather. Another factor with potential of short term price fluctuations is the behavior of trading entities. For instance power sector hedging strategies can impact future prices. The degree of preparation of regulated emissions sources prior to the 30 April deadline may also play a roll. It is thinkable that last minute spot transactions lead to price spikes on the spot market.

8.1.4 Administrative Burden for Business Aircraft Operators

After the first reporting period, many business aircraft operators have complained about the disproportionate high administrative burden of the EU ETS. This section gives an overview of costs related to monitoring, reporting and verification (MRV).

The advantage of emissions trading under perfect conditions is that emissions abatement occurs where costs are lowest. Besides abatement costs, transaction costs and administrative costs have to be considered to evaluate the full cost impact of the EU ETS. These costs may offset the advantage which emission trading holds over other environmental instruments.

Monitoring, Reporting and Verification

The administrative burden results from the compliance of business aircraft operators with the EU ETS Directive, the MRV Guidelines and the national legislation of the administering Member State.

The monitoring effort of non-commercial operators is relatively low because some kind of monitoring system is already in place. Almost all of them use flight planning software and flight tracking systems, sometimes even topped up with an EU ETS tool which makes the job of filtering Annex 1 flights automatically. Operators can also rely on simple record keeping systems, such as Microsoft Excel.

The bulk of business aircraft operators use the simplified procedure (such as the EC approved Small Emitters Tool) for estimating annual emissions rather than using the actual fuel consumption as basis for the emissions calculation. Only small emitters are eligible for the use of the simplified procedure. Small emitters are non-commercial operators operating fewer than 243 flights per period over three consecutive 4-month periods, or emitting less than 10,000 tCO2 per year (de-minimis threshold). It is the same threshold which qualifies commercial operators for the exclusion from the EU ETS. The Small Emitters Tool requires for the emissions estimation the ICAO aircraft type designator and the distance between the airport of departure and arrival. The calculation work is usually done prior to reporting at the end of the monitoring period.

The verification is the stage that follows monitoring. The EU ETS obliges all operators with Annex 1 flight activity to submit a *verified* emissions report to the Competent Authority of its administering Member State. The verification process allows aircraft operators to correct errors and inaccuracies identified by the verifier. The fee charged by the verification body adds to total MRV costs.

The verified emissions report is then ready for submission. National reporting rules and charging schemes are highly heterogeneous. The reporting is either done on the basis of a secured online emissions trading portal (Ireland, UK, Austria, Germany) or using a standard emissions reporting form (Excel spreadsheet).

Identification of MRV Costs

Table 13 provides an overview of MRV costs. We don't account for costs borne by the European Commission and national governments associated with the setting up and maintenance of the EU ETS.

Cost Categories	Monitoring, Reporting and Verification (MRV) Costs						
	One-Time Costs				Variable Costs		
	Regulatory Costs	Internal Costs	Consultancy Costs	Capital Costs	Regulatory Costs	Consultancy Costs	Internal Costs
Examples	Costs of monitoring plan submission and changes Costs of translation services	Staff time spent to become familiar with emissions trading and EU ETS rules	Developing emissions reduction and trading strategies	Costs of additional data storage equipment	Annual Subsistence charge Costs of verification Costs of equipment for electronic signature	Outsourcing ETS related tasks and use of EU ETS compliance service Costs for carbon trading (trading, clearing and broker fees)	Staff time spent for monitoring, reporting and verification

Table 13: Classification of MRV Costs

Source: Cost classification inspired by Jaraite, J., Convery, F., Di Maria, C. (2009)

It should be noted that the applicability of listed MRV costs highly depends on the administering Member State to which the operator is assigned. For instance the French Competent Authority DGAC does not require the translation of official documents, electronic signature or payment of any charges.

By contrast, the UK charges aircraft operators to recover one part of administrative costs. Figure 30 provides information on the structure and costs of the UK charging scheme for small emitters[42].

[42] The EU ETS defines small emitters as aircraft operators who operate fewer than 243 Annex 1 flights per period for three consecutive four-month periods or produce less than 10000 tonnes CO2 emissions per year.

