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Giving wings to emission trading

Inclusion of aviation under the European emission trading system (ETS): design and impacts

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Contents

Executive summary

1 Background

Air transport performs many important functions in modern societies. Aviation facilitates economic growth and cultural exchanges and in many regions the industry provides direct employment. However, aviation also contributes to global climate change, and its contribution is increasing. While the EU's total greenhouse gas emissions fell by 5.5% from 1990 to 2003, carbon dioxide emissions alone from the international aviation of the 25 Member States of the European Union increased by 73% in the same period. Even though there have been significant improvements to aircraft technology and operational efficiency this has not been enough to neutralise the effect of increased traffic. Without due policy intervention, the growth in emissions is expected to continue in the coming decades.

The full climate impact of aviation goes beyond the effects of CO_2 emissions, though. Apart from emitting CO_2, aircraft contribute to climate change through the emission of nitrogen oxides (NO_x), which are particularly effective in forming the greenhouse gas ozone when emitted at cruise altitudes. Aircraft also trigger formation of condensation trails, or contrails, and are suspected of enhancing formation of cirrus clouds, both of which add to the overall global warming effect. In 1999 the Intergovernmental Panel on Climate Change (IPCC), examining the total climate impact of aviation, estimated these effects to be about 2 to 4 times greater than those of CO_2 alone, even without considering the potential impact of cirrus cloud enhancement. This means the environmental effectiveness of any mitigation policy will depend on the extent to which these non-CO_2 effects are also taken into account.

A variety of economic instruments such as fuel taxation, emission charges and emissions trading have been proposed to mitigate the climate impacts of aviation. At the European level there have already been studies on an aviation fuel tax and en-route emission charges. In order to complete the existing knowledge base, the European Commission has now taken the initiative of investigating the detailed modalities and impacts of inclusion of aviation in the EU's emissions trading scheme.

2 Objective of the study

The overarching objective of the present project is:

> *To develop concepts for amending Directive 2003/87/EC to address the full climate change impact of aviation through emissions trading.*

This overarching objective has been achieved by securing the following specific goals:

1. To examine the means by which non-CO_2 effects of aviation impact on climate change and the ways in which the 'full climate change impact' of aviation might be captured within the EU emissions trading scheme without undermining the scheme's environmental integrity.
2. To design viable policy options for including aviation in the existing EU Emissions Trading Scheme (EUETS), in particular to propose viable options for:
   a. Scope in terms of geographical coverage and types of flights included.
   b. Allocation and surrendering of allowances.
   c. Monitoring, reporting and verification of data.
3. To assess the qualitative impact of policy options developed for including aviation in the EU ETS.

3 Design of policy options

The study identifies seven key design elements to be addressed if the climate impacts of the international aviation sector are to be included in the EU ETS:

- **Coverage of climate impacts** – besides CO_2 emissions, this refers to whether and by what metrics or instruments the non-CO_2 effects of aviation are to be addressed.
- **Geographical scope** – refers to the geographical coverage of aviation emissions under the trading scheme, i.e. specification of the countries, routes and type of flights/aircraft to be included.
- **Trading entity** – refers to the entities that would be obliged to surrender allowances for emissions generated and be allowed to trade.
- **Decision on allocation rules** – refers to the institutional level (EU or Member State) at which emission targets and methodologies for the distribution of allowances are to be set, i.e. the degree of subsidiarity granted to Member States with regard to the method used for allocating allowances.
- **Interplay with Kyoto Protocol** – refers to the question how aviation can be integrated in the EU ETS, given the separate treatment of this sector under the Kyoto Protocol.
- **Allocation method** – refers to the method to be used for initial distribution of allowances among entities.
- **Monitoring method** – refers to the emission measurement or calculation method to be used and the agency responsible for monitoring and reporting emissions.

Table 1 reviews the main choices to be made with respect to each of these key design elements.

Table 1 Key design elements and associated choices

Key design element	Choices (options)
Coverage of climate impacts	– CO_2 x multiplier to capture full climate impacts – CO_2 plus effect-by-effect approach to account for non-CO_2 impacts – CO_2 only, with flanking instruments (flight procedures, NO_x landing charge and NO_x en-route charge)
Geographical scope	– Intra-EU – Intra-EU routes and 50% of routes to and from EU airports – Emission of all flights departing from EU airports – All emissions in EU airspace – Emission of all flights departing from EU airports plus remaining emissions in EU airspace – Intra-EU and routes to and from third countries that have ratified the Kyoto Protocol
Trading entity	– Aircraft operator – Airport operator – Fuel supplier – Providers of air traffic management – Aircraft manufacturers
Decision on allocation rules	– Amount of aviation allowances defined at EU level and a uniform allocation approach – Amount of allowances set at Member State level and common allocation criteria
Interplay with the Kyoto Protocol	– Extension of the scope of the Kyoto Protocol – Borrowing of AAUs from sectors not covered by the EU ETS – No allocation of allowances to the aviation sector – Obligation to buy allowances for emissions growth above a baseline – Semi-open trading for aviation – Gateway (trade restrictions)
Allocation method (allowance distributing mechanism)	– Grandfathering – Benchmarking – Auctioning – Baseline – No allocation
Monitoring method	– Measured trip fuel by aircraft operators – Calculated emissions by e.g. EUROCONTROL

In order to develop coherent policy options for including aviation in the EU ETS, first the potential advantages and disadvantages of the choices associated with each of the above key design elements were evaluated. Below, the findings and conclusions are presented for each element.

Coverage of climate impacts
This study examined three scenarios by which the 'full climate change impact' of aviation might be captured under the EU ETS without undermining the scheme's environmental integrity:

1 CO_2 × multiplier to capture full climate impacts.
2 CO_2 plus effect-by-effect approach to account for non-CO_2 impacts.
3 CO_2 only, with flanking instruments for non-CO_2 effects.

The main findings and conclusions with regard to these three scenarios are presented below.

Scenario 1: CO_2 × multiplier to capture full climate impacts

The Kyoto Protocol and the EU ETS are based on the principle of emissions being a tradable commodity, so that some measure or 'metric' is required to calculate the degree of equivalence between different gases. In the Kyoto Protocol the Global Warming Potential (GWP) is used for this 'equivalency' and this aspect is mirrored in the EU ETS. The key question is then which metric is a suitable candidate for incorporating the non-CO_2 climate impacts of aviation in a single metric that can be used as a multiplier.

This study shows that it is not feasible to calculate GWPs for the complete suite of aviation impacts, particularly contrails and aerosols, and that there are conceptual difficulties associated with calculating GWPs for aircraft NO_x induced ozone. Because of this, there is no direct equivalency between GWPs and *all* radiative forcings due to aviation. The use of the radiative forcing index (RFI) in the EU emissions trading scheme as a multiplier for *emissions* is shown to be unsuitable, as it does not take future effects into account the way a GWP does. A newer metric, the Global Temperature Potential (GTP), has been shown to be closer to GWP. The GTP was examined in more detail and a derivative metric demonstrated here – an analogue of the RFI, coined the Global Temperature Index (GTI) – was shown to be a potentially suitable future candidate for a metric compatible with GWP. Instead of the individual forcings being summed and calculated as a ratio to CO_2 forcing, as in the RFI, in the GTI the resultant temperatures are calculated. The result was a GTI of approximately 2 with a range from 1.5 to 3. Overall, it is felt that the GTI will require more work before this approach has sufficiently matured. However, using the GTI metric to reflect non-CO_2 effects may be feasible within the next few years. It should be borne in mind that it is inherent in a multiplier scenario that CO_2 optimisation will be strengthened, with no specific incentives to address individual non-CO_2 climate impacts. Overall, a multiplier approach could not yet at present be based on an accurate scientific methodology but would have to be justified on the basis of the precautionary principle.

Scenario 2: separate climate effects on an individual flight basis

The aim of this scenario was to examine whether the individual non-CO_2 effects of aviation could be addressed using different metrics that might be compatible with the GWP under an emissions trading scheme. In general, the approach taken was to consider individual flights. It is shown that a flight-based approach to account for non-CO_2 effects requires sophisticated atmospheric modelling to account for ozone/methane changes due to NO_x emissions and contrails/cirrus. Models able to compute ozone/methane are still in the research domain and it is not possible to recommend one over another. Different models also yield different results, introducing another source of uncertainty into this approach. There is the added difficulty, moreover, that aircraft impact depends on background conditions and these conditions – and the ultimate effect – are time- and space-dependent. If it were hypothetically possible to agree on a model and it was accepted that globally aggregated emissions lead to a certain global ozone production rate, then under such broad assumptions it might be reasonable to disaggregate an ozone (mass) production rate per unit mass NO_x. However, to take such disaggregation to the next level of radiative forcing and disaggregate to individual flights, additional assumptions would have to be made that are hard to justify. Moreover, the coupling of NO_x with methane and ozone chemistry makes this very complicated. For contrails, similar difficulties arise in that the models are still in the research domain and there are uncertainties in the calculation of both contrail coverage and radiative effect. Again, to attribute an effect down to the level of individual flights is not currently feasible in any robust manner. It is in principle possible to formulate a GWP for ozone from NO_x but this is a contentious issue, debated vigorously in the literature; for contrails, it is not possible to derive a GWP, since a contrail cannot readily be related to a mass emission. Therefore, this scenario cannot be recommended.

Scenario 3: CO_2 only, with flanking instruments for non-CO_2 effects

Basically, the main question to be investigated here is whether flanking instruments could mitigate the non-CO_2 impacts of aviation effectively and possibly more efficiently if these are not covered by an emissions trading scheme. Possible flanking instruments that might be considered are:

- Flight procedures to prevent contrail and enhanced cirrus formation.
- Continued NO_x LTO stringency through ICAO.
- An NO_x cruise certification regime under ICAO.
- NO_x-based landing charges at all EU airports.
- An NO_x en-route charge.

The following conclusions were drawn. In general, flanking instruments may be an attractive way of mitigating non-CO_2 climate impacts, as they need not be explicitly compatible with the EU emissions trading scheme.

The science of contrail and enhanced cirrus cloud formation was considered to be currently too immature for implementation in a regulatory/control regime, i.e. for a flight routing mechanism incorporated in air traffic management. Of the various NO_x options, reliance alone on continued ICAO LTO NO_x certification was deemed unsuitable because of its inherent allowance for higher NO_x emission indices with higher OPR engines and because the process of agreeing LTO NO_x certification standards has complex international dependencies. ICAO cruise certification was also rejected, as it has similar international dependencies and may be a decade or so away from agreement and implementation, moreover. Alternatively, a NO_x-based landing charge was assessed to be a suitable flanking instrument, the general expectation within the sector being that a reduction of NO_x LTO emissions will also reduce NO_x cruise emissions. Furthermore, NO_x-based landing charges can be based on a straightforward metric: kg NO_x/LTO. As an added benefit, NO_x landing charges might have a positive effect on local air quality. NO_x en route charges are also considered to be feasible and probably effective to reduce overall NO_x emissions of aircraft operations. However, the sensitive issue is then: who is to receive the money generated by a NO_x en-route charge?

Geographical scope

In relation to geographical coverage several scenarios were considered in the study, specifying different sets of countries and routes for inclusion in the scheme, as follows:

– Scenario 1: Intra-EU routes.
– Scenario 2a: Intra-EU and 50% of emissions on routes to and from EU airports.
– Scenario 2b: Emissions of all flights departing from EU airports.
– Scenario 3: All emissions in EU airspace[1].
– Scenario 4: Emissions of all flights departing from EU airports plus remaining emissions in EU airspace.
– Scenario 5: Intra-EU and routes to and from third countries that have ratified the Kyoto Protocol.

Scenario 1 (intra-EU) can essentially be considered as a base-case option. Scenario 4 is a combination of the route-based scenario 2b and the airspace-based scenario 3. Table 2 shows the aviation CO_2 emissions addressed under the five scenarios for geographical scope in the year 2004. For comparison, the overall quantity of allowances allocated under the present EU ETS of the 25 EU Member States in the period 2005-2007 are also given. For the first trading period (2005-2007) the 25 Member States have been allocated approximately 2,200 Megatonne CO_2 emissions per year. As Table 2 shows, for the year 2004 the CO_2 emissions covered under the various aviation scenarios are between 2.4% and 7.7% of this amount. It should be noted that the climate impacts of aviation as a share of the total impact of all sectors under the geographical scope would increase significantly if non-CO_2 climate effects from all sectors were also taken into account.

Table 2 Comparison of CO_2 emissions under present EU Emission Trading Scheme and aviation CO_2 emissions covered by various geographical scenarios

	CO_2 emissions in million kg in 2004	% of present CO_2 emissions in ETS
CO_2 emissions under present Emission Trading Scheme (2005-2007)		
Allocated CO_2 emissions	2.200.000	100.0%
Geographical scenarios for aviation emissions (2004)		
1 Intra-EU	51,875	*2.4%*
2a Intra-EU +50% routes to/from EU	130,287	*5.9%*
2b Departing from EU	130,403	*5.9%*
3 Emission in EU airspace	114,337	*5.2%*
4 Departing from EU + EU airspace	161,988	*7.4%*
5 Intra-EU and routes to/from other KP states	72,449	*3.3%*

[1] In this study the EU airspace is defined on the basis of the Flight Information Regions (FIR) of the EU Member States as employed by EUROCONTROL and officially agreed on with ICAO. The FIRs employed by EUROCONTROL encompass not only the national territories of individual countries, but may also include particular areas of seas and oceans. For all intra-EU routes it is assumed that the full route length is covered, also if the airspace of non-EU States is used.

This study examined whether there are any legal obstacles to the geographical scenarios considered. As was soon apparent, emissions trading is not addressed by the instruments of current international aviation law. Therefore, the main conclusion with regard to legal feasibility is that international provisions such as the Chicago Convention and bilateral agreements contain no obstacles to including aviation's climate change impact in the EU ETS. This conclusion is in respect of the inclusion of all aircraft, irrespective of ownership or country of registration, within the scope of the options that are considered in this study.

Trading entity

Aircraft operators appear to be the most suitable entity for surrendering allowances in the EU ETS. This option provides the best guarantee of achieving the most effective and efficient incentives for emissions reduction, as it is aircraft operators that have greatest control over abatement measures and have easy access to detailed monitoring data.

All the other options for trading entities have one or more decisive disadvantages that led them to be rejected as inferior.

Decision on allocation rules

One of the pivotal issues of an emissions trading scheme is the level – EU or Member State – at which the total amount of allowances is to be decided and the rules according to which allowances are to be allocated among the entities covered. In essence, this task comprises decisions on whether and eventually how to distribute allowances.

