MODELLING AIR TRANSPORT'S CO_2-EMISSIONS AND EVALUATING THE IMPACT OF THE UPCOMING EU EMISSIONS TRADING SYSTEM

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Abstract

In February 2009, the European Union's (EU) Directive for the inclusion of international aviation into the EU Emissions Trading Scheme (EU-ETS) for CO_2-emissions came into force. From 2012 onwards, the EU-ETS will cover all flights departing or arriving in the EU. The initial allocation of emission allowances to airlines will be based on a benchmark which is calculated by dividing the 2004-2006 CO_2-emissions of the airlines participating in the scheme by their transport performance expressed in revenue tonne-kilometres of the year 2010. This paper describes an empirical simulation model for the future development of the European air transport sector and for the impact of the EU-ETS. Current and future CO_2-emissions and transport performance data of European aviation will be estimated. Furthermore, the economic effects of the upcoming EU-ETS on both the aviation sector in total and selected groups of airlines will be analysed and discussed. As a result, it can be shown that certain airline groups will be affected very differently by the new EU legislation.

This paper is organised as follows: Initially, it provides an overview of the new EU legislation on emissions trading and aviation for the years 2012 and beyond. Subsequently, our modelling approach and the main economic and ecologic effects for the aviation sector as well as for selected airlines and airline groups are presented and discussed. Finally, conclusions about the impacts on costs, airfares and competition within the aviation sector are drawn.

1. ABBREVIATIONS

ASK	Available Seat-Kilometres
BADA	Base of Aircraft Data (by EUROCONTROL)
CCS	Carbon Capture and Storage Technology
CER	Certified Emission Reduction
CDM	Clean Development Mechanism
CO_2	Carbon Dioxide
DLR	German Aerospace Center
EC	European Community
EFTA	European Free Trade Association
ERU	Emission Reduction Unit
ETS	Emissions Trading System
EU	European Union
EUA	EU Allowance Unit
EU-ETS	Emissions Trading Scheme of the EU
FAA	Federal Aviation Administration
FESG	Forecast and Economic Subgroup
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IFR	Instrument Flight Rules
ISA	International Standard Atmosphere
JI	Joint Implementation
LCC	Low Cost Carrier
MTOM	Maximum Take-off Mass
OAG	Official Airline Guide
PSO	Public Service Obligations
RPK	Revenue Passenger-Kilometres
RTK	Revenue Tonne-Kilometres
TFS	Traffic by Flight Stage
US	United States
VFR	Visual Flight Rules

2. INTRODUCTION

After long and highly controversial discussions both on EU- and on the level of the International Civil Aviation Organisation (ICAO), the European Council and the European Parliament agreed in July 2008 to include international aviation into the existing EU Emissions Trading Scheme for the limitation of CO_2-emissions. The Directive came into force in February 2009 [7]. Aircraft operators will be obliged to surrender allowances for virtually all commercial flights landing at and departing from any airport in the EU from 2012 onwards. The EU-ETS will not only affect European airlines, but also airlines from third-countries like the US or developing countries. The European Commission justifies this approach by stating that a distortion of competition in the international airline sector needs to be avoided to the most possible extent and that this approach will improve the environmental effectiveness of the scheme. Several non-EU states, however, have expressed doubts regarding the environmental effectiveness of the EU-ETS and whether the EU approach conforms to international law.

A number of economic studies on these controversial issues have been conducted lately, e. g. by Faber, van der Vreede and Lee [11], Forsyth, Dwyer and Spurr [13], Boon et al. [4], Forsyth [12] as well as Scheelhaase, Grimme and Schaefer [24]. These studies focus on different aspects of the topic such as the method of initial allocation of allowances, the impacts on tourism as well as the economic impacts on different airline types. The following analysis is based on these recent findings.

This paper analyses how the EU Directive for the inclusion of aviation into the EU-ETS will affect the international air transport sector both economically and ecologically. In order to analyse these questions, an empirical simulation model was developed. The model is based on global flight schedules of the Official Airline Guide (OAG) supplemented by a DLR developed flight plan for cargo and integrator airlines. All flight movements are simulated by DLR aircraft performance software in order to calculate their fuel consumption and CO_2-emissions. By employing this model, current and future CO_2-emissions and transport performance data of European aviation will be estimated. Furthermore, the economic effects of the upcoming EU-ETS on both the aviation sector and individual airlines will be estimated and discussed.

3. POLITICAL BACKGROUND

3.1. The EU Directive for the inclusion of aviation activities into the EU Emissions Trading Scheme in 2012

The EU Directive, as it came into force in February 2009 [7], contains the following provisions for the inclusion of aviation into the existing emissions trading scheme:

- The emissions trading scheme will cover virtually all flights departing from or arriving at EU airports from 2012 onwards. Domestic flights will be subject to the same rules as international air traffic. If any non-EU country introduced alternative measures with similar climate protecting effects, the geographical scope of the ETS could be modified such that flights arriving from or departing for this particular country are excluded from the scheme.
- Aircraft operators will be obliged to hold and surrender allowances for CO_2-emissions. Allowances are required for flights by fixed-wing aircraft with a maximum take-off mass of 5,700 kg or above. Flights performed under visual flight rules and rescue flights (amongst a number of other exceptions) are excluded from the scheme.
- Exemptions from the EU-ETS will also be granted for flights performed in the framework of public service obligations (PSO) on routes within outermost regions or on PSO routes where the capacity offered does not exceed 30,000 seats per year. Also excluded from the EU-ETS will be flights performed by a commercial air transport operator operating either fewer than 243 flights per four-month period for three consecutive four-month periods (so-called ‘de minimis’ clause) or flights with total CO_2-emissions lower than 10,000 tonnes per year. The ‘de minimis’ clause was added in order to reduce administrative costs for operators with a low number of flights to and from Europe.
- Regulations for emission monitoring and reporting will take effect in 2010 while an emission cap for all aircraft operators will be introduced in 2012.