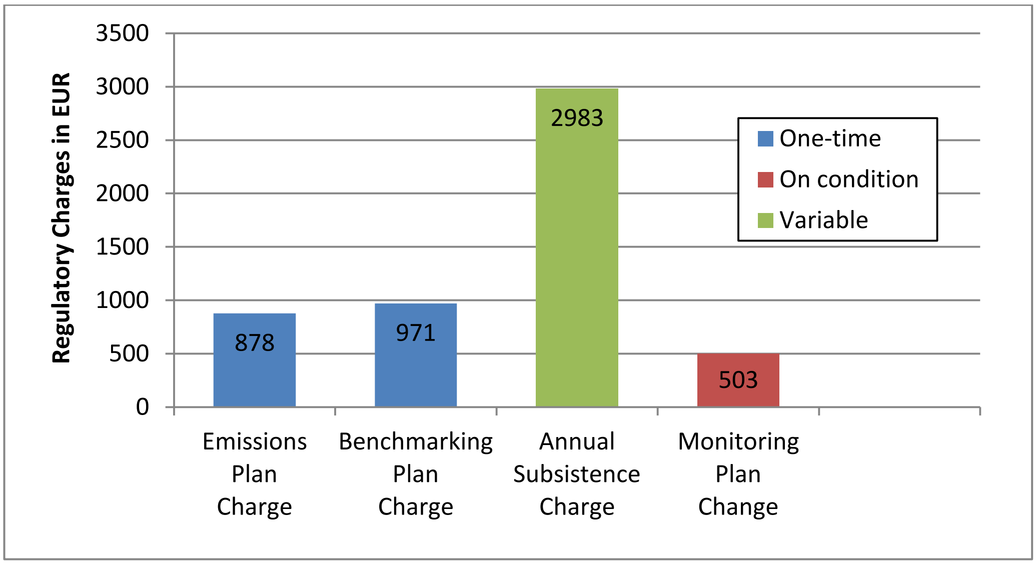

Figure 30: UK EA Regulatory Charges in 2011/12

Source: UK EA 2011/12 Guide to Charges
Notes: GBP 1= EUR 1.17

The UK Environmental Agency (EA) asks business aircraft operators to pay a one-time fee of EUR 878 (and EUR 971) for the submission of the emissions plan (and benchmarking plan). Operators pay an additional charge of EUR 503 if monitoring plans are changed and a technical assessment is necessary. The only charge that is 100 percent recurrent is the annual subsistence charge (EUR 2984).

Evaluation of EU ETS related Administrative Burden

We asked business aircraft operators in the BASE survey to evaluate the administrative burden of the EU ETS (see Figure 30).