As in the case of emissions trading for stationary sources, central decisions should be taken at the EU level. For example, Annex III of the emissions trading Directive (2003/87/EC) sets out 11 criteria which Member States must adhere to when drawing up their national allocation plan. Exactly how allowances are to be distributed among the emissions trading sector can then be decided by Member States under their own plan, which are then scrutinised by the Commission against these 11 allocation criteria. Accordingly, Member States have some scope for subsidiarity in their allocation decisions. This degree of subsidiarity may be considered an advantage. Member States can duly consider any specifics regarding the situation of the aviation sector within their country and alter their allocation formula accordingly, to the extent that an unfair advantage is not granted to the aviation sector vis-à-vis other sectors of that economy.

The present study, however, identified two convincing arguments for defining the amount of allowances at the EU level and employing identical allowance distribution rules for all regulated entities in the aviation sector:

- *International aviation is not included in the EU's Burden Sharing agreement*
  An important reason for allowing a degree of subsidiarity as to the quantity of allowances to be distributed to stationary sources was the Burden Sharing agreement, which established different emission reduction targets for each Member State. As international aviation is not covered by this agreement, no such barrier to harmonised allocation exists for this sector.
- *Prevention of competitive distortions and administrative costs*
  A uniform EU allocation method would prevent competitive distortions, as all the entities covered would be allocated allowances according to exactly the

same rules. For Member States it might also reduce the administrative costs associated with allocation decisions.

Interplay with the Kyoto Protocol

In contrast to domestic aviation emissions, greenhouse gas emissions from fuel consumption in international aviation are not assigned under the Kyoto Protocol and are consequently not the subject of so-called Assigned Amount Units (AAUs) – at least not during the first commitment period from 2008 to 2012. In addition, the non-CO_2 climate effects, which are not related to fuel burn, from both domestic and international aviation are not covered under the Kyoto Protocol and therefore not covered by AAUs. The quantity of AAUs is based on the commitments laid down in Annex B of the Protocol and specifies a country's permitted greenhouse gas emissions during the first commitment period. These are measured in tonnes of CO_2 equivalent (tCO_2e).

Including international aviation in the EU ETS may create accounting problems in the system and under the Kyoto Protocol unless specific design features are introduced to counteract any disparities between the quantity of emissions covered by the Kyoto Protocol which is in fact emitted and the quantity of Kyoto units which are retired for compliance purposes to cover these emissions. These accounting problems arise because the emissions of international aviation are not underpinned by the AAUs used for compliance control under the Kyoto Protocol, as explained above[2]. The most obvious problem case is where there is a net flow of tradable units from the aviation sector to sectors covered both by the EU ETS and by AAUs under the Kyoto Protocol.

This study identified and assessed several options for avoiding these problems:

1 *Extension of the scope of the Kyoto Protocol*
Repeal of the exemption of aviation from quantitative obligations.

2 *Borrowing of AAUs from sectors not covered by the EU ETS*
AAUs from sectors not covered by the EU ETS will be used temporarily to underpin any allowances issued for international aviation emissions under the geographical scope with AAUs. Correspondingly, aviation entities are allocated allowances that are fully fungible, i.e. the aviation sector can buy and sell allowances from and to other sectors under the EU ETS without any trade restrictions. Since all allowances will be surrendered at the end of the commitment period, the attached AAUs are only “loaned” to the aviation sector.

3 *No allocation of allowances to the aviation sector*
The aviation sector must buy all the allowances required for compliance from other sectors, with no additional allowances being granted to aviation. Emissions trading in aviation is based on allowances from the EU ETS and Kyoto units only.

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2 EU Allowances (EUAs) can be used for compliance under the EU ETS (Directive 2003/87/EC). AAUs are for compliance under the Kyoto Protocol. The registries for the EU ETS serve at the same time as registries under the Kyoto Protocol. Correspondingly, they contain all AAUs allocated to a country under the protocol, some of them earmarked as EUAs.

4 *Obligation to buy allowances for emissions growth above a baseline*
This option is similar to the previous one, but limits the obligation to surrender allowances to those for emissions growth relative to a base year or base period (baseline).

5 *Semi-open trading for aviation*
Aviation entities are allocated allowances. They can buy additional allowances from non-aviation sectors, but cannot not sell surplus allowances to these entities.

6 *Gateway (trade restrictions)*
Aviation entities are allocated allowances. They can buy additional allowances from non-aviation sectors, but can only sell to other sectors as many allowances as they, as a sector as a whole, have already bought from non-aviation sectors during the trading period.

The first option would avoid any trade restrictions, as AAUs would be created for international aviation as well. However, it is unlikely that international agreement on the incorporation of international aviation into the quantitative targets of the Kyoto Protocol would be realised in advance of the first commitment period of from 2008 to 2012. Consequently, at least up until 2013, this option is regarded as unfeasible for including aviation in the EU ETS.

Option two would also avoid any trade restrictions as AAUs are used from sectors not participating under the EU ETS. However, this option requires a clearing house mechanism for optimal registry purposes and a mechanism should be agreed on with all Member States for the event that not all borrowed AAUs are given back at the end of the commitment period. This situation may occur if there is a net flow of tradable units from the aviation sector to other sectors covered by the EU ETS.

As most of the emissions and effects of aviation are not underpinned by AAUs, all other options are designed to ensure continued integrity of the EU ETS. This implies either that no EU allowances are allocated to the aviation sector (options 3 and 4) or that trade restrictions are set (option 5 and 6).

If the aviation sector has high marginal abatement costs compared to other sectors, as is generally assumed, and in the absence of over-generous allocation of allowances, aviation would be a net buyer of allowances. Correspondingly, on these assumptions, bringing aviation into the EU ETS would result in additional demand for allowances on the EU ETS market. This implies that it is to be expected that the special design features under options 2 to 6 (e.g. closing of the Gateway), required in the case of net selling by the aviation sector, may not be 'switched on'.

Allocation method

Auctioning appears to be the most attractive option for allocation. From an economic angle it is to be considered the most efficient option. Other important advantages are the achievement of simplicity regarding the equal treatment of new entrants compared with existing operators and crediting for early action, and the lower administrative burden associated with data requirements. There is also a significant degree of flexibility regarding the extent to which auction revenues are recycled.

A second-best option would be to start off with benchmarked initial allocation. In general, it is felt that benchmarking is to be preferred over a grandfathering approach, the latter being less favourable to new entrants and those companies that already operated relatively energy-efficient aircraft in the baseline year.

Monitoring method

To establish monitoring and reporting protocols, emission inventory activities could rely either on self-reporting by participants or on third parties such as EUROCONTROL. The most accurate monitoring option for CO_2 is for aircraft operators to measure the actual fuel used on each trip flown within the chosen geographical scope of the emission trading system. CO_2 emissions can then be calculated from the carbon content of that fuel. Under current international regulations, the amount of fuel used on each flight must already be registered by airlines.

The environmental effectiveness of the emissions trading system would certainly benefit if actual trip fuel were used, as would its economic efficiency, for operational measures to reduce emissions would be duly rewarded. The European airline industry and their association have expressed their preference for a monitoring and reporting method based on actual trip fuel, reported by aircraft operators. They regard this as feasible and fairly straightforward to implement.

Selection of three policy options

Based on the assessment of the pros and cons of the individual key design elements cited above, three policy options were selected for further examination (see Table 3). The configuration of the options was based on the wish for coverage of each of the main feasible choices per key design element, for consistent combinations of the design variables and for comparable environmental impacts. Note, however, that none of these is necessarily 'the optimum', even though the results of the evaluation below may show one option to be less attractive than another because of a sub-optimum combination of key design elements.

Table 3 Overview of the three selected policy options for including aviation in the EU ETS

Design element	Option 1	Option 2	Option 3
Coverage of climate impacts	CO_2 and multiplier for non-CO_2 climate impacts	CO_2 only (with flanking instruments for other impacts)	CO_2 only (with flanking instruments for other impacts)
Geographical scope	Intra-EU	Emissions of departing flights from EU airports	EU airspace
Trading entity	Aircraft operator	Aircraft operator	Aircraft operator
Decision on allocation rules	Uniform approach set at EU level	Uniform approach set at EU level	Uniform approach set at EU level
Interplay with Kyoto Protocol	Aviation buys allowances from other sectors above a historic baseline	Unrestricted trading based on AAUs borrowed from other sectors	Trading with other sectors based on a gateway mechanism
Allocation method	Baseline	Benchmarked allocation	Auctioning
Monitoring method	Actual trip fuel reported by aircraft operator	Actual trip fuel reported by aircraft operator	EUROCONTROL data (*ex ante* and radar)

4 Impacts on operating costs and ticket prices

As the future price of allowances cannot be forecast with any great precision, a range of € 10 to € 30 per tonne CO_2 equivalent was assumed to gain an idea of the potential impact on operational costs and ticket prices. This range was assumed for both the price of allowances on the EU ETS market and the auction price under Option 3. The impacts are calculated for the year 2012. The impacts are shown by comparing the Business as Usual (BaU) situation in 2012 with a situation where one of the 3 policy options is implemented[3].

3 A quantitative impact analysis has been carried out for 2012, using 2008 emission levels as a historical baseline. Under Option 1, aviation has to buy allowances for all emissions above this baseline. Under Options 2 and 3, the total amount of emissions grandfathered or auctioned, respectively, to aircraft operators is assumed equal to the 2008 emissions level.

Table 4 Initial impact on aircraft operating costs and ticket prices in 2012 (in € per return flight) assuming an allowance price range of € 10 to € 30 per tonne CO_2

Aircraft operating costs	Option 1	Option 2	Option 3
Short haul	47 – 140	23 – 70	160 – 481
Medium haul	92 – 275	46 – 138	316 – 948
Long haul	0	228 - 684	546 – 1,638
Ticket prices	Option 1	Option 2	Option 3
Short haul	0.4 - 1.3	0.2 - 0.7	1.5 - 4.6
Medium haul	0.9 - 2.6	0.4 - 1.3	3.0 - 9.0
Long haul	0	1.0 - 2.9	2.3 – 6.9

Note: Figures indicate expected increase in aircraft operating costs and ticket prices in 2012, based on a load factor of 70% for a round trip. Costs due to inclusion of the multiplier in Option 1 are included, additional costs of flanking instruments are not. It is assumed that opportunity costs of 'grandfathered allowances' are not passed on in the ticket prices under Options 1 and 2. The first figure is the increase at an allowance price of € 10 per tonne CO_2, the second at an allowance price of € 30 per tonne.

Under Option 2, *ticket price* increases range from about € 0.20 (for a short-haul flight and an allowance price of € 10 per tonne) to € 2.9 (for a long-haul flight and an allowance price of € 30). Owing to the multiplier, price increases under Option 1 are twice as large for short- and medium-haul flights. The long-haul flight is not intra-EU and does not fall under the scheme in Option 1. Ticket price increases under Option 3 range from € 1.5 to € 9.0 for a round trip.

The impact on ticket prices is relatively small, for several reasons. In the first place, under Options 1 and 2 the only financial costs borne by aircraft operators are those associated with emissions growth. These costs are expected to be spread out over all tickets for flights falling under the scheme, however. Increases under Option 3 are generally greater because of the auctioning of allowances. As Option 3 is based on EU airspace, however, only a small portion of long-haul flights is subject to the scheme.

Furthermore, calculations are based on the assumption that the opportunity costs of allowances issued free of charge are not passed on to customers. If these opportunity costs were passed on *in toto*, the ticket prices increases under Options 1 and 2 would be about 7 times greater[4]. It should be borne in mind that passing on opportunity costs to customers would raise ticket prices, but it would also generate so-called windfall profits for aircraft operators by the same amount per ticket. I.e. inclusion of opportunity costs will not increase total costs of aircraft operators, since such an increase in ticket prices would not reflect a rise in actual operational costs for aircraft operators.

Since opportunity costs play no role in Option 3, the results for this option are not influenced by this assumption.

[4] Assuming a reference scenario of 4% growth of air transport CO_2 emissions annually, emissions in 2012 will be about 17% higher than baseline emissions in 2008. This growth amounts to 14.5% of 2012 aviation emissions. Consequently, under Options 1 and 2, financial costs are related to about 14.5% of emissions in 2012. Relating costs to the other 85.5% would lead to 1/0.145 = about 7 times higher costs.

5 Environmental impacts

Table 5 below summarises the total absolute CO_2 emission reduction impacts of the three policy options compared with emissions in the Business as Usual (BaU) scenario in 2012. It should be borne in mind that each policy option is based on different scenarios of geographical scope. For example, assuming an allowance price of € 10 per tonne, Option 1 would reduce CO_2 emissions by about 20 Mt of total intra-EU CO_2 aviation emissions in the BaU scenario (71 Mt), while Options 2 and 3 would reduce CO_2 emissions by 25.9 Mt of all emissions of flights departing from the EU (178.5 Mt) and 22.7 Mt of all emissions in EU airspace (156.5 Mt), respectively.

Table 5 Absolute and proportional CO_2 emission reduction of the three policy options in 2012 compared to BaU scenario in 2012 based on AERO-MS

	Option 1	Option 2	Option 3
BaU emissions in 2012	71 Mt	178.5 Mt	156.5 Mt
Baseline emissions 2008	60.7 Mt	152.6 Mt	133.8 Mt
Allowance price: €10 per tonne CO_2 eq.[5]			
Total reduction of CO_2 eq., *of which*:	20.3 Mt[6]	25.9 Mt	22.7 Mt
– Reduced within the aviation sector – Purchased from other sectors	0.3 Mt 19.9 Mt	1.1 Mt 24.8 Mt	2.0 Mt 20.7 Mt
Allowance price: €30 per tonne CO_2 eq.			
Total reduction of CO_2 eq., *of which:*	20 Mt	25.9 Mt	22.7 Mt
– Reduced within the aviation sector – Purchased from other sectors	0.7 Mt 19.3 Mt	3.2 Mt 22.7 Mt	5.6 Mt 17.1 Mt

The estimated CO_2 emission reduction impacts of all three Options up to 2012 assume that most of the cheapest emission reductions are available from non-aviation sectors covered by the EU ETS, who then sell their surplus allowances to the aviation sector.

In the medium term (about 5 years), the bulk of reductions *in* the aviation sector is due to reduced demand for air transport compared to the BaU scenario. In the longer run, about half the reductions *within* the aviation sector may be attributable to supply-side responses by airlines (technical and operational measures), mirrored through the purchase of somewhat fewer allowances from other sectors. Obviously, at an allowance price of € 30 supply-side responses may increase significantly as more of the abatement measures available to the aviation sector become cost-effective.