Further rules in the Directive include the following issues:

- In the first year of the inclusion of aviation into the EU-ETS, the total quantity of allowances to be allocated to aircraft operators shall be equivalent to 97% of the historical aviation emissions (so-called overall “cap”). The historical aviation emissions will be calculated on the basis of the average total emissions of the years 2004-2006 borne by all aircraft operators taking part in the scheme. The historical emissions will be defined by the European Commission with technical assistance from EUROCONTROL.
- Initially, allowances will be allocated to aircraft operators mostly free of charge. In the year 2012, 85% of the allowances shall be allocated for free. The method of allocating allowances to aircraft operators will be harmonised within the European Union.
- The total number of allowances allocated to each aircraft operator will be determined by a benchmark which is calculated in three consecutive steps: First, the share of auctioned allowances is subtracted from the overall “cap”. Second, the remaining CO_2-emissions will be divided by the sum of verified tonne-kilometre data for flights falling under the geographical scope of the EU-ETS in the monitoring year 2010, as reported by all participating aircraft operators. Third, the specific amount of allowances each operator receives is calculated by multiplying the respective individual tonne-kilometre value of the monitoring year with the benchmark. Each operator’s revenue tonne-kilometres are calculated by multiplying the mission distance (great-circle-distance plus an additional fixed factor of 95 km) by the payload transported (cargo, mail and passengers). For the calculation of the performed tonne-kilometres, each passenger including baggage is assigned a value of 100 kg.
- In the first year of the inclusion of aviation into the EU-ETS, allowances allocated to aircraft operators will be valid within the aviation sector only. However, it will be possible to purchase additional permits from other sectors or from the project based Kyoto instruments “Joint Implementation” and “Clean Development Mechanism”. In the year 2012, aircraft operators may use emission permits from “Joint Implementation” and “Clean Development Mechanism” up to 15 % of the number of allowances they are required to surrender for this year. Allowances not used in 2012 can be ‘banked’ to the third trading period of the EU-ETS. This means unused allowances issued in 2012 can be carried over for use up to the year 2020.
- Allowances not allocated free of charge will be auctioned by the Member States. Each Member State will receive a number of allowances to be auctioned proportionately to its share of the total aviation emissions. The revenues should be used to tackle climate change in the EU and third countries, inter alia, to reduce greenhouse gas emissions, to adapt to the impacts of climate change or to fund research and development in these fields.

3.2. The EU Directive for the improvement and extension of the EU Emissions Trading Scheme in the years 2013 until 2020

The EU Directive for the period 2013-2020 [6], as it was agreed in December 2008, aims at improving and extending the greenhouse gas emission allowance trading system of the Community. Due to its broader nature, it adopts regulations for all sectors included in the system and very few aviation-specific rules. It is understood that most of the regulations for the first year of the inclusion of aviation into the EU-ETS which are described above will be further applied in the years 2013 until 2020. These regulations include reference to the geographical coverage of the scheme, exemptions from the scheme, the rules for emission monitoring and reporting, the method of calculating the sector-specific benchmark, and the criteria for the use of the revenues from auctioning allowances. In contrast to this, modifications are introduced for the following aviation-specific regulations for the period 2013-2020:

- The total quantity of emission allowances to be allocated to aircraft operators shall be equivalent to 95 % of the historical aviation emissions multiplied by the number of years in the (eight-year) period. This way, the so-called ‘cap’ for the participants in the scheme will be lowered by another 2 %. A further modification of the overall “cap” for aviation may be possible after a general review of the Directive, which is scheduled for the year 2014.
- From the year 2013 onwards, the use of the project based Kyoto instruments “Joint Implementation” and “Clean Development Mechanism” will be lowered significantly for aircraft operators. In the period 2013 until 2020, aircraft operators may use emission permits from “Joint Implementation” and “Clean Development Mechanism” only up to 1.5 % of the amount of allowances they are required to surrender per year. However, purchasing emissions permits from stationary sources is possible without limitations.

Finally, the European Commission emphasises the need for a global agreement on measures to reduce greenhouse gas emissions from aviation.

4. MODELLING AIR TRANSPORT’S CO_2-EMISSIONS AND TRANSPORT PERFORMANCE

4.1. Overview

Modelling the upcoming EU-ETS requires an estimation of both European aviation’s fuel consumption (and hence CO_2-emissions) and the corresponding transport performance measured in tonne-kilometres. This is not an easy task since no detailed and publicly available statistics regarding CO_2-emissions of the European air transport sector exist to date. The approach chosen for our study combines world-wide flight schedules with an aircraft performance software. OAG flight schedules for the years 2004-2008 were supplemented by an additional flight plan for all-cargo flights. The aircraft performance software determines fuel consumption and CO_2-emissions for each flight contained in the schedules. The summation of the CO_2-emissions of all flights within the regional scope of the EU-ETS was used as a best-estimate of the airline sector’s total CO_2-emissions subject to the scheme.