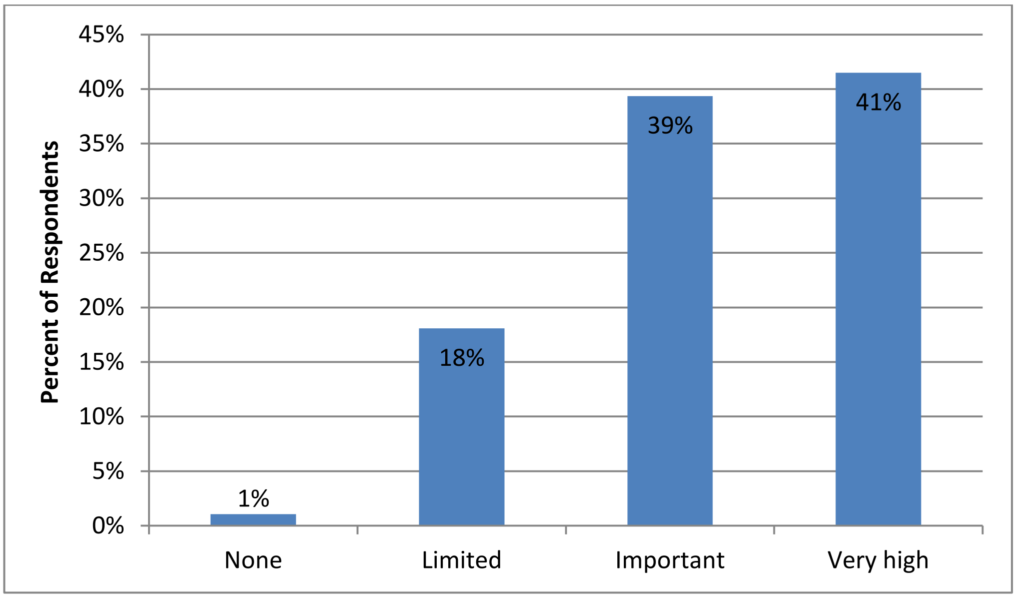

Figure 31: Evaluation of EU ETS Administrative Burden

Source: BASE survey

80 percent of all respondents judge the administrative burden as important and very high. This may serve as an indicator that EU ETS costs are far higher than costs related to the purchase of missing emissions allowances alone. The EC allowed the use of the Small Emitters Tool to take some weight off the shoulders of business aircraft operators. But what we retain from interviews is that users of the Small Emitters Tool would actually prefer to monitor the actual fuel consumption which is more meaningful to them than the Small Emitters Tool which is considered as a 'black box'.

8.1.5 Determining the Full Cost Impact of the EU ETS

Figure 32 models annual costs for monitoring, reporting and verification (MRV) and costs related to the purchase of emissions allowances (carbon costs) for a US corporate flight department operating 30 Annex 1 flights on a G450 in 2012.

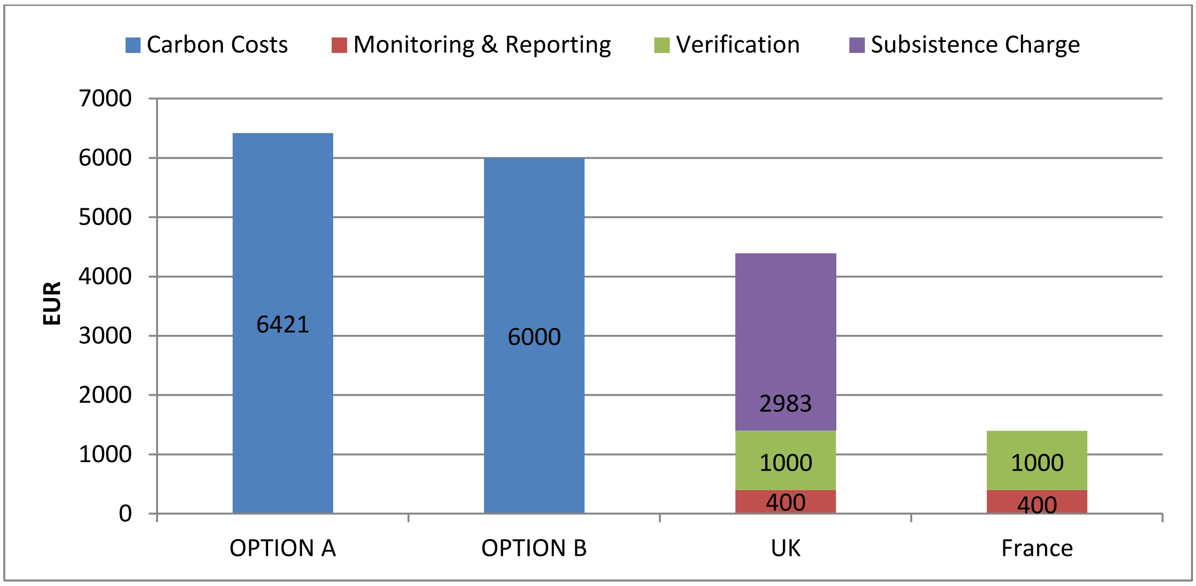

Figure 32: Value of EUA Shortfall and Variable MRV Costs

Assumptions: *US Corporate Flight Department operating 30 Annex 1 flights on a G450 in 2012 (28 long haul flights between Europe and East Cost of the USA, 2 domestic flights within UK), EUA shortfall equals 898; 27 EUAs received free of charge, EUA/CER spot = EUR 7.15 / 4.10 [13/04/2012]*

Monitoring & Reporting: *Price for the ETS Support Facility of EUROCONTROL*
Verification: *Verification fee of EUR 1000 for the verification of an annual emissions report*
Subsistence Charge: *Annual subsistence charge, see Figure 30.*

Figure 32 shows annual MRV costs and costs associated with the purchase of missing emissions allowances for a US corporate flight department with 30 Annex 1 flights. The share of annual MRV costs varies between 22 and 74 percent depending on whether the operator chooses option A or B and the administering Member State. The share would be even higher for operators having fewer than 30 Annex 1 flights because MRV costs are relatively insensitive to the number of reported flights. The size of carbon costs depends on whether the operator uses exclusively EUAs for compliance purposes (option A) or whether he purchases cheaper CERs to a maximum of 15 percent of the total number of emissions allowances and fills up the rest with EUAs (option B). Option B is preferable because the operator could so save EUR 421.