5 The term CO_2 *equivalent* applies here because some of the allowances bought from other sectors may be based on emission reductions of other gases covered by the Kyoto Protocol (e.g. methane, F-gases) which are achieved under the EU ETS in other sectors.

6 The total reduction of CO_2 equivalents under Option 1 is not equal to the growth of emissions in the aviation sector between 2008 and 2012. This is due to the multiplier of 2, assumed to capture the full climate impact of aviation. Because of the multiplier, for each additional emission unit two allowances will have to be purchased from other sectors. The amounts of reduction within the aviation sector are presented without the multiplication factor. If the allowance price is higher, the reduction within the sector will be larger and the overall reduction smaller, because the multiplier affects less allowances.

The three Options do differ significantly in their environmental effectiveness. This depends on the incentive 'at the margin' (i.e. the change in an aircraft operator's marginal costs associated with production of one extra tonne of CO_2) and on the amount of emissions for which allowances must be surrendered. This amount influences the financial incentive for the aviation sector, since it is these emissions that are associated with costs, either effective or opportunity. It depends on the choices made regarding three key design elements.

- **Coverage of climate impacts**. If a multiplier were applied to CO_2 emissions to account for non-CO_2 impacts, the strength of the incentive would be proportional to the multiplier. With a multiplier of two, for example, the incentive created in Option 1 would be twice as great as in Option 2. Clearly, flanking instruments would provide incentives of their own, possibly reinforcing the incentives provided by the EU ETS for CO_2 emissions.
- **Geographical scope**. The strength of the incentive to the aviation sector depends on the geographical scope of the option. If more routes are included, environmental effectiveness will increase. Moreover, the greater the share of a route, the stronger the incentive, which will rise in direct proportion to the CO_2 emissions falling under the scheme. In addition, options with a limited scope, such as Intra-EU (Option 1) and to a lesser extent EU airspace (Option 3), benefit long-haul more than short-haul flights, as only the latter are (fully) covered by the scheme.
- **Allocation method**. Although the strength of the incentive for operators does not depend on whether allowances are grandfathered or auctioned[7], it does depend on the amount of emissions for which allowances must be surrendered. Option 1 differs from a standard baseline and credit system, because aircraft operators are accountable only for emissions above their historic baseline. The scheme therefore provides no incentives for reductions beyond this baseline.

Potential trade-offs of CO_2 optimisation

The crucial question with a CO_2-only scheme is whether it will lead to any *negative* trade-offs. This is an extremely difficult issue to evaluate, because of its speculative nature and also for lack of technological documentation in the public domain.

CO_2 - NO_x

This study indicates that emission trading based on CO_2 only (with potentially a multiplier covering the non-CO_2 effects) would not adversely impact NO_x emissions overall. In the medium term, at constant engine technology level, overall fleet reductions in CO_2 that might arise from emissions trading go more or less hand in hand with NO_x emissions reductions. This is because in the short and medium term, the total amount of fuel used by all air traffic in Europe can to a large extent only be reduced by fuel efficiency measures that also reduce NO_x, such as operational measures (network, load factor, speed, climb angle, etc.) and any reduced demand for air transport.

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7 In either case it pays to reduce emissions, either by being able to sell allowances or by having to purchase fewer allowances.

In the longer term, it is more uncertain whether CO_2 optimisation would also reduce overall NO_x. The NO_x emissions index (NO_x emissions per unit fuel) might increase *faster* if aviation were incorporated in the European Emissions Trading Scheme on a CO_2-only basis. In other words, the EI NO_x of the aircraft fleet might increase compared with a Business as Usual scenario owing to the higher combustor temperatures and pressures resulting from technological innovations to increase the fuel efficiency of gas turbine engines. However, although it is uncertain, an *additional* EI NO_x increase is expected to be offset by other measures aimed at increased fuel efficiency such as operational measures, demand effects and airframe innovations (e.g. weight reduction). Moreover, there is a European commitment (ACARE) to improve NO_x performance (bearing in mind that not all aircraft flying in Europe have European-manufactured engines/airframes).
Based on the above findings, we conclude that a CO_2-only based scheme will most probably reduce both CO_2 and NO_x emissions in the shorter term and longer term, but that the uncertainties of the impact in the longer term suggest that a precautionary approach to NO_x emissions is appropriate.

CO_2 - contrails
Whilst environmental conditions of ice supersaturation and temperature are the primary determinants of whether a persistent contrail is formed, it has been reported that more modern technology has a higher propensity to cause contrails because of a cooler exhaust, causing contrails over a greater depth of the atmosphere than was the case with older technology. Based on assumptions regarding the likely increase in propulsive efficiency (η), this trend is expected to continue in the future. This effect and whether it will increase over a BAU situation (like NO_x) is rather speculative. However, that there is an effect of more modern engines has been shown from observations and theoretical calculations. If the pressure on fuel efficiency increases as a result of incorporating aviation in the ETS, then η will also increase, with a consequent impact on contrail production. As an indication of the potential of this effect, sensitivity calculations from the literature suggest that an η of 0.5 in 2050 will result in 20% greater contrail coverage than an approximate estimate of the 1990's η of 0.3. It is uncertain, however, whether this trend will increase faster if aviation were incorporated in the EU ETS.

6 Economic impacts

Impacts on the competitive position of EU carriers
Besides examining general economic impacts, this study also looked specifically at potential economic distortions. Of particular concern in this respect would be effects on competition between EU and non-EU carriers. The main conclusion is that none of the policy options considered in this study will significantly damage the competitive position of EU airlines relative to non-EU airlines. This conclusion is based on the following arguments:

- Foremost, none of the options considered differentiate with respect to nationality of the aircraft operator or type of operation. All commercial aircraft flying on a route falling under the scheme are subject to it. This means that

European and non-European airlines receive equal treatment under all the proposed policy options for including aviation in the EU ETS. This is not the case for other sectors already covered by the EU ETS. Most of their competitors based outside the EU do not face similar cost increases. as they are obviously not covered by the EU emissions trading scheme.

- Furthermore, this study shows that the impact on the size of the home market is too small to have substantial effects on the operating efficiency of EU carriers. It is sometimes argued that the competitive position of carriers might also be affected by changes in the size of their home market. Obviously, one second-order effect of including aviation in the ETS might be somewhat lower growth of the European air transport market due to increased air fares. meaning that over time there might be an effect on European carriers' economies of scale. However, this study shows that an allowance price range from € 10 to € 30 per tonne CO_2 would decrease air transport volume in the short term on the EU market by 0.1% to 0.2% under Option 1, by 0.1% to 0.4% under Option 2 and by 0.5% to 1.4% under Option 3. Based on this relatively small impact on market size, we conclude with regard to the home market argument that introduction of none of the three policy options would affect the operating efficiency of EU carriers significantly compared with non-EU carriers. These figures are average impacts for the sector as a whole and may differ for individual aircraft operators.
- Most non-EU carriers will be affected by inclusion of aviation in the EU ETS on a relatively small proportion of their flights compared to EU aircraft operators. The response of non-EU carriers might be to deploy their newest and cleanest aircraft on routes falling under the scheme, diverting older and less fuel efficient aircraft to other routes. This may give non-EU carriers a competitive advantage over EU carriers. However, this effect may in practice be limited by other constraints and commercial considerations that play into fleet management and deployment strategies.

To bring things into perspective, although aviation is an international business, it is less vulnerable to economic distortions than other sectors of the EU economy. This is for two reasons. First, the 'product' in the aviation industry, transportation, is by definition geographically bounded (to a major extent), with passengers and freight having relatively fixed origins and in many situations also relatively fixed destinations. An increase in the cost of European flights will not make a Frenchman with business in Denmark buy a ticket to America instead, and any air carrier operating between e.g. Paris and Copenhagen will be subject to exactly the same competitive conditions. In comparison, many other products would appear to be more vulnerable, as the only relevant aspect here regarding their purchase and use anywhere in the world is the cost associated with production of the product and transportation to its place of use. A second reason is that the air transport market is highly regulated by bilateral air service agreements that limit competition from airlines outside the EU.

Marginal impact on the EU ETS and the allowance price

Table 6 shows that under all three policy options aviation would buy about 1% of the allowances available under the present EU Emissions Trading Scheme in the year 2012. It should be stressed that this percentage would be even lower if markets for emission reduction credits (JI and CDM) were also taken into account. A certain additional supply of CERs from a few big additional CDM projects may easily absorb the relatively small additional demand from aviation. In all three Options we therefore expect no significant rise in the allowance price in the short term if aviation were included in the EU ETS.

Table 6 Absolute and relative amount of allowances bought by the aviation sector from the EU ETS in 2012

	Allowances (in million tonne)	% of present allowances in ETS
Allowances for CO_2 emissions under present Emission Trading System (2005-2007)		
Allocated CO_2 emissions	2,200 Mt	100.0%
Allowances bought by aviation from other sectors (2012)		
Allowance price: € 10 per tonne		
Option 1	20.0 Mt	0.9%
Option 2	24.8 Mt	1.1%
Option 3	20.7 Mt	0.9%
Allowance price: € 30 per tonne		
Option 1	19.3 Mt	0.9%
Option 2	22.7 Mt	1.0%
Option 3	17.1 Mt	0.8%

In the long run, if any option is introduced for more than one commitment period, continued growth of aviation might cause the allowance price to rise. The extent to which including international aviation in the EU ETS could, in the long term, cause the allowance price to rise faster than would have otherwise been the case depends on many factors influencing the demand and supply side of the international carbon markets, not least the marginal abatement cost curves of other sectors of the economy.

7 Overall conclusion

This study examined the feasibility of including international aviation in the EU Emissions Trading Scheme in order to mitigate the climate impacts of this sector by encouraging airlines to integrate reduction of those climate impacts into their business objectives. The introduction of emissions trading for the aviation sector, most immediately in respect of its CO_2 emissions, while keeping the structure open for including non-CO_2 impacts in the future, does not appear to pose many challenges that have not already arisen in the context of the existing EU Emissions Trading Scheme. This suggests that emissions trading is a policy option that can be considered alongside other policy instruments to tackle the climate impact of aviation.

1 Introduction

1.1 Background

Air transport performs many important functions in modern societies. Aviation facilitates economic growth and cultural exchanges and the industry directly provides employment in many regions. However, aviation also contributes to global climate change, and its contribution is increasing. While the EU's total greenhouse gas emissions fell by 5.5% from 1990 to 2003[8], carbon dioxide emissions alone from international aviation of the 25 Member States of the European Union have increased by 73% in the same period [EEA, 2005]. Even though there have been significant improvements to aircraft technology and operational efficiency this has not been enough to neutralise the effect of increased traffic. Without due policy intervention, the growth of global aviation CO_2 emissions is expected to double in the coming decades[9].

The full climate impact of aviation goes beyond the effects of CO_2 emissions, though. Apart from emitting CO_2, aircraft contribute to climate change through the emission of nitrogen oxides (NO_x), which are particularly effective in forming the greenhouse gas ozone when emitted at cruise altitudes. Aircraft also trigger formation of condensation trails, or contrails, and are suspected of enhancing formation of cirrus clouds, both of which add to the overall global warming effect. In 1999 the Intergovernmental Panel on Climate Change (IPCC), examining the total climate impact of aviation, estimated these effects to be about 2 to 4 times greater than those of CO_2 alone, even without considering the potential impact of cirrus cloud enhancement. This means the environmental effectiveness of any mitigation policy will depend on the extent to which these non-CO_2 effects are also taken into account.

A variety of economic instruments such as fuel taxation, emission charges and emission trading have been proposed to mitigate the climate impacts of aviation. At the European level there have already been studies on an aviation fuel tax and en-route emission charges. In order to complete the existing knowledge base, the European Commission has now taken the initiative of investigating the detailed modalities and impacts of inclusion of aviation in the EU's emission trading scheme.

This report has been prepared jointly by CE Delft (leading contract partner), the Centre for Aviation, Transport and the Environment (CATE) of Manchester Metropolitan University, the Oeko-Institute in Germany and, as legal advisor to the team, the Institute of International Air and Space Law, Leiden.

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[8] Annual European Community greenhouse gas inventory 1990-2003 and inventory report 2005, Technical report No 4/2005, European Environment Agency.

[9] AERO2K Global aviations emissions inventories for 2002 and 2025 [Eyers, et al., 2004].

1.2 Objective of the study

The overarching objective of the proposed project is:

To develop concepts for amending Directive 2003/87/EC to address the full climate change impact of aviation through emissions trading.

This overarching objective has been achieved by securing the following specific goals:

1. To examine the means by which non-CO_2 effects of aviation impact on climate change and the ways in which the 'full climate impact' of aviation might be captured within the EU emissions trading scheme as of 2008 without undermining the scheme's environmental integrity. This will take into account state-of-the-art scientific knowledge and the need for a conservative approach consistent with the precautionary principle.
2. To design viable policy options for including aviation in the existing EU Emissions Trading Scheme (EU ETS), in particular to propose viable options for:
   a. Scope in terms of geographical coverage and types of flights included; this includes methods for quantifying the emissions within the scope and preliminary estimates of these for the purpose of ex ante impact assessments.
   b. Allocation and surrendering of allowances.
   c. Monitoring, reporting and verification of data.
3. To assess the qualitative impact of policy options developed for including aviation in the EU ETS (and amending Directive 2003/87/EC).

1.3 Demarcation of scope

The scope of the present study is demarcated in a number of significant respects, most of which are discussed in greater detail in Chapters 2 and 3. The following are the most important:

- The principal aim of the emission trading system concepts considered is to mitigate the full climate impacts of air transport in Europe, taking as the point of departure the scientific knowledge on the climatic effects and related emissions of aviation presented in the Special IPCC report 'Aviation and the Global Atmosphere', published in 1999. Chapter 2 of this report elaborates extensively on the scope for also including the non-CO_2 climate impacts of aviation in the scheme, thereby taking into account the latest scientific developments since the Special IPCC Report of 1999.
- The aim of this study is not to design a new and independent emission trading scheme for aviation, but to develop and assess design options for including aviation in the existing Emission Trading Scheme (ETS) of the European Union, which started on 1 January 2005. Consequently, this study does not consider a 'closed' emission trading system for aviation, as this would be inherently independent of the EU ETS.
- In order to minimise potential competitive distortions, this study considers only system variants that are 'non-discriminatory' with regard to participants. This means that European and non-European airline companies are treated

equally under the proposed policy options for including aviation in the EU ETS, implying in turn that all commercial aircraft operators flying a particular route are covered by the scheme, irrespective of nationality or type of operation[10].

1.4 Project organisation

This study has been conducted under a consulting contract dated November 2004 between CE Delft and the European Commission. This study therefore presents facts and professional estimates regarding the scientific and policy effects of including the full climate impact of aviation in the EU ETS. Selection of a particular policy line or variant is the sole prerogative of the client, however.