While flight schedules contain information on seat- and payload capacity available on each flight, actual passenger numbers and the (total) payload transported had to be estimated. For this purpose, each flight in the schedules was supplemented by load factor data from different sources. The sources used to determine both seat load factors and overall weight load factors include the ICAO Traffic by Flight Stage databank and ICAO’s Air Carrier statistics. By combining such data with the available seats and payload capacities from the schedules, an estimation of European aviation’s transport performance for the years 2004-2008 could be provided.

As the EU-ETS will be introduced in 2012, forecast flight schedules were produced based on the latest available scheduled data. Given the current economic situation, no traffic growth was assumed between 2008 and 2010. For the years 2010-2012, on the other hand, regional growth factors derived from common manufacturers’ forecasts were applied to the base year flight schedules in order to produce a forecast up to the year 2012. The introduction of more fuel-efficient aircraft, potential improvements in the field of Air Traffic Management and a further increase in terms of load factors were considered by assuming a 1 % efficiency improvement per year resulting in a corresponding reduction of fuel-consumption and emissions per tonne-kilometre. This way, a reliable and best possible estimation of traffic volumes and CO_2-emissions of European flight operations up to the year 2012 could be performed. A more detailed description of our modelling approach is found in the following sections.

4.2. Modelling air transport’s historical CO_2-emissions and transport performance

4.2.1. Flight movements

The database of flight movements is based on world-wide flight schedules provided by OAG for the years 2004-2008 [22]. For 2004 and 2005, schedules for January and July were available for this study while for the remaining years all twelve months are covered by the data. A supplemental schedule with information from other sources such as airport and airline websites gathered by the authors covers additional all-cargo services. Schedules from OAG were selected since information on actual aircraft movements from filed flight plans or radar data collected by EUROCONTROL are not publicly available. The flight schedules used for this study were converted into flight movements by filtering out ground services and helicopter flights and by splitting up entries with one or more intermediate stop(s) into single-leg operations. Duplicate entries in the database were identified and removed. Flights from and to the European Union (EU27 plus outermost regions) were identified by evaluating the origin and destination country codes.

There are good reasons for employing the OAG/DLR database in our model: For the passenger sector, OAG data contain virtually all scheduled flights worldwide (except some domestic flights in certain non-European countries), including services provided by most low-cost and leisure carriers. However, some charter services operated on behalf of tour operators and ad-hoc charters are not included in OAG. Nevertheless, we regard OAG data as a good proxy for the air transport volume in the passenger sector considering the following aspects:

- According to DLR calculations based on EUROSTAT figures for 2007, non-scheduled flights account for about 12% of all IFR passenger flights [9]. With OAG data containing all scheduled and some of the unscheduled air traffic, the percentage of non-OAG passenger flights should be smaller than this figure.

- A large percentage of these non-scheduled flights can supposed to be operations exempted from the EU-ETS, e.g. flights with aircraft of less than 5,700 kg maximum take-off mass or flights falling under the 'de minimis' clause.
- As some flights are typically cancelled, OAG will slightly overestimate the real traffic volume from scheduled services. This overestimation, in turn, may compensate for the unscheduled passenger flights not included in OAG.

For the air cargo market, in contrast, data availability is less satisfying. While OAG comprises most scheduled cargo services, data on integrator services and ad-hoc services are not publicly available. Integrator and ad-hoc services, however, account for a relatively large part of the all-cargo market: According to EUROSTAT, more than one third of all air cargo shipments (measured in tonnes transported on flights from and to airports in the EU27 countries) were carried on non-scheduled flights in the year 2007 [9]. In order to improve the data availability in the cargo sector, we have compiled a flight plan comprising a presumably large part of the non-OAG all-cargo flights from and to Europe. This additional schedule mainly consists of double-checked flight information found in airport timetables, in press releases of air cargo companies and on websites run by aviation enthusiasts.

4.2.2. Fuel consumption and CO_2-emissions

An aircraft performance software developed at the DLR Institute of Propulsion Technology was employed to calculate fuel consumption and CO_2-emissions of each flight in the flight schedules. This tool uses data from various sources, most prominently the EUROCONTROL Base of Aircraft Data (BADA) [8]. This database contains information on 91 aircraft types including most large airliners. Aircraft for which no data are available can be represented by models with similar characteristics. Fuel burn and emissions calculations based on BADA data have a history of being used for global emission inventories (e.g. the FAA's SAGE inventories) and can be considered a standard for such applications [10].

The aircraft performance software considers taxiing on the ground, take-off, climb, cruise and descent flight phases. The fuel consumption of a flight is calculated iteratively, reducing the aircraft mass (due to fuel burn) in each calculation step. Since the take-off mass of a flight is initially unknown, the program performs the calculation process "backwards", i.e. starting with reserve fuel quantities and analysing all flight phases in reverse order. More details on the calculation methodology can be found in [24]. A number of assumptions were required for flight simulations, most prominently regarding actual flight distances and cruise altitudes. These simplifications would not be required if "real" flight tracks in the form of radar data were publicly available. For our CO_2-calculations, the main assumptions are:

- The flight distance of each flight was estimated by applying an empirical "inefficiency" factor to the great-circle distance between origin and destination airports. The factor ranges from 1.06 on short-range flights (up to 500km) to around 1.03 on long-range missions.
- Typical cruise altitudes were assigned as functions of mission distance and aircraft type or category. Reserve fuel policies as applied by major airlines were used for mission analyses.
- International Standard Atmosphere (ISA) conditions were assumed with neither head- nor tailwinds.

The payload assumed for each flight could be calculated based on the aircraft's maximum payload multiplied by a flight's weight load factor (see section 4.2.3). With the simplifications mentioned above, the software is capable of calculating fuel burn and CO_2-emissions along the flight path. As will be explained in chapter 5, the CO_2-emissions of all flights subject to the EU-ETS were summed up and processed further in order to calculate the emissions cap and the benchmark.