Figure 32 slightly underestimates the full EU ETS related cost impact. It ignores the following cost positions:

- One-time costs for plan submission and changes

- Costs of translation services and equipment needed for a qualified electronic signature (signature card, card reader, signature software) as required in Germany and Italy
- Costs of carbon trading (trading, clearing and broker fees)
- Costs of EU ETS compliance service or consulting (optional)
- Staff time

Costs for monitoring and reporting can be higher if the operator outsources all ETS relevant tasks and uses an EU ETS compliance service. The latter would take care of all monitoring and reporting obligations. It was assumed that the operator subscribes to the ETS Support Facility. EUROCONTROL provides a completed annual emissions report (against a charge of EUR 400) and makes any monitoring activities redundant.

Overall ETS related Cost Burden

We noticed that the general discussion taking place in the business aviation industry often overstates the ETS related cost burden for business aircraft operators. To allow an informed debate, it should be noted that aircraft operators are very unlikely to pay more than one cent USD per gallon jet fuel to fulfill their obligations under the EU ETS as to what regards the purchase of emissions allowances[43]. The carbon price would have to exceed EUR 23 per tonne CO_2 to increase the costs to 2 cents USD per gallon which is still very low compared to the price for jet fuel offered by home-based FBOs.

The full cost burden of the EU ETS comprises costs for monitoring, reporting and verification, as illustrated in Figure 32. The G450 operator with 30 Annex 1 flights (and an estimated 230 flight hours) faces annual EU ETS induced costs of EUR 7,400 if regulated by France (EUR 10,383 if regulated by the UK) under the assumption that it purchases CERs to the maximum allowable level of 15 percent of its emissions allowances need. As measured as percentage of annual direct

[43] It is assumed that the operator receives no free emissions allowances. The costs per gallon jet fuel reflect the carbon price projection of Thomson Reuters of EUR 12 per tonne CO2 at average for the period 2013-2020. We assumed that the EUR/USD quotes 1.3.

operating costs (DOCs), we calculate that the EU ETS adds costs equivalent to 0.3 / 0.4 percent (France/UK) of total DOCs. This example illustrates that the inclusion of business aviation into the EU ETS comes far cheaper than often described by business aviation experts to professionals and the general public.

8.1.6 Impact of EU ETS on Operators and Manufacturers

The previous chapter modeled costs related to the EU ETS. This chapter discusses the impact of the scheme on business aircraft operators. The economic literature exclusively concentrates on how the EU ETS is likely to affect commercial aviation. To our best knowledge, business aviation is addressed in none of the released reports. But before assessing the EU ETS induced impact, we would like to remind the reader why people use business aircraft instead of scheduled services. Interviews held under BASE have revealed that the user benefit of business aviation arises from the following advantages: time savings, scheduling flexibility, comfort, productivity, accessibility to smaller airfields and confidentiality. These were the most recurrent answers received on the question why people would use business aircraft. Cost considerations only played a minor role. In contrast to commercial airlines prioritizing cost reductions, business aircraft operators seek to maximize the user benefit. The business models are completely different one from another. However, survey results indicate that pilots minimize the fuel consumption (1) if it does not compromise the benefits of business aviation and (2) whenever Air Traffic Control (ATC) allows. ATC could for instance contribute to more fuel efficient operations through more direct routing and by allowing large and long haul business aircraft to fly above commercial airlines on fuel efficient altitudes. The survey outcome refutes the claim according to which business aircraft operators do not consider costs. Costs are well taken into account when preparing the flight plan. Some aircraft operators state that they will fly around European territory to avoid (or lower) EU ETS related costs. Tech stops could be performed outside the boundary of the geographical area for which the EU ETS applies. Operators have the possibility to refuel the aircraft in unregulated territories, such as Switzerland, Turkey, Jersey, Guernsey or Isle of Man. The financial incentive to fly around Europe only exists if foregone EU ETS costs exceed the costs for additional fuel consumption on longer routing. Flying longer to avoid the EU ETS would weaken the environmental integrity of the scheme. The so called ‘carbon leakage' is defined as increase of emissions in one region as a result of an emissions constraint introduced in another[44]. BASE provides evidence for carbon leakage in the business aviation sector. The BASE survey also asked (predominantly) US corporate aviation departments whether they consider ceasing operations to European airports as response to the EU ETS. 81 percent of all respondents answered no, against 19 percent who ticked yes. Although the bulk of respondents don't think about ceasing operations to Europe, we haven't expected that many "yes" votes. But why would users give up all the advantages associated with the operation of business aircraft? Besides the discontent with the disproportionate administrative burden associated with EU ETS, survey participants signal their opposition to the regulation of emissions produced in non-EU airspace and the missing guarantee of using auction proceeds exclusively for the fight against climate change. However, it seems to us unlikely that US companies making business in Europe will stop operations. In the end, business aircraft users, such as top executives, rather than pilots and corporate aviation managers, decide on whether to fly to Europe or not.