Besides CE Delft, the following consortium partners have also made important contributions:
Professor David S. Lee of the Centre for Air Transport and the Environment (CATE) of Manchester Metropolitan University, who was responsible for examining by which metrics or instruments non-CO_2 effects of aviation might be captured within the EU emissions trading scheme (Chapter 2).
Mr. Martin Cames and Odette Deuber of the Oeko Institute in Berlin, who made important contributions to Chapter 3 (key design elements) and provided valuable ideas for other parts of the project.
Mr. Pablo Mendes de Leon of the International Institute of Air and Space Law of the University in Leiden, who advised the team on identification of relevant international legal obligations.

Involvement of stakeholders
From the beginning this project has benefited from input collected from and ideas discussed with many stakeholders, including representatives of individual Member States, representatives and associations from airlines, airports, aircraft and engine manufacturers, NGOs and the oil and refining and marketing industry. Furthermore, the results of a public internet consultation held by the European Commission between March and May 2005 were also used in the study.

The structure of the study and the draft results have been presented and discussed at several meetings. At the outset of this project, in November 2004, an outline of the study was presented and methods to address the full climate impact of aviation were discussed in depth during an EU emission trading seminar organised by the UK Energy Research Centre (UKERC) in Oxford. In March 2005, the project structure and main research questions were discussed at AEA in Brussels with many European airlines. Later, in May 2005, separate consultations were held with representatives of IATA, the International Air Carrier Association (IACA) and the European Business Aviation Association (EBAA). Furthermore, a meeting was held with the Airport Council International (ACI Europe). Finally, in June 2005, the draft final results were presented and

[10] Exemptions with regard to military aviation and general aviation are discussed in section 3.3.3.

discussed with the 25 EU Member States as well as with stakeholders involved during a whole-day meeting organised by the European Commission during the Green Week[11]. The assessments and analyses underlying this study benefited greatly from the contributions made during these discussions. The authors therefore wish to extend special thanks to these contributors for their constructive discussions and comments.

1.5 Acknowledgments

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Particular thanks are due to Nigel Harle for his editing of the English of this report.

Notwithstanding all the help received, the content of the report is the sole responsibility of the authors.

1.6 Report structure

The structure of this report is as follows.

Chapter 2 examines the means by which non-CO_2 effects of aviation impact on climate change and the ways in which the 'full climate impact' of aviation might be captured within the EU emissions trading:
- Science state of the art – aviation and climate change (2.2).
- Climate metrics: formulation and limitations (2.3).
- Scenario 1 – the multiplication factor approach (2.4).
- Scenario 2 – the individual effects based approach (2.5).

[11] http://europe.eu.int/comm/environment/greenweek/index_en.htm.

- Scenario 3 – CO_2 only and flanking instruments (2.6).
- Conclusions and outlook (2.7).

Chapter 3 presents the design and evaluation of pros and cons of key elements of an emission trading scheme for aviation that will be integrated in the EU ETS:
- Overview of key design elements (3.1).
- Trading entities (3.2).
- Geographical scope (3.3).
- Interplay with the Kyoto Protocol (3.4).
- Allocation (decision level, rules and methods for distributing allowances) (3.5).
- Administrative tasks: role Member states and the EC (3.6).
- Monitoring and reporting methods (3.7).
- Verification (3.8).
- Phasing-in (3.9).

Chapter 4 discusses the selection of three main system variants, or policy options, for further examination in the remaining chapters.

Chapter 5 present the results of an evaluation of the environmental impacts of the three selected policy options:
- Assumptions and the 'Business as Usual' scenario (Section 5.1).
- Incentives provided by the various policy options (Section 5.2).
- Impacts on operating costs and ticket prices (Section 5.3).
- Quantitative environmental impacts of three policy options (Section 5.4).
- Effects of a 'CO_2-only' regime and negative trade-offs (section 5.5).
- Impacts of flanking instruments (section 5.6).

Chapter 6 presents an evaluation of the economic and distributional impacts of the three policy variants. The following aspects are discussed:
- A definition of what, in this study, is considered to be an economic distortion (Section 6.1).
- Impacts on transport volume (Section 6.2).
- Analysis of the change of the competitive position of EU carriers compared with non-EU carriers (Section 6.3).
- Potential economic distortions between airports (Section 6.4).
- Potential economic distortions between tourist areas (Section 6.5).
- Revenues from grandfathering (windfall profits) and auctioning and options to use the auctioned revenues (Section 6.6).
- Marginal impact on the EU ETS and the allowance price (Section 6.7).

Chapter 7 examines whether there are any potential legal obstacles to including aviation in the EU ETS.

This report is supplemented by a glossary and 8 annexes (A to H) providing more detailed information on several key issues and descriptions of the models and databases used.

2 How to address the full climate impact of aviation?

2.1 Introduction

This chapter sets out the scientific background as to why there is an issue about addressing the 'full climate change impact' of aviation in a CO_2-only emissions trading regime and how these impacts might be addressed through emissions trading. Here we review some of the latest scientific understanding of aviation's effects on climate and assess the *scientific* robustness of potential mechanisms by which non-CO_2 effects of aviation could be incorporated (or not) into the European Emissions Trading Scheme. Given that the state of the science in this field is changing, it is evident that policy development must often be precautionary in approach; moreover, the best science is not always available or mature when policy decisions need to be taken.

Three scenarios are set out and examined in terms of scientific integrity, climate metrics, usability in terms of the existing constraints of the present Directive, and acceptability to stakeholders in terms of fairness and uncertainty in the underlying scientific data. These may be summarised as follows:
- Scenario 1: CO_2 × some multiplication factor to capture the full climate change impacts.
- Scenario 2: CO_2 plus effect-by-effect approach to account for non-CO_2 effects.
- Scenario 3: CO_2 only, and CO_2 plus flanking instruments for non-CO_2 effects.

In this chapter a brief overview of the state of the science regarding aviation's impacts on climate is first given in **Section 2.2**. This is not intended to be a comprehensive review but rather a review of the most recent and important literature relevant to this study. In **Section 2.3**, climate metrics are discussed. In **Sections 2.4 to 2.6**, the feasibility and the scientific robustness of the three aforementioned scenarios are addressed. Finally, some conclusions are drawn in **Section 2.7**.

It is assumed in this document that the reader has a basic understanding of what the 'greenhouse effect' is, and how human influences are thought to affect climate. Nonetheless, some particularly relevant concepts are described and discussed in some detail; in particular, climate metrics, their calculation and their limitations.

2.2 Science state of the art – aviation and climate change

What is the issue? Quite simply, aviation is considered to be a constituent part of human-induced climate change. That aviation affects climate change is not a new debate. In fact, a review of the early literature shows that the debate over the effect of contrails on climate dates back to the late 1960s and the early 1970s for the effect of subsonic aviation on NO_x and tropospheric O_3 [Lee, 2003].

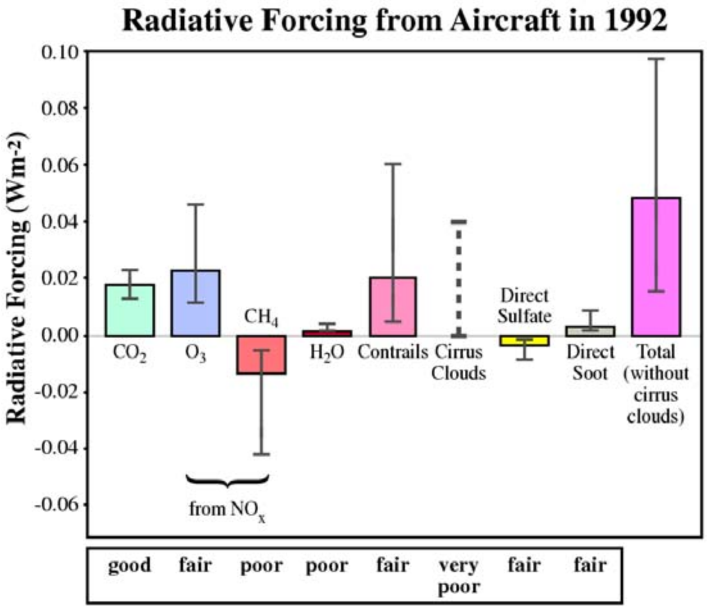
The complicating factor, the current subject of discussion for this study contract, is that aviation either has unique effects, in terms of an emission source, or particular effects such as cloud formation and modification that are unique to aviation. This conspires to make the total climate change effect of aviation more than that arising from its CO_2 emissions alone.

Essentially, this can be said to be the heart and essence of the conclusions of the Intergovernmental Panel on Climate Change's (IPCC) Special Report '*Aviation and the Global Atmosphere*', published in 1999. The effects of aviation emissions were quantified in terms of the conventional climate metric, '*radiative forcing of climate*', often simply referred to as '*radiative forcing*' (hereafter abbreviated to RF). What RF is and why it is used will be discussed later.

The IPCC report quantified aviation's RF effects for 1992, 2015 (a forecast) and various scenarios for 2050 [IPCC, 1999]. Radiative forcing is affected by aviation as follows:

- *Positively* (warming) by emissions of CO_2 (a direct greenhouse gas, sometimes referred to as 'radiatively active').
- *Positively* by tropospheric O_3 (via atmospheric chemistry from emissions of NO_x).
- *Negatively* (cooling) by the reduction of ambient CH_4 (via atmospheric chemistry from emissions of NO_x).
- *Negatively* by sulphate particles arising from sulphur in the fuel.
- *Positively* by emissions of soot particles.
- *Positively* by linear persistent contrails (condensation trails) formed in the wake of the aircraft.
- *Positively* by enhanced cirrus cloud coverage formed from spreading contrails and/or additional cloud condensation nuclei (particles) introduced into the upper atmosphere by aircraft exhaust emissions.
- The quantification of these RF effects is reproduced from the IPCC report in Figure 1 below and given numerically in Annex I.

Figure 1 Globally and annually averaged radiative forcing from aviation in 1992 and its sub-components. The bars represent a best estimate of the forcing, whilst the lines represent the two thirds uncertainty range. Also presented are relative appraisals of the level of scientific understanding



Source: IPCC, 1999

The well-known IPCC RF chart for aviation has been recently updated from the results of the EU 5th Framework Project, TRADEOFF[12] by [Sausen *et al*., 2005] and the assessment of RFs for 2000, based upon the most recent models and their results, is provided in Annex I. Included in Annex I is an assessment of what the RF would have been if the [IPCC, 1999] results for 1992 had simply been scaled up to the year 2000 in terms of traffic and fuel[13].

In both the cases of [IPCC, 1999] and TRADEOFF [Sausen *et al*., 2005], the estimate for cirrus cloud enhancement was given as a potential range, which in both cases was omitted from the total RF for aviation. However, the absence of a best estimate of RF conceals the advances in scientific understanding since the publication of the IPCC report. In fact, the basis for an assertion that aviation potentially affects (enhances) cirrus cloud coverage is now more robust, particularly from the studies of [Zerefos *et al*., 2003] and [Stordal *et al*., 2005], both originating from the TRADEOFF project.

The RF effect of aviation in terms of its contribution to total RF was estimated to be 3.5% in 1992 and 5% in 2050 [IPCC, 1999]. As mentioned above, in both these estimates, any effect from cirrus enhancement was excluded because of the uncertainties that disallowed a best estimate of the forcing. The 2050 total RF

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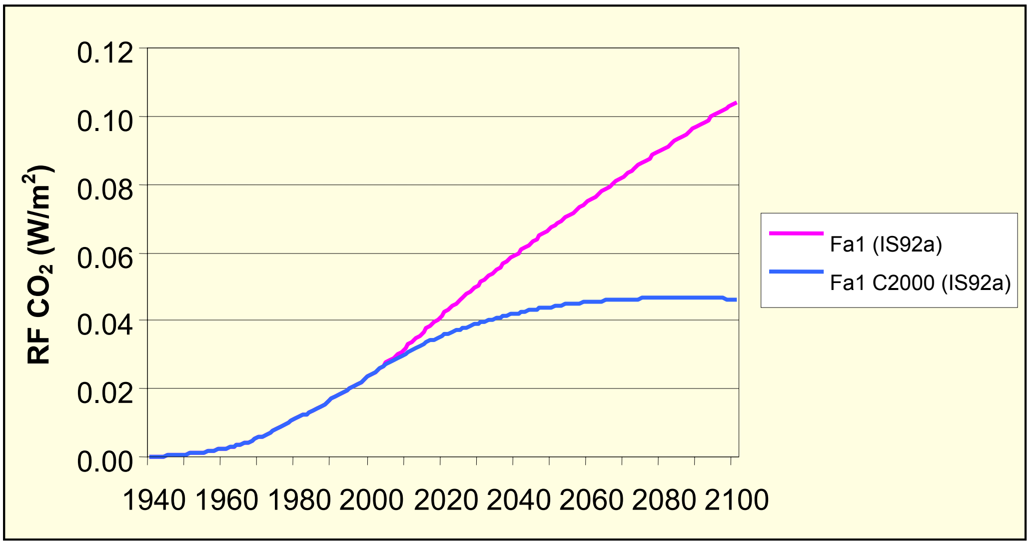
12 http://www.iac.ethz.ch/tradeoff/.

13 Whilst such scaling has been done by fuel, it is *via* fuel, not from the fuel figure alone: CO_2 emissions must be first converted to atmospheric concentrations using a C-Cycle model and then the radiative forcing calculated – typically using a natural logarithmic function to simulate saturation of CO_2 forcing at higher concentrations.

contribution was based upon scenario Fa1: FESG IS92a technology scenario 1. FESG (1998) constructed the scenarios, and this particular one was based upon GDP growth assumptions from IS92a (see [IPCC, 1994]), according to ICCCAIA (1997) technology scenario 1, in which the focus was on fuel efficiency rather than NO_x reduction. In the subsequent period from the [IPCC, 1999] publication, it has become clear that the IS92a growth assumption is too low, to date.

The TRADEOFF RF estimates have changed the picture, as is clear from Figure 1 and Annex I. The CO_2 forcing has increased as a result of increased traffic and therefore fuel burn from 1992 to 2000. However, the effect of accumulated CO_2 concentrations is also implicit in this: because of the lifetime of CO_2, the RF would increase, even under constant emissions. This effect is illustrated in Figure 2, where the (aviation) CO_2 RF is shown over time for scenario Fa1 and a scenario in which aviation emissions increase over time to 2000 and thereafter remain constant. The background (non-aviation) CO_2 emissions remain the same (IS92a) in both cases. This has been calculated with an extended version of the [Sausen and Schumann, 2000] model [Lim *et al*., 2005], which is similar to the CO_2 models used in [IPCC, 1999] to calculate the forcings given there.