4.2.3. Payload & transport performance

The transport performance of all flights is required both for our traffic forecast (see chapter 4.3) as well as for the economic assessment of the EU-ETS (see chapter 5). A flight's transport performance can be measured in tonne-kilometres and is usually calculated by multiplying the payload transported by the great-circle distance between origin and destination airports. While flight schedules contain the great-circle distance as well as information on seat- and payload capacities of each flight, actual passenger numbers and the total payload transported had to be calculated. Furthermore, as was described in the previous section, the payload of each flight can be used in order to improve the quality of the emissions calculations. As a consequence, each flight in the schedules was assigned a representative seat load factor and a weight load factor based on various data from ICAO statistics [18].

The preferred source of such data is the ICAO's Traffic by Flight Stage (TFS) database, which provides yearly statistics on passenger numbers, freight and mail carried per city-pair, airline and aircraft type. Since the number of seats and the total payload capacities are also available from the database, yearly averaged seat- and weight load factors can be calculated and assigned to the flights in the flight schedules. In case no information is found for the lowest available level of aggregation (i.e. seat and weight load factors given for city-pair/airline/aircraft combinations), the next higher level of aggregation was chosen.

Unfortunately, ICAO TFS information only includes data for international air traffic reported to the ICAO by selected airlines. For flights for which no information was found in TFS, the ICAO Air Carrier statistics were used as second-best data source. This database contains yearly averaged seat and weight load factors for a large number of airlines specified separately for passenger and cargo flights, domestic and international air traffic and scheduled or unscheduled operations. Flights for which no data could be found in the ICAO statistics were assigned load factors looked-up manually in airline corporate reports or, as a backup solution, yearly averaged load factors for international aviation derived from ICAO TFS data.

While the use of seat load factors to calculate passenger numbers is a straight-forward approach, care should be taken when using weight load factors from various sources. By definition, the weight load factor of a flight is calculated by dividing the tonne-kilometres transported by the tonne-kilometres available. As most aircraft carry both passengers and freight, a certain passenger weight needs to be applied in order to calculate the transport performance as well as the weight load factor. The passenger weight used for reporting average payload capacities, revenue tonne-kilometres or weight load factors to ICAO may vary from airline to airline and is mostly unknown.

In order to calculate weight load factors from the ICAO TFS database we assumed a passenger weight (including luggage) of 90kg, which is suggested to be a typical average by ICAO [18]. The load factors and actual payload data obtained by the use of this value were treated as our most "realistic" estimates. This data was used for flight mission simulations and to calculate a "best estimate" of the transport performance in tonne-kilometres. A second and separate calculation of each flight's transport performance with slightly different assumptions was performed for EU-ETS analyses: According to the EU's reporting scheme, airlines are obliged to report their tonne-kilometres assuming a default passenger weight of 100kg as well as an addition of 95km to the great-circle distance of each flight [7].

TAB 1. Assumed traffic growth rates for the years 2010 to 2012 for the passenger sector

From Sub-Region	To Sub-Region	Annual Growth Rate
Africa	Central Europe	5.30 %
Australia	Western Europe	5.20 %
Canada	Central Europe	5.03 %
Canada	Western Europe	4.45 %
Carribean	Europe	4.48 %
Central America	Europe	4.75 %
Central Asia	Europe	5.65 %
Central Europe	Western Europe	4.40 %
Central Europe*	Central Europe	3.98 %
Central Europe**	Central Europe	4.43 %
China	Europe	5.98 %
CIS	Europe	5.57 %
Japan	Western Europe	5.18 %
Middle East	Europe	5.60 %
North Africa	Western Europe	5.25 %
Northeast Asia	Europe	5.78 %
Pacific	Western Europe	5.43 %
Russia	Europe	5.37 %
South Africa	Western Europe	5.45 %
South America	Europe	5.53 %
Southeast Asia	Europe	5.70 %
Southwest Asia	Europe	6.00 %
Sub Sahara Africa	Western Europe	5.20 %
USA	Central Europe	4.95 %
USA	Western Europe	4.38 %
Western Europe*	Western Europe	3.40 %
Western Europe**	Western Europe	3.63 %
Others	Others	4.93 %
**) domestic, **) cross-border intra-EU*		

Source: DLR compilation based on manufacturers' and ICAO FESG forecasts [1], [3], [16], [23]

4.3. Forecast of transport performance and CO_2-emissions for 2010 to 2012

Forecasts of traffic volumes and CO_2-emissions were created for this study covering the years 2010 to 2012. In our forecast of traffic volumes we assume that recent market developments like heavily fluctuating oil prices, as well as the costs for participating in the EU-ETS, will have no sustainable negative impact on future aviation growth in the medium and long-term. This is because a number of studies indicate that airlines will be able to pass on, to a large extend, the additional costs to the customers, of whom many are not very price sensitive (see e.g. [5], [25]). However, we are taking into account the 2008/2009 worldwide recession:

The latest traffic figures and short-term forecasts show a decrease of the worldwide air traffic volumes starting in September 2008 and lasting well into the year 2009. For this study we assume a recovery point in the second half of 2009, leading to 2010 traffic volumes equal to those of 2008 before the recession (i.e. until August). From September 2010 onwards the forecast is based on our data for the last twelve months before the recession in combination with average annual growth rates derived from the most common manufacturers' forecasts, i.e. the Airbus Global Market Forecast [1], Boeing's Current Market Outlook [3] and Rolls-Royce's Market Outlook [23]. Additionally, the forecast of the ICAO Forecast and Economic Subgroup (FESG) was analysed [16]. Each of these forecasts provides average annual growth rates for the transport performance on either region or country pair level up to 20 years into the future. For our model, a consensus forecast was created, using the mean growth rate of all four market forecasts for each region or country pair. Tables 1 and 2 present these growth rates for the passenger and cargo sectors respectively.