One objective of EU ETS designers was to provide incentives for the use of cleaner technologies. For instance winglet retro fitting could reduce the fuel consumption by estimated two percent[45]. It should be noted that private operators use aircraft less often than commercial airlines. Whereas airlines try to maximize the time in operation, non-commercial use of the aircraft may not exceed 100 flight hours per year for some operators. As a matter of fact, fuel cost savings increase with higher aircraft utilization. In this regard, investments in technical fuel reduction measures only pay off if the aircraft ensures a minimum activity level.

One could think that carbon costs provide operators with incentives to fly more fuel efficient. Virtually all business aircraft operators covered by the EU ETS use the Small Emitters Tool to estimate emissions rather than calculating emissions on the basis of actual fuel burn. The Small Emitters Tool only requires information on aircraft type and distance flown. It neither accounts for weather nor for ATC related deviations and payload. Consequently, the Small Emitters Tool gives poor incentives

[44] Ellerman, A., Convery, F., De Perthuis (2010), 194.

[45] OMEGA (2009)

because operators can only decrease compliance costs by replacing the old aircraft by a new more fuel efficient one. The Small Emitters Tool provides no additional incentives beyond fuel costs to tackle emissions by means of operational measures. It creates cost inefficiencies if aircraft operators buy emissions allowances where a measure of actual fuel consumption would have prompted them to rather reduce emissions through operational improvements.

It can be retained that the EU ETS provides no additional incentives of operating business aircraft more fuel efficient. By contrast, it may create unintended side effects, such as carbon leakage, and question the cost efficiency of the scheme because of the overall high administrative burden and the use of the Small Emitters Tool.

Interviews were also held with representatives of business aircraft manufacturers. According to them, the carbon price will have no impact on manufacturers. They state that the market puts sufficient pressure on manufacturers to develop more fuel efficient aircraft. Table 14 elaborates on the motivation for developing more fuel efficient aircraft.

Motivation	Description
Increased aircraft performance	It primarily refers to range capacity. Manufacturers have an incentive to produce more fuel efficient aircraft in order to increase the range aircraft can fly. Better range performance saves time (no tech stop) and allows operators to access remote places.
Lower operating costs	Fuel costs are one of the biggest cost items of operating costs. The production of more fuel efficient aircraft lowers the fuel bill. Fuel cost savings are even higher under higher Jet A kerosene prices.
Technological progress	Aircraft buyers are also interested in new technologies. Aerodynamic advances or the use of lighter material has the positive side effect of increasing the aircraft fuel efficiency.

Table 14: Motivations of Business Aircraft Manufacturers

Source: BASE Interviews

9 Conclusion

This paper analyzes existing and near-future environmental constraints and their cost impact on business aircraft operators. Although the environmental impact is relatively low (compared to other mobile and stationary polluters), business aircraft are covered by a number of environmental regulations. The primal motivation is to treat different business models equally and to strengthen the environmental integrity of emissions and noise regulation**.** We described by means of which measures IBAC/GAMA seek to achieve aspirational emissions reduction targets. We pointed out that environmental regulation can play a major role if biofuel fails to reduce emissions as promised. Most environmental restrictions on aviation are only tested against their impact on commercial aviation. The regulator is recommended to account for the specifications of business aviation so as to mitigate the risk of unintended consequences. Take for instance the administrative burden of the EU ETS for small emitters. We found out that administrative costs can be even higher than the costs related to the purchase of missing emissions allowances.