Figure 2 Radiative forcing of aviation CO_2 over time for scenario Fa1 (pink line) and constant emissions of aviation CO_2 after 2000 (blue line) against a background of IS92a CO_2 emissions calculated with model of [Lim et al., 2005]



Source: Lim et al., 2005

The TRADEOFF O_3 forcing has stayed approximately the same as 1992 – this is considered to be the consequence of improved models to calculate the O_3 perturbation, which may be less diffusive although this hypothesis has not been properly tested. Likewise, the CH_4 reduction – also calculated in chemical transport models – has become smaller for similar reasons to the change in O_3. The water vapour, sulphate and soot forcings scale with fuel usage, so are slightly increased over 1992 estimates. One of the largest changes is the contrail RF. Contrail RF has been studied by three groups, most effort being committed by DLR. Essentially, as a consequence of much more refined assumptions and parameters in the modelling, the contrail RF has reduced. The change is up to a factor of 4 – 5 smaller depending upon which estimate is taken; the TRADEOFF estimate being a factor 2 lower than was made for [IPCC, 1999]. Lastly, as has been mentioned, the cirrus enhancement still has no best estimate, although the basis of the analysis has been improved from the recent work of [Zerefos *et al*., 2003] and [Stordal *et al*., 2005]. [Stordal *et al*., 2005] used 16 years of satellite data to determine trends of cirrus in regions of air traffic and non-trafficked regions and found a significant correlation between positive trends and air traffic. They calculated a 'mean' RF of 30 mW m^{-2} with lower and upper bounds of 10 and 80 mW m^{-2}. This upper bound is twice as large as that given by the [IPCC, 1999], i.e. 40 mW m^{-2}. The 'mean' value of 30 mW m^{-2} was not used in the overall assessment of RF by [Sausen *et al*., 2005] as it did not have the same qualitative certainties as the other RF 'best estimates'. However, the mean value and its range give some quantitative measure of the potential magnitude of the cirrus effect.

2.3 Climate metrics: formulation and limitations

2.3.1 Introduction

The origin of climate metrics lies in the physics of the phenomenon of climate change. The basic property that is affected by 'greenhouse gases' is the energy balance (radiative balance) of the atmosphere. This is the balance between incoming short-wave solar radiation and outgoing long-wave infrared radiation. Any perturbation to this equilibrium is called 'radiative forcing' and is expressed in terms of a change of energy flux in W/m^2.

The use of radiative forcing and other climate metrics and indices has been discussed in great detail by [Fuglestvedt *et al*., 2003] and this comprehensive review is commended to the interested reader. In this report, only the aspects of climate metrics that are relevant to the problem in hand – that of aviation and emission trading – are dealt with and discussed in some detail.

2.3.2 Radiative forcing

Here, we consider RF as a unit of equivalency. This, on the face of it, is attractive since the basic usefulness of RF as a concept is its ability to compare forcings arising from very different phenomena (e.g. GHGs, changes in particles, clouds, solar variation, land-use change). This is because of the following property:

$$\Delta T_s \approx \lambda \, \Delta RF \qquad [1]$$

That is, there is an approximately linear relationship between a change in global mean radiative forcing (ΔRF) multiplied by a constant, λ, and the global mean perturbed surface temperature (ΔT_s), where λ is the climate sensitivity parameter (K (W $m^{-2})^{-1}$). The climate sensitivity parameter, λ, has been found to be quite

stable for a number of different forcing agents within a Global Climate Model (GCM) but has been found to vary between GCMs [Cess *et al*., 1990, 1996].
More recently, the robustness of λ has been questioned for some effects, some researchers having found that λ can differ for some forcings [e.g. Joshi *et al*., 2003]. This is sometimes denoted the 'efficacy' [Hansen and Nazarenko, 2004; Hansen *et al*., 2005] and is defined as the ratio of the climate sensitivity parameter λ_i for a given forcing agent to λ for a doubling of CO_2 (see e.g. [NRC, 2005]).

Whilst the determination of robust efficacies is in its infancy, it is nonetheless still reasonable to conclude that RF remains a relatively robust and useful metric of climate change, a view that is currently endorsed by the IPCC.

2.3.3 Global warming potentials

The EU Emissions Trading Directive is based upon the principles of emissions being a tradable commodity, so that some measure or 'metric' is required that allows calculation of equivalence between different gases. In the Kyoto Protocol, the Global Warming Potential (GWP) is utilised for this 'equivalency' and this aspect is mirrored in the EU Emissions Trading Directive (2003/87EC). In the IPCC's First Assessment Report [IPCC, 1990], the GWP was introduced as a useful policy tool that allowed an equivalency between CO_2 and other GHGs such as CH_4, N_2O, SF_6 etc.

The GWP is defined as the ratio of the time-integrated radiative forcing arising from the instantaneous release of 1 kg of a trace substance, relative to that of 1 kg of a reference gas [IPCC, 1990], i.e.:

$$GWP_x = \frac{\int_0^{TH} a_x[x(t)]dt}{\int_0^{TH} a_r[r(t)]dt} \qquad [2]$$

where TH is the time horizon over which the calculation is made, a_x is the radiative efficiency arising from a unit increase in atmospheric abundance of the substance (*x*) in question (in W m^{-2} kg^{-1}), [*x*(t)] is the time-dependent decay in the abundance of the instantaneous release of the substance, and *r* refers to the reference substance in the denominator [IPCC, 2001]. Thus, the GWP represents the integrated forcing of a pulse of a substance relative to the same mass emission pulse of a reference gas over the same time-horizon (typically CO_2). The radiative forcings are based upon infrared radiative transfer models that utilise laboratory measurements. Thus, GWPs are suitable for long-lived gases such as CH_4, N_2O and the halocarbons. The time horizon chosen is arbitrary: however, it should be realised that different values for GWPs arise from the use of different time horizons.

The GWP is not without its critics: [Smith and Wigley, 2000a,b] show that the accuracy of GWPs is limited because of a flaw in the mathematical construction. [Fuglestvedt *et al*., 2003] provide a comprehensive overview of the issues.
In the case of aircraft emissions, it is not possible to derive GWPs for particles or their indirect effects. In the case of NO_x emissions, the effect is upon O_3 and is therefore also *indirect*. The O_3 thus produced is the result of complex atmospheric chemistry and is dependent upon the presence and abundance of a range of other chemical species; moreover, the radiative property of O_3 and atmospheric lifetime of O_3 and NO_x are height- and location-dependent. This gives rise to large uncertainties in GWPs for NO_x and O_3 [Fuglestvedt, 1999].

The calculation of GWPs for O_3 and, in particular aviation NO_x-induced O_3, has been a contentious issue. [Fuglestvedt *et al*., 2003] reviewed some of these studies. A cursory view of GWPs is that they are simply RFs calculated over a time horizon, which would allow calculation of aviation GWPs. However, it is defined as the time-integrated forcing of a *pulse* of a reference *mass* of emissions. Clearly, from this definition, it is not possible to calculate the GWP of contrails, as the definition refers to the *mass* of a trace gas release is required – contrails being a cloud phenomenon that has little relationship with any mass emission. Thus, in some respects, the intricacies of whether one can or cannot calculate an O_3 GWP are irrelevant for the total climate change effect of aviation since a ‘contrail GWP’ cannot be calculated. Nonetheless, it is still worth citing [IPCC, 1999] on the subject of O_3 GWPs:

> *‘There is a basic impossibility of defining a GWP for ‘aircraft NO_x’ because emissions during takeoff and landing would have one GWP; those at cruise, another; those in polar winter, another. Different chemical regimes will produce different amounts of ozone for the same injection of NO_x, and the radiative forcing of that ozone perturbation will vary by location [Fuglestvedt et al., 1999]’.*

A further potential complication for the usage of GWPs for aviation effects is that the climate sensitivity parameter, λ, does not appear in equation [2] defining the GWP. This is because it is implicitly assumed to be equal for the various trace gases and therefore cancels out. As outlined in the previous section, equality of λ for aviation effects cannot be assumed based on work thus far. It is, of course, trivial to reintroduce this parameter, but λ is not well-characterised for the various aviation effects and its determination remains, at present, a research activity.

Thus, GWPs are not a useful tool for calculating the *complete suite* of aircraft effects in terms of equivalency to CO_2. At best, some approximation could be made for an aircraft NO_x GWP, although this remains a contentious calculation and has large uncertainties.

2.3.4 Global temperature potential

Recently, [Shine *et al*., 2004] have introduced the concept of the Global Temperature Potential (GTP). In its simplest description, the GTP is a calculation of the global mean temperature change resulting from emissions of a GHG. Two metrics were formulated and tested by [Shine *et al*., 2004]: the Global Temperature Change Potential for a pulse emission of a gas (GTP_P); and the effect of a sustained emission change of a reference gas (GTP_S). Both metrics rely on use of a simple analytical climate model providing a link between radiative forcing and temperature change and therefore take the metric one step closer to an actual tangible climate effect.

[Shine *et al*., 2004] compared both metrics against a more complex upwelling-diffusion energy balance model and found that the pulse version did not perform well except for the long-lived gases, whereas the sustained emissions metric (GTP_S) compared well with results from the energy balance model for gases with a wide variety of lifetimes. For time horizons in excess of 100 years, the GTP_S and GWP produced very similar results.

[Lim *et al*., 2005 (in preparation)] have recently constructed a simplified climate response model (LinClim) to represent the effects of aviation on both RF and temperature change. At the core of the model is a simple analytical climate model, almost identical to that used by [Shine *et al*., 2004]. LinClim is an extension of the model published by [Sausen and Schumann, 2000] and, in turn, is a well-based model approach, originally formulated by [Hasselman *et al*. 1993, 1997]. The advantage of LinClim is that it splits up the temperature response of different aviation effects (extending the scope of the Sausen and Schumann, 2000, model) and the GTP approach for aviation can be explored.

Lee (2004: see summary of Keay-Bright, 2005) made a first estimation of a GTP for aviation, analogous to the aviation RFI approach, coined 'Global Temperature Index' (GTI) whereby instead of the individual forcings being summed and calculated as a ratio to the CO_2 forcing, the resultant temperatures were calculated in this ratio[14]. The model was tuned to the recent TRADEOFF RF results of [Sausen *et al*., 2005] such that the resultant RFI was approximately 2, and the GTP calculated for both a sustained emission whereby aviation emissions were kept constant after 2000 (the background CO_2 remained as IS92a) and a time-evolving scenario, here referred to as GTP_{scen}. This metric has been further developed for this work and is dealt with in more detail in Annex D.

2.3.5 Similarities and differences between RF, GWP and GTP

From the preceding sections it is clear that there are similarities and differences between GWP, RF and GTPs. The basic physical phenomenon, radiative forcing, underlies all the metrics, i.e. the perturbation of the earth-atmosphere energy balance.

The GWP represents an attempt to relate the warming potential of a pulse of an emission of a GHG to that of CO_2 – it is a relative measure (usually to CO_2). Absolute Global Warming Potentials (AGWPs) have also been formulated and are simply the numerator or denominator in equation [2] of the gas, *x*, and the reference gas, *r*, respectively. However, the usage of AGWPs in the policy context is somewhat redundant as they do not provide an equivalency in the sense that the GWP provides an equivalency to CO_2.

14 Note that the calculations presented in October 2004 were preliminary and have been superseded as the work developed.

The RF provides an equivalency that might seem rather attractive, since it does away with the limitations of the GWP. However, there are important differences to be considered. The RF of CO_2, for example, considers the *history* of the emission, as the calculation of CO_2 RF has to incorporate a time element. It says nothing about its *future* effect, which can be more than its effect at any time after its calculation because of the accumulation of CO_2 in the atmosphere. For other short-lived phenomena, this does not necessarily apply. The GWP overcomes this by the application of a *forward* time integration over an arbitrary period of an additional pulse emission. So, it becomes apparent that we cannot mix RF with GWPs in terms of formulating an equivalency.

The GTP_S overcomes some of these problems, having some of the advantages of the GWP but apparently lacking the disadvantages. Both [Fuglestvedt *et al*., 2003] and [Shine *et al*., 2005] have pointed out that the 'chain' of events can be simplified as follows: emission changes → concentration changes → radiative forcing → climate impacts → societal and ecosystem impacts → economic 'damage'. As one moves down this chain, the relevance increases but so does the uncertainty. The GTP approach is attractive as it moves closer to 'impacts' but evidently it introduces more uncertainties. At present, GTP is not embedded in international policy as the GWP is[15]; moreover, the GTP is a new metric formulation and requires more work to consolidate its usefulness as a policy metric. Its usefulness in concept will be demonstrated further in this work.

2.4 Scenario 1 – the multiplication factor approach

Scenario 1, as defined in the proposal, involves assessing the literature for the best possible RFI (and its uncertainty range); a consideration of current technology regimes; and, assessment of contrails and enhanced cirrus. This leads to a view on how, or whether, the Emissions Trading Directive might be amended and what monitoring guidelines would be necessary. The use of an RFI to weight emissions is sometimes mistakenly attributed to [Lee and Sausen, 2000], who propounded a simple thesis that incorporating aviation into an open 'CO_2-only' emissions trading regime for aviation had the potential to *degrade* the environment, the very opposite of the underlying policy objective. This thesis critically assumed that aviation was a net purchaser of permits (since it wanted to grow) and the regime was 'open', i.e. inter-sectoral trading was allowed. The reason for this is that transferring a permit for, say, 1 tonne of CO_2 from a ground-level source to aviation had a larger equivalent radiative effect than if it had been released from a surface emission of CO_2. This was not the result of the CO_2 *per se* but rather the additional non-CO_2 effects. [Lee and Sausen, 2000] concluded:

> '*The obvious way forward in an open-sector emissions trading regime is to weight any CO_2 permits purchased by aviation such that the additional RF effects are accounted for. However, such weighting functions would be*

[15] However, similar concepts have been proposed for the policy process, see [Meira Filho and Miguez, 2000].

spatially and temporally variable, and the supporting science to define these require further development.'

The phrasing is rather subtle but nonetheless very careful; they proposed to *weight* CO_2 emissions permits, they did not propose the weighting factor, *nor did they propose weighting a unit emission of CO_2 by the RFI*. This has been frequently misunderstood and misrepresented as there is a difference between stating – correctly – that '*aviation has approximately 3 times the radiative forcing of its CO_2 **forcing** alone*' and – incorrectly; '*aviation has approximately 3 times the radiative forcing of its CO_2 **emission** alone*'. These are two different statements and [Lee and Sausen, 2000] did not state the latter.