TAB 2. Assumed traffic growth rates for the years 2010 to 2012 for the cargo sector

From Sub-Region	To Sub-Region	Annual Growth Rate
Africa	Europe	5.70 %
Asia	Europe	5.63 %
Caribbean	Europe	5.70 %
Central America	Europe	5.50 %
China	Europe	7.45 %
CIS	Europe	5.02 %
Europe	Europe	4.15 %
Indian Subcontinent	Europe	6.65 %
Japan	Europe	5.15 %
Middle East	Europe	4.50 %
North America	Europe	4.65 %
Pacific	Europe	4.15 %
South America	Europe	5.48 %
Others	Others	5.80 %

Source: DLR compilation based on Airbus and Boeing market forecasts [1], [3]

As can be seen from the tables, the projected growth for air traffic from and to Europe in terms of passenger-kilometres lies between 3.4 % p. a. (domestic flights within Western Europe) and 6.0 % p. a. (flights between South East Asia and Western Europe). In the cargo market, forecasted growth rates are typically higher and vary between 4.15 % (within Europe) and 7.45 % (China-Europe).

For CO_2-Emissions, however, a factor of 1 % per year for autonomous efficiency gains is included in the forecast. This value is based on long-term observations of the air transport system and correlates with the fuel efficiency target of IATA for the years 2000 to 2010 [14]. The factor represents the efficiency gains that will be achieved in the air transport system by e.g. optimisation of operational procedures, air traffic control or the introduction of larger, more modern and more fuel-efficient aircraft.

5. MODELLING THE UPCOMING EU-EMISSION TRADING SYSTEM

5.1. Overview

Given the world-wide flight movements, the transport performance in tonne-kilometres and CO_2-emissions, core elements of the upcoming EU-ETS can be modelled. Our modelling approach is based on the Directive 2008/101/EC [7]. The regional scope assumed for the emissions trading scheme comprises all flights from and to the European Union (plus outermost regions). While the participation of EFTA (European Free Trade Association) states seems likely, flights within and between Norway, Switzerland, Iceland and non-EU-countries are not included in our model.

The 'de minimis' clause (see chapter 3.1) was incorporated in the model and operators with less than 10,000 t CO_2 emitted per year or fewer than 729 flights per year in 2010 were identified. The results of the model show that none of the airlines contained in the OAG flight schedules and operating to/from the EU emits less than 10,000 t CO_2 per year. However, 95 operators were identified with less than 729 flights per year, representing about 1 % of the total emissions and 2 % of the revenue tonne-kilometres according to the reporting standards of the EU-ETS. For simplification, further checks for public service obligation (PSO) routes or routes within the outermost regions were omitted, as both the emissions and RTKs of these flights are negligible with less than 0.1 % of the total RTKs performed on flights to or from the EU. Actually, most PSO routes in the EU will require emission allowances, as the exclusion criterion of 30,000 seats offered annually (which corresponds to only 82 seats per day) is exceeded by most of them.

The most important elements of modelling the economic effects of the upcoming EU-ETS for aviation are the initial allocation of CO_2-emission allowances and the future development of CO_2 allowance prices. The modelling of these elements is explained below.

5.2. Initial allocation of CO_2-emission allowances

The first step in modelling the initial allocation of the upcoming EU-ETS is the calculation of the total amount of emission allowances available to the aviation sector in the first trading period in 2012. The total constitutes 97 % of the average historical aviation emissions from 2004 to 2006:

$$\text{(1)} \quad \text{Total Allowances}_{2012} = 0.97 \times \text{Historical Emissions}_{2004-2006}$$

As 15 % of the total allowances will be auctioned, the number of allowances allocated to the operators free of charge will be calculated as follows:

$$\text{(2)} \quad \text{Free Allowances}_{2012} = 0.85 \times \text{Total Allowances}_{2012}$$

Subsequently, for the calculation of the benchmark, which will be used for the free allocation of allowances to each individual operator in 2012, the total allowances allocated free of charge will be divided by the revenue tonne-kilometres reported for the year 2010:

$$\text{(3)} \quad \text{Benchmark}_{2012} = \frac{\text{Allowances allocated free of charge}_{2012}}{\text{Reported RTK}_{2010}}$$

In compliance with the EU Directive [7], a passenger weight of 100kg and an addition of 95km to the great-circle distance of each flight need to be considered when calculating the reported RTKs.