Chapter 4 discussed emissions and noise standards. Engine emission standards set limits for NO_x, CO, HC emissions and smoke. To be certified, emissions from engine prototypes must stay below applicable regulatory limits. We showed that not all engines are subject to the emissions standard. Light jet engines typically don't exceed 26.7 kN of maximum thrust and thus fall outside the scope. However, we think that engine manufacturers are likely to pass on technology advances from larger jet engines to unregulated smaller engines. There is a general discussion on the impact of certification standards on airframe and engine technology. Regulators seek to incentivize manufacturers to develop cleaner aircraft. They can only do so by setting a stringent noise or emissions limit. But they should also ensure that manufacturers can meet the regulation with reasonable costs. Too ambitious standards could harm the whole industry.

The ICAO is currently working on the design of a CO_2 emissions standard. A measure of block fuel (as full mission performance standard) and specific air range (as instantaneous performance standard) were identified as the two most promising

CO_2 standards. We found out that aircraft are much easier to certify using SAR. It measures the aircraft fuel efficiency during cruise. Opponents argue that SAR is not accurate enough because it does not account for the fuel consumption during take-off and landing. However, SAR is correlated with block fuel which implies that aircraft performing well in cruise are just as fuel efficient in all other flight stages. Regulators must ensure that larger aircraft face higher regulatory limits than smaller aircraft because they require more thrust and fuel to move the aircraft through the air. That is the reason why regulators normalize the metric with variables reflecting the aircraft capacity (MTOW) or operational practice (payload). Business aircraft are better off under a MTOW based metric. Payload would penalize business aircraft because they are typically operated with lower load factors.

Aircraft have to comply with noise standards to be certified airworthy. Chapter 4.3 provided an introduction into the ICAO noise certification standard and demonstrated how business aircraft perform relative to chapter 2, 3 and 4 noise limits. We compared the noise levels of aircraft from the F50/F900 series and found out that Dassault constantly improved the noise performance over the last 30 years. We explained that higher engine bypass ratios contributed to noise mitigation at source.

The ICAO pursues the so called Balanced Approach which ensures that airports take the most cost effective measures to reduce noise. Airports can mitigate the impact of noise through the introduction of operating restrictions, the prescription of noise abatement operational procedures and the implementation of smart land use planning & management strategies. Chapter 6 lists the most commonly used noise restrictions and operating procedures. It comes out that establishing curfews is the most popular noise restriction. As to what regards noise abatement operational procedures, business aircraft operators make use of, or consider using, reduced thrust take-offs, CDAs and idle instead of max reverse thrust.

Most European airports levy noise and emissions charges on landing and departing aircraft. The proceeds are largely invested in alleviation and prevention but emissions and noise charges can also serve as an attractive source of income. The tariff system accounts for the different levels of noise and pollutants to promote and accelerate the introduction of best available technology. What we retain from BASE is that most business aircraft operators don’t even know that emissions charges exist. Emissions charges are far lower noise charges which, in turn, make up a substantial part of airport charges.

Chapter 7 analyzes taxation as alternative regulatory instrument. An excise tax on jet kerosene would generate income and provide additional incentives (beyond the fuel price itself) to operate business aircraft more fuel efficient. Interviews with business aircraft operators revealed that the acceptance of *environmental* taxes largely depends on whether the proceeds are used for investments destined to improve the environmental performance of business aviation.

The analysis of environmental constraints largely focuses on the European Union Emissions Trading Scheme – the world largest cap and trade system of CO_2. Overall compliance costs are high not because of the costs related to the purchase of emissions allowances but rather due to a disproportionate high administrative burden. We also explained that the EC approved Small Emitter Tool, as used by the majority of business aircraft operators, fails to provide incentives to reduce emissions by means of operational measures. Operators can only decrease carbon costs by replacing older by new more fuel efficient aircraft. The impact analysis identifies competitive distortions to the detriment of non-commercial operators because the scheme does not regulate small or mid-size commercial operators. The BASE project provides evidence for carbon leakage in the business aviation sector. Some participating operators stated that they will fly around European territory to avoid (or lower) EU ETS related costs.

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