2.4.1 Radiative forcing

In Section 2.3.2, the basic concept of RF was explained and it has been shown that this physical quantification underlies other metrics such as RFI, GWP and GTP_s. Thus, the question arises '*why not simply use RF as a unit of equivalency?*' In answer to this, there are a number of objections. Whilst RF provides a convenient metric of equivalency of effect, it is a 'now' metric: in other words, it quantifies the forcing at any given point in time, which may or may not require a consideration of the forcing's history. What it does not quantify is the forcing at any given point in the future arising from historical emissions or effects. This has been demonstrated in Section 2.3 (Figure 3).

The usage of RF as a climate metric was reviewed by [Fulestvedt *et al*., 2003]. [Hammond *et al*., 1990] suggested using an instantaneous heating via RF for a time period of 1 year in calculating GWPs, arguing that this removes the arbitrary nature of choosing a time horizon for GWPs. However, as outlined above, the disadvantage of this is that the post 1 year effects of emissions reductions are not considered in this approach.

Thus, using RF as a unit of equivalency for emissions reduction through emissions trading is not considered a viable option.

2.4.2 The Radiative Forcing Index

In addition to quantifying the RF from the different components of aviation's total RF effect, the [IPCC, 1999] report presented another simple metric, the Radiative Forcing Index (RFI), which is the sum of the individual aviation forcings divided by that from CO_2 alone. This has proven to be a useful simple metric to express the total RF of a sector – in this case aviation – in relation to its CO_2 forcing. The [IPCC, 1999] estimated the RFI for aviation in 1992 to be 2.7 with a range of 1.9 to 4.0. However, the figure of 2.7 should not be interpreted with spurious accuracy. In layman's terms, 'about 3' would be faithful to the uncertainties of the underlying science (although this does not constitute a recommendation to use 3 in an arithmetic sense).

This is emphasised, as it has been attempted by some to ‘correct’ the aviation RFI to a total ground-level source RFI of 1.5[16] (which was given in Section 6.2.3 of IPCC, 1999, page 200). Such corrections are unwarranted and attribute unjustifiable accuracy to the RFI for aviation.
The IPCC assessment of the RFI for 1992 was 2.7 (range 1.9 – 4.0). The TRADEOFF assessment of RF implies an RFI of 1.9 ([Sausen *et al*., 2005]; see Appendix II); in both cases, a cirrus RF was excluded from the calculation of RFI.
The uncertainties of the individual RFs were not assessed numerically within TRADEOFF as it was felt that this was a difficult task, given that the underlying modelling relied in some cases on one model. Nonetheless, this is not so different from the case of [IPCC, 1999] – this was a matter of individual choice of the responsible scientists. It is possible that the uncertainties associated with the TRADEOFF RFs may be examined at a later date.

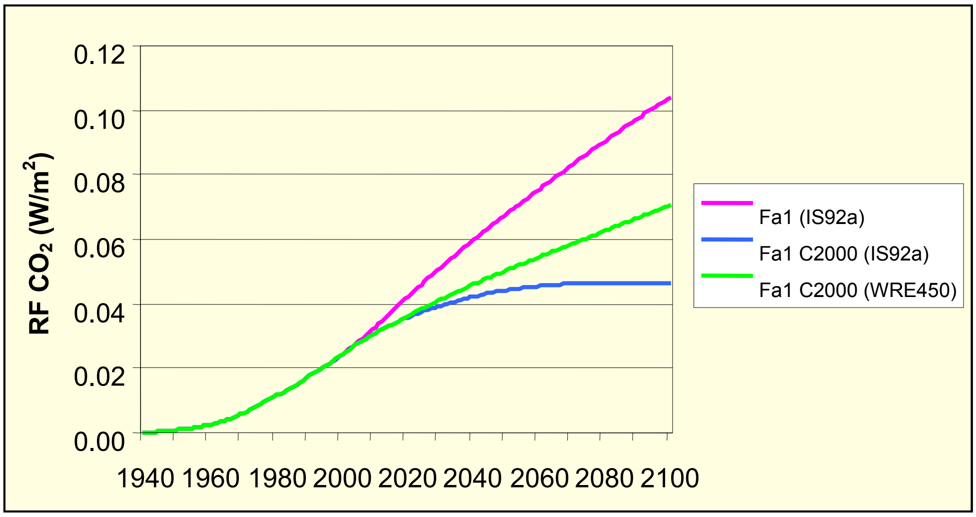
What is not commonly appreciated is the underlying calculations to individual RFs. A question frequently posed is whether any time element is incorporated into the aviation RF calculations. This is made clear in the [IPCC, 1999] report, although it is in the detail. For example, the basis of the CO_2 forcing calculation is given in a footnote to Table 6-1 in Chapter 6 of [IPCC, 1999]. For CO_2, it is possible to calculate RF with a radiative transfer model that simulates the effect of CO_2 concentrations on infrared radiation in the Earth’s atmosphere. However, it is more common to use simplified functions that simulate the performance – rather accurately – of these radiative transfer models such that CO_2 RF can be more easily calculated. A function for this was given by the [IPCC, 1994] in the supplementary report to the First Assessment Report. Subsequently, this was elaborated in a report of simplified climate models by the [IPCC, 1997] and a further critique and summary of these functions given in the Third Assessment Report [IPCC, 2001].

There are two important points to be made regarding CO_2 forcing calculations. Firstly, because of the long lifetime of CO_2 in the atmosphere, it is necessary to calculate the RF based upon a concentration profile over time. Secondly, the RF does not scale with CO_2 concentration because the functions used mimic the saturation effect of CO_2. From this, two subtle points emerge: firstly, that an RF calculation for a given point in time is just that – the RF at time ‘x’ is that *based upon the history of concentrations and the consequential time profile of RF*. It says nothing about the future RF arising from that (past) profile. This will be returned to. Moreover, if one is interested in a component part – e.g. aviation – of that CO_2 forcing, the fractional contribution depends upon the background concentration of CO_2. Put another way, the same mass emission profile over time

16 In fact, such a ‘correction’ is a selective and incorrect use of the data: IPCC says ‘*For comparison, in the IS92a scenario the RFI for all human activities is about 1; for greenhouse gases alone, it is about 1.5, and it is even higher for sectors that emit CH_4 and N_2O without significant fossil fuel use.*’ The origin of ‘*about 1*’ is Table 6-2 of IPCC and is in fact 0.9 (and 1.7 for the greenhouse gases alone). The usage of 1.5 is selective (i.e. greenhouse gases alone) and ignores the negative forcing of aerosols. A scientifically compatible correction to the aviation RFI would be to include the aerosol forcing, which would *increase* the effective RFI of aviation to 3.0. However, such ‘corrections’ are not recommended as they imply a level of accuracy to RFI values that cannot be justified.

from aviation can produce different forcings, depending upon the background emissions. This is illustrated in Figure 3, which is similar to Figure 2, except that in addition, CO_2 aviation RF was calculated for constant 2000 emissions against a background of scenario 'WRE450'[17], whereby the same emissions produce a *stronger* RF. This is a point more relevant for forward projections.

Figure 3 Radiative forcing of aviation CO_2 over time for scenario Fa1 (pink line) and constant emissions of aviation CO_2 after 2000 (blue line) against a background of IS92a CO_2 emissions and a background of WRE450 emissions (green line) calculated with model of [Lim et al., 2005]



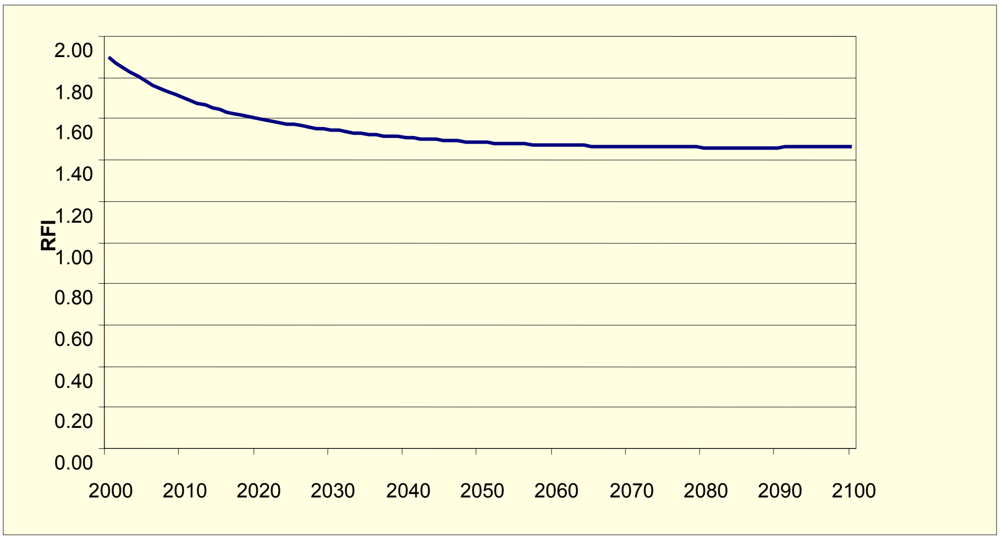
Source: Lim et al., 2005

Of the other aviation-relevant forcings, the only one that needs a time element is CH_4 as it has a lifetime of approximately 8 – 12 years. This is commonly accounted for in the calculations that provide the CH_4 concentration reduction.

What are the implications of these subtleties? If one examines the RFIs for the [IPCC, 1999] 2050 scenarios, they are shown to be different, ranging from 2.2 to 3.1 ([IPCC, 1999] see also Appendix I). The reason for this is that the RFI is not an intrinsically fixed number – it is completely dependent upon either the actual history or the assumed forward scenario. To illustrate this, if aviation emissions were held constant from e.g. 2000 onwards, *the RFI decreases over time*, as CO_2 assumes a more important role because of its long lifetime. This is illustrated in Figure 4, below.

[17] This emission scenario is a 'stabilisation scenario', whereby (all) CO_2 emissions were adjusted over time such that a maximum concentration of 450 ppm(v) was achieved [Wigley *et al.*, 1996].

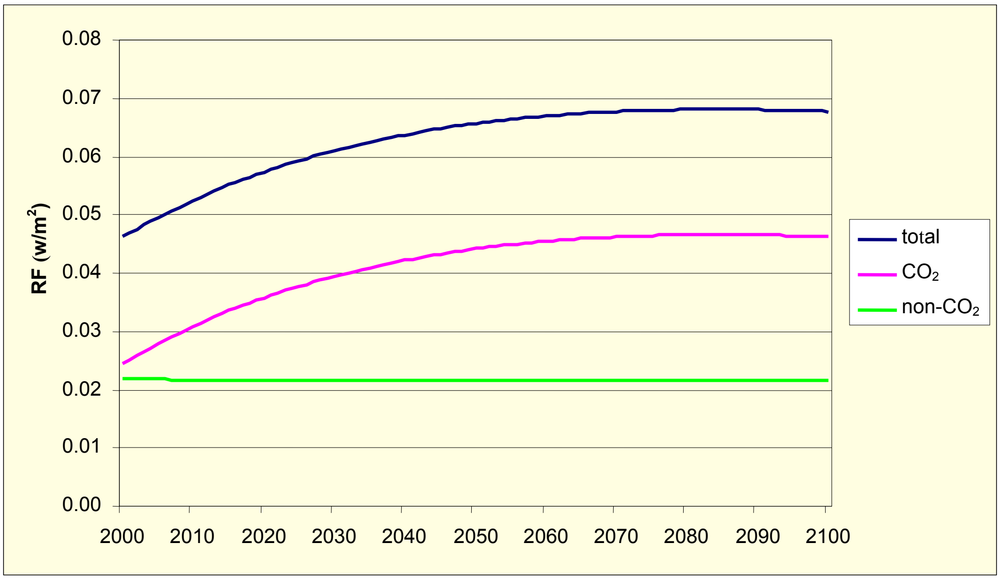
Figure 4 Radiative Forcing Index (RFI) for aviation over time for scenario Fa1 and constant emissions of aviation CO_2 after 2000 against a background of IS92a CO_2 emissions; model tuned to RFI of 1.9 in 2000 calculated with model of [Lim et al., 2005]



Source: Lim et al., 2005

In this respect, it is worth examining the RFs over time for an emissions rate set constant at 2000, as shown in Figure 5 below. However, it should be noted that the *temperature* response over time looks rather different to that of RF, a theme returned to later.

Figure 5 Radiative forcings for aviation CO_2 and non-CO_2 effects (sum of O_3, CH_4, contrails, soot, sulphate) over time for scenario Fa1 and constant emissions of aviation CO_2 after 2000 against a background of IS92a CO_2 emissions; model tuned to RFI of 1.9 in 2000 calculated with model of [Lim et al., 2005]



Source: Lim et al., 2005

Since this is an implausible situation in the absence of some substantial policy intervention, it need not be considered *as a scenario* but rather as a 'thought experiment'. Nonetheless, it is important in illustrating the point that an RFI depends entirely on the scenario. That the RFI for 2050 under scenario Fa1 is 2.6, i.e. more or less constant over the time period from the 1992 base year, is entirely fortuitous. Thus, the higher growth rate scenario Fe1 has an RFI of 3.1 and the lower growth rate scenario Fc1 has an RFI of 2.2.

The RFI is therefore incompatible with an emissions trading system operating under GWPs since:

- The RFI is a 'now' metric, that accounts for the past and not for the impacts occurring in the future.
- Instantaneous or pulse mass emissions of CO_2 (as in GWP) cannot be readily related to an RFI.
- The RFI is entirely dependent on the history or, for a future scenario, the underlying growth of emissions – in other words, the RFI is not a fixed number and will respond to underlying growth rates.

It is therefore concluded that RFI as a 'multiplier' does not provide a robust method of accounting for aviation's non-CO_2 effects in an emissions trading regime.

2.4.3 Prognosis for radiative forcing and other indices as multipliers

Radiative forcing has been shown to be an unsuitable metric for the basis of trading and whilst it underlies other metrics (e.g. GWP), it does not provide an equitable unit of equivalency for emissions trading as it does not consider the long-term effects of some long-lived gases.

In considering RFI, it is important to remember the purpose of the metric [Fuglesvedt *et al*., 2003]. The RFI was designed to compare the relative climate impacts of *sectors*. Moreover, it has been shown that the value of a sector's RFI is dependent on the time evolution of historical emissions for a present-day quantification or the scenario of emissions for a future quantification. It has been shown that using a simple multiplier of RFI for CO_2 *emissions* is incorrect. Doing so would not account for the potential effect of longer-lived gases such as CO_2 in a way that a GWP does.