5.3. Development of the CO_2-emission allowances price until 2020

The prices of EU Allowances (EUAs), certified emission reductions (CERs) from Kyoto-based Clean Development Mechanism projects and emission reduction units (ERUs) from Kyoto-based Joint Implementation projects and the future development of these prices are important factors for the economic impact of the EU-ETS on the aviation sector. Our assumptions on the carbon price in the years 2012 and 2020 are based on findings in relevant literature ([5], [20] and [21]) and on four general thoughts:

1) The carbon price is directly determined by the abatement costs for an additional unit of CO_2. This is because emitters can either abate CO_2 or buy CO_2 permits to comply with their individual reduction target in an ETS. In the course of time, CO_2 abatement in the EU will become more costly due to the tightening of the EU-ETS overall cap. A number of researchers believe that the ambitious target set by the European Commission to reduce CO_2-emissions by 2020 can only be realised by the deployment of CCS coal plants (coal plants that are equipped with carbon capture and storage technology) and renewable energy sources. In the medium term it could become viable at prices of €35/t CO_2 to €40/t CO_2 [20].
2) Also important for the further development of the carbon price is the possibility of 'banking' unused allowances from one trading period to another. Within the EU-ETS, 'banking' of permits from phase two to phase three will be allowed – permitting holders of unused allowances issued in 2008-2012 to carry them over for use up to the year 2020. This possibility of 'banking' will ensure a relatively common EUA price across both trading periods (2008-2020).
3) The inclusion of the aviation sector as well as the aluminium, petrochemical and ammonia industry into the EU-ETS starting from the year 2012 will not raise EUA prices significantly. This was shown by a num-

ber of studies, for instance by [19] and [5]. But the progressively rising level of auctioned allowances and the ambitious overall greenhouse gas cap will lead to rising prices for EUAs until 2020.

4) The prices for CERs and ERUs will mirror the EUA price developments because the prices for these project-based permits are in principle also determined by the factors explained above. Due to a higher risk of non-delivery related to CERs and ERUs (compared to EUAs), CER/ERU prices are currently a bit lower than EUA prices. We believe that this spread between the prices for both kinds of permits, which at present amounts to about 4 €, will persist in the future.

On this basis, we assume price ranges for EUAs and CERs/ERUs for the years 2012 and 2020 as shown in table 3. Taking into account the rather high levels of uncertainty of these future developments, we assume a price spread for each trading period and permit type.

TAB 3. Assumptions on the EUA and CER/ERU price development in the future

Permit type	EUAs		CERs/ERUs	
Trading period	2008-2012	2013-2020	2008-2012	2013-2020
€ per tonne CO_2	25-40	40-55	21-37	37-52

Source: DLR estimation

6. RESULTS

6.1. World-wide transport performance

The modelled CO_2-emissions and the transport performance for flights to and from the European Union are not directly comparable to any publicly available data. However, as our model covers not only flights to and from the EU but the global air transport system, it is possible to compare the results for the world-wide transport performance with statistics published by ICAO. It should be noted, however, that the integrator and all-cargo services considered in our model do not cover all such flights within and between countries outside the EU (see chapter 4.2.1), which are likely to be included in the ICAO statistics. Table 4 compares model results and ICAO data for world-wide scheduled air traffic.

It can be observed that, on a global level, the goodness of fit between modelled transport performance and ICAO data is within a range of 5 %. Generally, it seems that the model overestimates available seat-kilometres (ASK) and revenue passenger-kilometres (RPK) slightly compared to ICAO statistics. The total tonne-kilometres (RTK) calculated are very close to the reference, but given the incomplete coverage of all-cargo flights in our model, this seems to be consistent with the slightly overestimated ASKs and RPKs. Looking at the reference data from another angle, it is also questionable if data published by ICAO can be considered as 100 % accurate. This is because ICAO is dependent on data delivered by its contracting states as well as on data availability. As a result, the quality of ICAO data is likely to be rather heterogeneous.

TAB 4. Comparison of selected model results with ICAO data for world-wide scheduled traffic

Year	Kilometres flown in million (modelled)	Kilometres flown in million (ICAO)	Delta
2004	30,103	29,163	3.2 %
2005	32,362	30,862	4.9 %
2006	33,541	32,137	4.4 %

Year	ASK in billion (modelled)	ASK in billion (ICAO)	Delta
2004	4866.1	4704.7	3.4 %
2005	5209.1	4975.9	4.7 %
2006	5444.1	5197.3	4.7 %

Year	RPK in billion (modelled)	RPK in billion (ICAO)	Delta
2004	3565.3	3445.3	3.5 %
2005	3867.7	3721.7	3.9 %
2006	4107.6	3940.6	4.2 %

Year	RTK in million (modelled)*	RTK in million (ICAO)	Delta
2004	459,598	458,910	0.1 %
2005	500,464	487,860	2.6 %
2006	516,998	514,750	0.4 %
** assuming a passenger weight of 90kg*			

Source: DLR model results; ICAO data from [15] and [2]

6.2. Transport performance and CO_2-emissions for flights to/from the EU & allowances available to aircraft operators

The CO_2-emissions of flights from and to EU airports and the corresponding transport performance are shown in table 5. The average yearly emissions from 2004 to 2006 amount to 183.3 million tonnes. Considering the 'de minimis' clause and subtracting emissions of operators with less than 729 flights per year, the historical CO_2-emissions subject to the EU-ETS are estimated at 180.9 million tonnes. It is worth noting that, through the EU-ETS, roughly one third of global aviation's CO_2-emissions will be subject to a regulation.