The GWP does not provide a satisfactory solution for non-CO_2 effects of aviation. This is because GWPs are only really suitable for similarly long-lived gases. GWPs for shorter-lived gases, such as O_3, can be calculated but there are conceptual difficulties with this. For effects such as contrails, a GWP cannot be calculated as the effect cannot easily be related to a mass emission.

The GTP_s/GTI_s approach goes some way towards solving the inherent problems of using GWPs or RFIs. This approach is able to capture CO_2 and non-CO_2 effects of aviation, using changes in global mean surface temperature (ΔT). Moreover, a linear relationship between increases of CO_2 emissions and changes in ΔT has been demonstrated for both CO_2 and non-CO_2 effects (see Annex D).

The *ratio* of these temperature effects provides a more robust measure of relative effects and shows some stability at the 100 year time horizon. However, this approach is not yet well developed and such a new metric will take some time before its usage is better developed and more widely accepted.

2.5 Scenario 2 – an individual effects-based approach

Under Scenario 2, a different perspective is taken. In Scenario 1, in determination of RF and RFI etc., an essentially *global* view is taken that establishes indices that can be used for some time in the future (although, as emphasised in Section 4, this is entirely dependent upon the assumed scenario for future usage of either RF or RFI). In Scenario 2, knowledge of day-to-day operations and effects of aircraft is assumed and each effect is assessed in turn to look for GWP-compatible metrics. Here, the requirements of this for a regionally-based assessment of incorporation of the full climate impact are examined.

2.5.1 Regional-scale and operational modelling approaches

Here, we may make a convenient distinction between emissions and effects. To construct a regional-scale model of aircraft emissions is relatively straightforward and less of a research task than to assess the effects.
Quantifying emissions requires the typical inventory approach of knowledge of the activity (the flights) and the emission factors. Much detail and computational complexity is nonetheless required in order to provide robust estimates of emissions. A few groups have attempted either global or regional-scale inventories, some of which (global) are reviewed in [IPCC, 1999], Chapter 9.

2.5.2 Quantifying regional emissions

Recently, EUROCONTROL have developed an emissions model on a regional scale that is currently being configured for operational day-to-day *modus operandi* (Watt, personal communication). In such four dimensional (i.e. latitude, longitude, height, time) models of aircraft emissions, two component parts (or data sources) are critical in their provenance: the movements and the fuel-flow data. The former are easily provided by EUROCONTROL and are expected to be of the highest quality. There is a difference between a flight plan, however, and the actual flight – but these differences are currently being resolved by incorporation of radar surveillance data into the flight movement data (Watt, personal communication). The fuel flow tends to be more difficult to calculate with accuracy. Aircraft performance data are commercially sensitive to airframe and engine manufacturers and, indeed, to airlines. Thus, one has to model fuel flow via some modelling technique. This can take the form of specific mission modelling (with assumptions over loading, profile, altitude etc.) or using derivative data (also requiring similar assumptions at some point in the derivation of the data) in the form of data tables, an approach taken by EUROCONTROL with the so-called 'BADA' data[18]. Recent testing has shown good agreement with

[18] http://www.EUROCONTROL.fr/projects/bada/.

EUROCONTROL's modelling system and fuel data provided by airlines/manufacturers (A. Watt, personal communication).

Whilst in essence portrayed as 'simple', the flight and emission inventory system should not be underestimated in terms of computational complexity, particularly in an operational mode, where large amounts of data need to be processed and stored (and possibly post-processed).

Whilst CO_2 emissions are simply calculated from the fuel as a fixed ratio, the emissions of NO_x, CO, HCs, do not simply scale with fuel (as does CO_2). There are very few data available on the emissions of these pollutants under altitude conditions and algorithms generally need to be applied to correct well-known sea-level emissions under fixed conditions (essentially, the ICAO certification testing regime) to altitude emissions. There are very few data with which such algorithms can be validated [Norman *et al*., 2003]. Such techniques have been applied in the development of global emissions inventories of NO_x etc. (e.g. Boeing/NASA, ANCAT/EC2, AERO2k, FAST, SAGE, AEM, DLR, AERO etc.) and are widely accepted as being able to produce good data. In a few cases, such algorithms have been validated from altitude test data (e.g. [Lister *et al*., 1995]).

In conclusion, calculation of NO_x emissions on a flight-by-flight basis is eminently possible. However, NO_x emissions, *per se*, are not compatible with GWP since NO_x does not cause the effect, but the derivative gas, O_3. In the next section we examine the possibilities of determining O_3 production on a flight-by-flight basis.

2.5.3 Quantifying regional NO_x emissions effects on O_3

Here, the *effects* of NO_x emissions on O_3 and CH_4 concentrations are considered and it is noted that flight and NO_x emission inventories are a prerequisite for the assessment of such effects.

In order to calculate the chemical effects of NO_x emission on O_3 and CH_4, for example, a complex *research* model is required (a 3D chemical transport model, or CTM). Such models have evolved from early lower-dimensional chemistry models of the atmosphere [Derwent and Friedl, 1999]. Enormous progress has been made in recent years with CTMs, although significant uncertainties remain. Large datasets with which such models can be validated are becoming available and sophisticated methods for model validation are being developed (e.g. [Brunner *et al*., 2003; Brunner *et al*., 2005]). However, despite the much improved modelling in terms of resolution, completeness of processes, etc., there still remain fundamental problems to such models in their ability to reproduce the low O_3 concentrations observed in the early twentieth century and the O_3 trends over the past 30 years [NRC, 2005].

Once O_3 concentrations are calculated (aviation constitutes an extra NO_x source in the model) the RF from the O_3 can be calculated relatively easily. The key difficulty is calculation of the O_3. However, attribution of O_3 formation to an individual flight is conceptually difficult. The formation of O_3 depends upon the presence and abundance of some 100 trace chemical species in the atmosphere and is inherently non-linear. For example, the O_3 production rate is known to be lower in high-NO_x environments than in lower-NO_x environments. Indeed, there is a theoretical turn-over point from O_3 production to O_3 destruction. Thus, even in a modelling sense, the O_3 production from a single flight cannot be calculated in the absence of others, since they partially represent the background NO_x source. Ideally, the way to calculate this would be to take the difference with and without the individual flight; however, as part of a pragmatic and precautionary approach average estimates of the accumulated impact divided by the total emissions could conceivably be used for policy purposes if the regional inaccuracies can be accepted. However, this ignores other difficulties of determining a relationship between the O_3 and GWPs for equivalency with the ETS. GWPs of O_3 from aircraft NO_x have been calculated by some authors, but this remains contentious, as was outlined in Section 3.3.

Lastly, there are no accepted regional/global scale models in an operational sense. There are a variety of modelling systems that have varying degrees of acceptability (usually depending upon publication in the peer-reviewed scientific literature of their performance) but such models are notoriously difficult to validate and there is no simple 'right answer' that can be used to benchmark them.
In conclusion, it is not possible to recommend an assessment of aircraft NO_x *effects* as a basis for inclusion in the ETS on the following grounds:

- The chemical transport models are still in the research domain and there remain significant shortcomings and uncertainties in the models – it cannot be envisaged when such models would be reliable enough to be used in an operational sense.
- From a scientific point of view, calculating aircraft O_3 on a flight-by-flight basis has conceptual difficulties because of the non-linearity of the chemistry unless all flights are calculated on an iterative basis – even so, the impact in e.g. Europe would be quite different to that in a clean-air region. However, in a given region, an average might arguably be used as a first-order proxy for the actual impacts.
- Calculations of GWP from aircraft NO_x-generated O_3 remain contentious.

2.5.4 Quantifying regional air traffic effects on contrails and cirrus

The current state of the science in relation to contrails and cirrus has been reviewed briefly in Section 2.2. Cirrus effects remain potentially the most important, although, as mentioned above, no best estimate for cirrus forcing can yet be provided, only 'tentative' upper estimates (see Section 2.2).

Whilst contrail RF effects are now considered to be lower [Sausen *et al*., 2005] than estimated by the [IPCC, 1999] it is possible that cirrus enhancement arises primarily from spreading contrails rather than secondary effects from aviation particles, although no quantification of the relative importance is available. Thus, the operational prediction of contrail formation (for tactical avoidance) might still provide a means of avoiding cirrus enhancement, although this is by no means demonstrated.

Modelling of contrail coverage has been developed that may allow a future means of building an 'operational' model. In such modelling, linear persistent contrails are implied, although the point at which a contrail ceases to be a 'contrail' and becomes a spreading contrail/cirrus cloud is an artificially and operationally defined one, mostly based upon definitions used to isolate linear contrails from satellite data retrievals.

The same point that was made about the O_3 modelling is made about contrail coverage modelling: these are *research* tools and there is no accepted operational model. In some senses, such modelling is far more uncertain than the above described chemical modelling for NO_x effects, as calculations of contrail coverage is a relatively recent activity, originating from the approach of [Sausen *et al*., 1998] who described a methodology to calculate contrail coverage. No (radically) different methodology has either been proposed or developed since.

The methodology of [Sausen *et al*., 1998] was essentially one that relied on statistical data, not operational data, since an operational model would be much more difficult to validate. Indeed, the methodology of [Sausen *et al*., 1998] is elegant in that it does not try to validate the methodology but rather normalises the results (in a particular region) to satellite observations. It should be noted that detection of contrails from satellites is not entirely straightforward and a research topic in and of itself. Subsequently, [Sausen *et al*., 1998] technique has been adapted by [Ponater *et al*., 2002] for use in a global climate model (GCM) so that some elements of the contrail coverage calculation could be refined and the radiative forcing more easily and consistently (with other cloud forcings) be calculated. But once again, this is in essence a technique that relies on statistical data, albeit from a GCM's internal calculations.

It would be feasible nonetheless to construct an operational model for contrail coverage, if flight data and reliable meteorological data would be available for a fully validated model. However, this again is at the cutting edge of research and development. Currently, operational meteorological models do not predict ice-supersaturation accurately enough [Lee *et al*., 2000] although the current generation of meteorological models being developed are improving in this respect (B. Hoskins, A. Thorpe, personal communication). Moreover, validation of such a model is by no means trivial. Such activities are underway within the jointly sponsored EUROCONTROL/ESA project, although no details are as yet available.

To construct a model of forward prediction, i.e. of where contrails might form in order to avoid them, is an even more difficult task and the conclusions of [Lee *et al*., 2000] that this is premature – in terms of *actually* trying to avoid them – remain valid. Additionally, if one considers *how* to avoid contrails, whilst in theory this is rather easy to do [Mannstein *et al*., 2005], this presupposes that it is worth doing so. This, again, remains a research topic.

Whilst the above 'operational approach' evaluates the effect of contrail coverage, it does not provide consequential radiative forcing estimates – this is one step further into the research domain and even more difficult to calculate and validate results. In fact, it is almost impossible to validate. It *might* be possible to evaluate the specific radiative properties of individual clouds from research flights (above and below the clouds) but evidently extrapolation and representative sampling are almost insuperable problems to get to the point at which 'validation' could be performed on radiative transfer models of contrails at a practical level.

If it were currently possible to calculate contrail coverage in a reliable, satisfactory manner, there still remains the difficulty of how to relate this to an effect. The direct effects of contrails are on both solar (cooling) and infra-red radiation (warming), although the overall balance is considered to be warming [Meerkötter *et al.*, 1999]. Calculating the total forcing is rather sensitive to the assumptions over cloud overlap [Marquart and Mayer, 2002]. Nevertheless, relating contrail RF to warming, or any other similar metric, can only be done with a climate model (either simple or complex), as it is impossible to derive a contrail GWP, as outlined in Section 3.3.
In conclusion, it is not currently possible to quantify on a flight-by-flight basis the effect of contrails for inclusion in the European ETS because:
- The models for coverage are immature and require further development.
- An 'operational', validated, contrail coverage model running on real meteorology does not exist.
- The radiative transfer models, and how they treat other clouds, are critical and in the research domain.
- There is a fundamental impossibility of calculating a contrail GWP.

2.5.5 Prognosis for the development of a flight-based metric for the ETS to assess and monitor the full climate change impacts of aviation

Essentially, the overall outlook is poor for this scenario/approach to addressing non-CO_2 effects in terms of assessment and monitoring for the purposes of ET. However, techniques and approaches to provide an operationally-based evaluation and prediction of CO_2 emissions from aircraft are well advanced in Europe and the outlook is good: this applies equally to the quantification of aircraft NO_x emissions, although the uncertainties are greater than for CO_2.

For the non-CO_2 effects, models remain firmly in the research domain and are some years away from being available to fulfil an operational role. Nonetheless, it is *critical* that such research be pursued and encouraged, as such investigations are well suited to their original purpose (*cf.* ETS), i.e. quantification of effects and improving scientific understanding.

2.6 Scenario 3 – CO_2 only and potential flanking instruments: science

In Scenario 3, alternatives to Scenarios 1 and 2 are considered. Here, aviation is assumed to be included in the European ETS on the basis of 'CO_2-only' and other policy measures and possibilities are considered to address the non-CO_2 effects.

The following flanking instruments are considered:
- Continued LTO NO_x certification.
- Cruise NO_x certification.
- NO_x airport charges.
- NO_x en-route charge
- Regulation of cruise altitudes to limit the production of contrails.

Whether these flanking instruments should be introduced depends on the question whether a 'CO_2-only' regime causes negative trade-offs. This question will be answered in Chapter 5 (environmental effects).

2.6.1 LTO NO_x certification as a potential flanking instrument

Aircraft emissions of NO_x have been the subject of much study and are one of the primary foci of CAEP. Within the CAEP context, this is primarily certification for the Landing Take-Off cycle (LTO). Continued NO_x stringency through the ICAO LTO certification regime is one possibility by which NO_x emissions might be tackled as a flanking instrument.
The ICAO LTO Certification Standards have greatly reduced emissions of CO, hydrocarbons (HCs) and smoke (as operationally defined by the measurement methodology). Certainly, the visible smoke from aircraft engines has been dramatically reduced. Emissions of NO_x have also fallen, but this is a more complex situation.

In the constant effort towards more fuel-efficient engines, the OPR has tended to increase, as outlined in Section 6.1. This makes NO_x emissions more difficult to reduce and this has been recognised in the regulatory parameter, D_p/F_{oo} (g NO_x/kN thrust), which is allowed to be greater for higher OPR engines. Thus, the overall effect has been for the emissions index for NO_x ($EINO_x$, g NO_x/kg fuel) to *increase* over time, across the global fleet.

Moreover, the correlation between NO_x emissions between sea-level testing results and altitude is not well understood for different engines and combustor designs to recommend this course of action with complete confidence. [Norman *et al.*, 2003] found some divergence between LTO NO_x and cruise NO_x, particularly for double annular combustors.