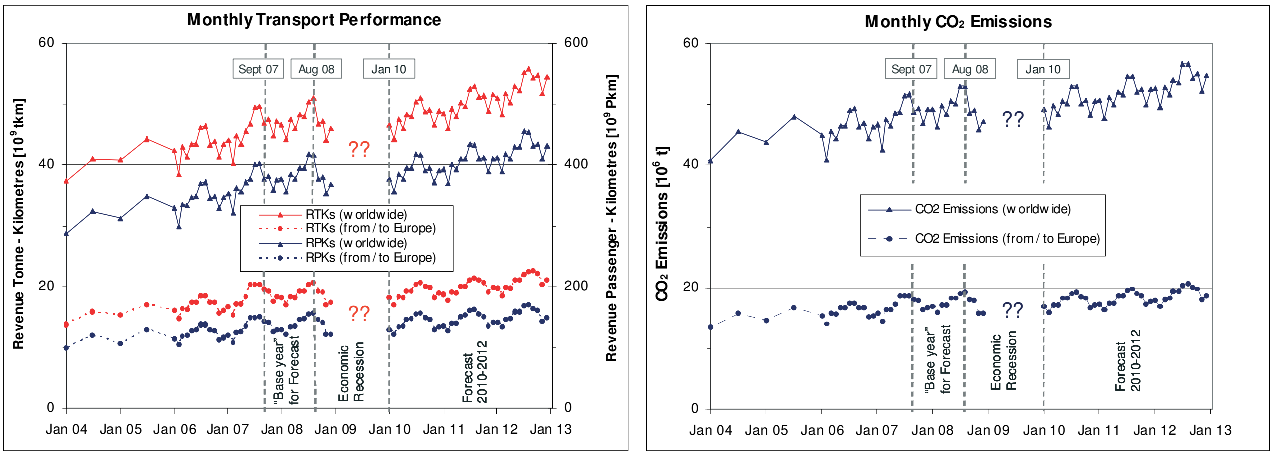
By applying the formulae described in chapter 5.2., the total amount of allowances available to the aviation sector can be calculated. This amount represents the total emissions limitation for the aviation sector, the so-called 'cap'. Given this 'cap', the number of allowances allocated for free and the number of allowances allocated by auctioning can be calculated.

TAB 5. Historical transport performance and CO_2-emissions of flights to/from the EU

Year	RTK in million (modelled)*	CO_2-Emissions in million tonnes (modelled)
2004	175,214	171.5
2005	193,209	185.7
2006	202,600	192.7
** assuming a passenger weight of 90kg*		

Source: DLR model results

FIG 1. Historical and forecasted transport performance and CO_2-emissions (Transport performance assumes a passenger weight of 90kg)



Source: DLR model results based on [22] supplemented by all-cargo services from and to Europe

According to our model, the aviation sector will receive 175.5 million allowances for the emission of CO_2 in the year 2012, since the owner of one allowance has the right to emit one tonne of CO_2. 85% of all allowances, i.e. 149.2 million will be allocated free of charge while the remaining 15% (26.3 million allowances) will be auctioned. Considering the estimated range for the future price of allowances (25 € - 40 €), governments of the EU Member States will receive between 660 million and 1050 million € as a revenue from the auctioning of allowances.

6.3. Benchmark calculation

The calculation of the benchmark applied for the free allocation of allowances in 2012 requires the estimation of the reported tonne-kilometre data for all operators subject to the EU-ETS. For 2010, we estimate the transport performance of all flights from and to EU airports at 229,196 million tonne-kilometres flown (see table 6). This translates into 254,400 million tonne-kilometres according to the reporting standards of the EU-ETS. The difference between these two values is the fixed surcharge of 95 km to each flight's great-circle distance allowing for any route inefficiencies and the uniform assumption of 100 kg per passenger for the conversion of passenger kilometres into tonne-kilometres (see chapter 4.2.3). It becomes obvious that the 95km addition favours airlines operating a large number of relatively short flights, as it significantly increases their reported tonne-kilometres. In contrast, airlines operating a bigger share of relatively long flights will have a disadvantage, as their tonne-kilometres will not increase as much as for operators with shorter flights.

TAB 6. Forecasted transport performance and CO_2-emissions of flights to/from the EU

Year	RTK in million (modelled)*	CO_2-Emissions in million tonnes (modelled)
2008	224,750	208.9
2010	229,196	211.6
2012	251,215	226.4
** assuming a passenger weight of 90kg*		

Source: DLR model results

Carriers which operate less than 729 flights per year in the EU, will not be obligated to participate in the EU-ETS. As a consequence, their transport performance will have to be excluded from the calculation of the benchmark. We identified all carriers for which this exception applies in our forecast and subtracted their RTKs from the tonne-kilometre data described above. In the year 2010, 95 operators with 5,166 million reported tonne-kilometres are to be excluded according to our forecast. This represents approximately 2 % of the total tonne-kilometres of all flights from and to EU airports.

The benchmark, calculated by dividing the amount of freely allocated allowances by the tonne-kilometres reported for the year 2010 is estimated by our model at 0.60 kg CO_2 per RTK.

6.4. Freely allocated allowances vs. emissions in 2012 and acquisition costs for the aviation industry

An important parameter for estimating the costs of the EU-ETS for the aviation sector is the difference between the number of allowances allocated for free and actually needed allowances for the first trading period. By applying the forecasting method described in chapter 4.3, we estimate that the CO_2-emissions of flights to and from airports in the EU will amount to a total of about 226.4 million tonnes in 2012 (see table 6). Considering the 'de minimis' clause and excluding operators with less than 729 flights per year, emissions of 223.6 million tonnes of CO_2 will be subject to the EU-ETS.

With 149.2 million allowances allocated for free (see chapter 6.2), airlines will need to buy allowances for about 74.5 million tonnes of CO_2-emissions. Taking into account the estimated price span of 25 € to 40 € for allowances, the cost for the acquisition of allowances will be between 1.9 and 3.0 billion € for the entire aviation sector subject to the EU-ETS (in 2012). The results also show that CO_2 allowances for about 48.1 million tonnes will have to be purchased by aircraft operators from other sectors, as only 175.5 million new allowances will be available to the aviation sector on the basis of Directive 2008/101/EC.

6.5. Comparison of acquisition costs for different groups of airlines

As the forecast of individual airlines' future emissions is associated with a rather large uncertainty, for the following analysis we focus on groups of airlines, clustered by their geographical origins and business models. According to our assumptions, traffic and emissions of each airline will develop according to the growth rates described in chapter 4.3.

Table 7 shows forecasted CO_2-emissions, the estimated amount of allowances allocated for free and the potential acquisition costs for three groups of airlines. The first group (10 largest EU network carriers) contains the EU-based network carriers with the largest transport performance measured in RTK, i.e. Lufthansa, British Airways, Air France, KLM, Iberia, Virgin Atlantic, Alitalia, SAS, TAP and Finnair. The second group (10 largest non-EU network carriers) consists of Singapore Airlines, American Airlines, Emirates, United Airlines, Delta Air Lines, Cathay Pacific, Continental, Thai, Korean Air and JAL. The third group consists of the ten largest EU-based low cost and charter carriers, which are Ryanair, easyJet, Air Berlin, Condor, LTU, TUIfly, Corsair, Clickair and Vueling.

TAB 7. Comparison of initial allocation, forecasted emissions and acquisition costs for different airline groups

	10 largest EU network carriers	10 largest non-EU network carriers	10 largest EU low cost and charter carriers
Free allocation of EU-allowances in Mt for 2012	60.8	24.0	12.4
Forecasted CO_2-emissions for 2012 in Mt	93.0	31.8	18.4
Percentage of free allocation / required allowances	65.4	75.6	67.5
EU allowances to be acquired in Mt	32.2	7.8	6.0
Acquisition cost for additional allowances (25 € per allowance) in million €	805.3	193.9	149.7
Acquisition cost for additional allowances (40 € per allowance) in million €	1288.5	310.2	239.5

Source: DLR model results

EU-based and non-EU-based network carriers compete quite strongly on the majority of city pairs between Europe and other continents. Our model confirms earlier findings by the authors [24] that EU-based network carriers will be affected by a competitive disadvantage compared to their non-EU-based counterparts: Table 7 shows that the percentage of allowances allocated for free compared to the allowances required for the airlines' operations remains at a significantly lower level for EU-based network carriers than for non-EU carriers. This can be explained by the fact that EU-based carriers operate their feeder network under the ETS, while non-EU-based carriers operate only long-haul flights with comparably lower specific emissions under the ETS. The results also indicate that the addition of 95 km to each mission's great-circle distance according to the reporting standards of the EU-ETS cannot compensate European carriers for the relative inefficiency of their short-haul flights.

The percentage of freely allocated allowances for low cost and charter carriers (LCC) is in between the corresponding percentages for EU-based and non-EU-based network carriers. While most low cost routes are relatively short, such airlines operate at high seat densities, high passenger load factors and with modern aircraft, therefore achieving a relatively high percentage of free allocation. However, as we assume the growth of the LCCs to be in line with overall market growth rates, a higher growth of traffic and emissions could effectively result in a lower percentage of free allocation and, consequently, higher acquisition costs.

7. CONCLUSION

From 2012 onwards, the EU emissions trading system will be applied to the aviation sector and cover virtually all flights departing or arriving in the EU. The initial allocation of emission allowances to airlines will be based on a benchmark which is calculated by dividing historical CO_2-emissions of the airlines participating in the scheme by their transport performance (expressed in revenue tonne-kilometres) of the year 2010. In this paper, we have applied a DLR-developed simulation model. This model is one of the first of its kind capable of simulating the future development of the aviation sector. In particular, it allows for the estimation of the economic impact of the EU-ETS on both the aviation sector in total and on selected groups of airlines. The four main results of our analysis can be summarised as follows:

First, if the EU will be successful in integrating non-EU carriers into the EU-ETS as planned today, a relatively ambitious CO_2 control will be possible: Our results show that roughly one third of global aviation's CO_2-emissions will be subject to the new regulation.

Second, the benchmark, which is the basis of the initial allocation of allowances to aircraft operators, is estimated by our model at 0.60 kg CO_2 per RTK. Apart from very few exceptions, virtually all passenger airlines will need to purchase additional CO_2 allowances for their operations in 2012 and beyond. On average, carriers operating from and to EU airports will have to purchase allowances for about one third of their emissions in 2012.

Third, based on the estimated range of future allowance prices (25-40 € per ton of CO_2), the total cost for the aviation sector is expected to be in the range between 1.9 and 3.0 billion € in the year 2012 alone. As the potential for endogenous emission reduction in the aviation sector is rather low, the airlines will have to buy allowances for about 48.1 million tonnes of CO_2 from stationary sources taking part in the EU-ETS.

Finally, a more detailed analysis of selected airline groups reveals that resulting from the EU-ETS, European network carriers will be affected by a competitive disadvantage compared to non-EU airlines. For EU-based carriers, the percentage of freely allocated allowances compared to the total allowances required will remain below the corresponding level for non-EU carriers. This is because the former operate their feeder network with relatively high specific emissions under the ETS, while the latter operate only long-haul flights to and from Europe. This implies a systematic cost disadvantage for European network operators.

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Aircraft performance data contained herein are based on data drawn from the EUROCONTROL Base of Aircraft Data (BADA). It is to be noted that the aircraft performance models and data contained in BADA have been developed by EUROCONTROL from a set of aircraft operational conditions available to EUROCONTROL. EUROCONTROL has validated BADA aircraft models only for those conditions and can therefore not guarantee the model's accuracy for operating conditions other then the reference conditions.

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