Moreover, there is the international dimension to this approach, as agreed through ICAO's CAEP and ratified by ICAO Council. Various options for increases in stringency (expressed as a percentage over some datum) are typically identified by CAEP WG3 and the economic implications analysed by FESG. However, the actual agreed level is an arbitrary political negotiation process at the CAEP meeting. In actuality, the stringency tends to follow the technology and 'technology forcing' within CAEP is a highly contentious topic (whilst noting that technology forcing is widely used as a regulatory approach in other sectors). In terms of timing, additional NO_x stringency was agreed at the last CAEP meeting, CAEP6 in February 2004. However, at CAEP6, it was also agreed that NO_x stringency would not be further reviewed until CAEP8 in 2010.

2.6.2 Cruise NO_x certification

One of the CAEP activities has been to address the climate change impacts of aircraft NO_x emissions through studying the potential for a cruise NO_x certification. This activity got underway in 1998 under the auspices of CAEP Working Group 3 (Alternative Emissions Methodology Task Group – AEMTG). In addition, this has been studied under the 5th Framework Project 'NEPAIR' [Norman *et al*., 2003]. AEMTG has been considering the methodologies by which NO_x emissions might be certified and no recommendation was forthcoming at the CAEP6 meeting, other than that the so-called 'P3T3' method was the best NO_x calculation methodology. The AEMTG is continuing its work during the CAEP7 work programme towards recommending an overall methodology by which cruise NO_x might be characterised.

Thus, there is no cruise certification regime in prospect for the CAEP7 work programme – indeed the validation of the 'weighted NO_x' concept is looking as if it will not be completed, as promised by the WG3 Task Group AEMTG. Even if validation of the weighted NO_x concept were completed, a certification value/regime could not be accomplished before the CAEP8 meeting, at the earliest. This is approximately 2010. It would be reasonable to speculate that under current rates of progress and the recognised difficulties of achieving international consensus under ICAO, it may take longer, if achieved at all. Thus, the outlook for such a regime coming into international agreement and effect is possibly a decade or more away. Moreover, this would affect NO_x (and therefore O_3, CH_4 effects) only, and in a holistic approach would only be one regulatory tool within a suite of tools, or anticipated tools.

2.6.3 NO_x airport charges

Historically, ICAO LTO NO_x Certification has been the means by which local air quality concerns have been addressed. In Europe, air quality standards are in place for NO_2 that take no cognisance of the source, only whether the ambient level is exceeded or not. In addition, there are short-term and long-term standards. Thus, in the vicinity of an airport, if air quality standards are exceeded, the onus is upon the competent governmental authority to produce an air quality action plan that will result in compliance.

Such air quality regulations in Europe potentially represent a barrier for future growth and developments at airports (London Heathrow being a case in point), such that an emphasis on reducing NO_x for reasons of air quality is necessary in any case.

As part of the initiatives necessary to protect air quality, a small number of airports across Europe (notably in Sweden and Switzerland) have introduced locally-based landing charges, based upon NO_x emission levels. More recently, BAA have introduced such charges at LHR. This is on a kg NO_x/LTO basis: as such, this levies a higher penalty on larger aircraft. The basis of the LTO-NO_x calculation is the ICAO NO_x Certification data, as these are carefully made, internationally recognised measurements. However, there is no linkage, beyond this, to the D_p/F_{oo} parameter. The introduction of NO_x landing charges has been somewhat contentious and ICAO-CAEP have established a small group to examine the efficacy of such a regime.

However, for the purposes of introducing a NO_x-based flanking instrument, it is attractive as it does not need to be introduced in a GWP-compatible manner; it is not dependent on ICAO completing work before it can be introduced within Europe. Additionally, it has the added benefit of bringing extra pressure to bear on local air quality, and so is a co-benefit. The disadvantage of this approach is that it does not directly address contrails. This is taken up later in this chapter.

2.6.4 NO_x en-route charge

Calculation of NO_x emissions from aircraft is a relatively easy task that has been undertaken, even at high levels of sophistication, many times before. For example, this has been done in numerous 3D inventories (e.g. [Gardner *et al*., 1998; Baughcum *et al*., 1996; Eyers *et al*., 2004]).

The practicalities of dealing with large amounts of data are far from trivial but the basic computations are well established. The essence of such a calculation requires the following. A known aircraft type flies from a departure point to an arrival destination over a known route at given altitudes: from this, the fuel flow can be calculated with either proprietary or public-domain models and/or data (e.g. PIANO, BADA). Established algorithms can then be used to calculate NO_x emissions from the fuel flow using the ICAO engine certification data, along with temperature and humidity corrections from sea-level to altitude (e.g. [Gardner *et al*., 1998]). There are two principle algorithms is widespread usage; the DLR-2 fuel-flow method [Deidewig *et al*., 1996] and the Boeing-2 method [Baughcum *et al*., 1996].

Thus, it is conceptually possible to ‘monitor’ NO_x emissions. The primary data sources are the movements and the fuel flows. In principle, fuel flow could be provided by the airline. Such data are proprietary and not usually available. However, other modelled sources of data (e.g. PIANO and BADA) are considered to be accurate to within 10% or better. Thus, emissions can be calculated on an individual flight basis based either on actual data reported by the aircraft operator or on ex ante modelling data.

In conclusion, the most robust attribution that can be achieved practically, robustly and with high scientific certainty is NO_x emissions on a flight-by-flight basis, for which there is no reason why this should not be calculated with good accuracy. A NO_x en-route charge therefore appears to be a feasible flanking instrument in the near future. The question which arises, then, is how to distribute and use the revenues of such a charge? Who should receive revenues related to NO_x emissions produced above high seas? These questions are not analysed in this study and may require further research if this flanking instrument is selected.

2.6.5 Regulation of cruise altitudes to limit the production of contrails

In theory, it is relatively easy to avoid contrails. Persistent contrail production is determined *largely* by environmental conditions (ice supersaturation and temperature), *not* by the aircraft emissions (of water and particles) themselves, although a second-order effect is the *temperature* of the aircraft exhaust [Schumann et al., 2000]. Theoretical calculations demonstrate that contrails could be produced in the absence of any emission of particles [Kärcher *et al.*, 1998]. Also widely misunderstood is the role of water vapour emissions in contrails (and cirrus enhancement). Although the water vapour emitted from the aircraft engine serves to trigger initial formation of the contrail, the bulk of the water in the ice crystals of a contrail originates from the atmosphere itself [Schumann, 1996].

Recently, [Fichter *et al.*, 2005] have performed parametric studies of raising and lowering overall cruise altitudes of the global fleet. The 'headline result' was that for a lowering of 6,000 feet of the overall cruise altitude, a reduction of 43% contrail coverage could be obtained. The penalty for this was an increase of CO_2 emissions (note: *emissions*, not CO_2 radiative forcing – the consequential RF is rather complicated to calculate and depends upon various assumptions) and an increased emission of NO_x by approximately 4%. Other, similar work [Grewe *et al.*, 2002] suggests that the increased NO_x at lower cruise altitudes does not result in increased O_3 concentrations but rather reduced O_3 concentrations because of the complexities of atmospheric chemistry and removal rates. Clearly, such a crude approach was not intended to be a suggestion but rather a parametric study to determine the scale of the effect. More refined calculations are currently being designed (D.S. Lee and C. Fichter, personal communication).

However, the control of contrails once again begs the question of whether it is *worthwhile* to consider doing this – this remains an open topic and one firmly in the research domain. Worth mentioning is that whilst the large reduction obtained by [Fichter *et al.*, 2005] (on what apparently is a relatively small RF, according to recent estimates [Marquart and Mayer, 2002]) seems a somewhat fruitless exercise, it should be recognised that, to a first order, cirrus enhancement is a product of contrails. Thus, the potentially large estimates of RF from cirrus enhancement should be borne in mind before dismissing such an option. But as discussed above, even if it is established that reduction of contrails is a worthwhile 'target', implementing a system to manage the problem is a decade or more away.

2.6.6 Overall prognosis for the potential of flanking instruments to tackle non-CO_2 effects of aviation

As a result, flanking instruments have been examined. In terms of ICAO NO_x certification, the degree to which this achieves the goal is unclear; moreover, the regulatory process is slow, is not technology forcing and politically fraught because of its international dependencies. An ICAO-based cruise NO_x certification regime is many years away from fruition and is by no means guaranteed to succeed, since the same constraints over time and international negotiation apply as to the current NO_x certification regime. Lastly, for the limitation of contrails the prospect is potentially good, but this is many years away and besides all the technical difficulties and economic implications of such a regime, even on a European basis, the science is not good enough to embark on this route, and a subjective evaluation is that we are potentially 5 – 10 years away from a robust understanding of contrails and cirrus effects on RF. This leaves an airport NO_x landing charge as the most easily implemented and likely successful instrument. A careful regime will have to be devised, since it should not follow the ICAOI LTO scheme that allows for higher emissions from higher OPR engines.

2.7 Conclusions and outlook: Implications of science for policy making

In this chapter, the latest science regarding aviation and climate change has been reviewed and it has been found that the overall RF from aviation is effectively lower than that determined by the [IPCC, 1999] report. This is largely a result of the lowering of the contrail RF with improved model assumptions and parameterizations. However, the evidence for an effect of aviation on enhanced circus cloud coverage is much stronger, although no best estimate is yet available. If it is at the upper end of the estimated range, it would double the effective RF of aviation.

The metrics of climate change and their relation to aviation effects have been examined in detail. Apart from emissions of CO_2, it is difficult to equate aviation O_3-NO_x to GWPs and impossible to equate other effects such as contrails to GWPs. Aviation O_3 GWPs remain highly contentious. Radiative forcing provides an equitable means of comparing aviation effects, although this in itself is not completely clear because of the variability of the climate efficacy parameter (λ). However, RF and its derivative, RFI, were not designed to provide equivalency in the same way that GWPs were. A newly devised metric, the Global Temperature Potential, may provide an equitable way of comparing short-term effects with GWPs.

Three scenarios were contrived and examined in turn for their scientific integrity and practicality.

Scenario 1 required incorporating aviation CO_2 with a multiplier. The multiplier and its basis were not specified but the RFI was the obvious candidate. The RFI was examined in detail as to whether it was suitable and equitable to GWP and was found not to be. The GTP was examined in more detail and a derivative metric demonstrated here, an analogue to the RFI, the Global Temperature Index (GTI), was shown to be a potentially suitable candidate in the future for an equitable metric with GWP. Scientifically, scenario 1 cannot at present provide a suitable basis for incorporating aviation into the European Emissions Trading Scheme and doing so would have to be justified on the basis of the precautionary principle.
Scenario 2 required examining the potential for providing a GWP-compatible metric on an individual flight-by-flight basis. This scenario was not considered feasible at present, as O_3 enhancement was found to be too uncertain to provide

robust data and had intrinsic non-linearities and location/height dependencies. Moreover, aviation O_3 GWPs are contentious and the coupling with CH_4 chemistry makes this even more to devise metrics of quantification for ET. Contrails are difficult to quantify on a flight-by-flight basis except in a statistical sense. Moreover, the coverage is not the effect: the consequential RF is the effect and this is not GWP-compatible.

Scenario 3 was examined in terms of potential flanking instruments that needed no compatibility with GWPs and could be separately implemented. Flanking instruments for NO_x and contrails were discussed to ensure that potential negative trade-offs were minimised or further reductions of NO_x and contrails were induced. The candidate instruments for NO_x were: ICAO LTO Certification regime; a potential future ICAO cruise NO_x certification regime; and a local NO_x emissions landing charge. For contrails, a flight routing mechanism incorporated into air traffic management was considered. For this latter case, the science of contrail and enhanced cirrus cloud formation was considered too immature for implantation into a regulatory/control regime. For the NO_x options, reliance alone on further stringency increases in ICAO LTO NO_x was deemed unsuitable because of its allowance for higher NO_x emission indices with higher OPR engines and its long-term nature, with complex international dependencies. ICAO cruise certification was also rejected as it has similar international dependencies and, moreover, is possibly of the order of a decade away from agreement and implementation. A NO_x-based landing charge is considered as the most suitable flanking instrument in the short term and a kg NO_x/LTO is a straightforward metric that has no complexities over allowances of higher $EINO_x$ with higher OPR. Moreover, it has the co-benefit of going towards protecting local air quality. NO_x en route charges are also considered to be feasible[19].

19 For options on who might receive and what might be done with the proceeds generated by such charges, see Chapter 6 of the main report *Economic incentives to mitigate greenhouse gas emissions from air transport in Europe*, CE Delft, 2002.

3 Designing an emission trading scheme

3.1 Overview of key design elements

The study identifies several key design elements that would be required to cover climate impacts from the international aviation sector in the EU-ETS. In order to develop coherent policy options for including aviation in the EU-ETS, first the potential advantages and disadvantages of the choices associated with each of the above key design elements were evaluated. In this chapter, a description of the various choices within each design element and the results of the assessment are presented.

3.2 Trading entities

Which entity of the aviation sector should be responsible for surrendering allowances? This is one of the most important questions that must be addressed during design of an emissions trading system, since it has considerable impact on the administration of the scheme. Several options are available:

1 Aircraft operators.
2 Airports.
3 Fuel suppliers.
4 Providers of air traffic management (ATM).
5 Aircraft manufacturers.

Each of these options has specific advantages and disadvantages with regard to criteria of environmental effectiveness, possible distortions in competition and administrative and legal feasibility[20]. These are discussed below.

[20] In principle one can oblige any entity involved in the 'air transport services' product cycle to surrender allowances. This starts at one end with fuel suppliers or aircraft manufacturers and ends at the other with airlines or even passengers. If the emissions trading scheme is geared to entities on the 'cradle' side, one speaks of an 'upstream system', while a scheme geared to the 'grave' side is known as a 'downstream system'. Thus, obliging passengers to surrender allowances would be an additional option. This would involve enormous transaction costs, however, as millions of allowance traders would have to be supervised and monitored. This option has therefore not been included in the detailed analysis below.

3.2.1 Options

1 Aircraft operators

In this option, aircraft operators would have to surrender allowances for the climate impact they have caused. Non-EU aircraft operators would be treated exactly like their EU counterparts. They would also have to surrender allowances according to the climate impact they caused under the geographical scope of the European emissions trading scheme. In the case of free allocation of allowances, they would be allocated with allowances according to the same rules as EU air carriers. There would be no discrimination on the basis of an aircraft operator's country of registration[21].

Aircraft operators and air carriers

As an alternative rather similar to aircraft operators, air carriers – often also termed 'airlines' – might be obliged to surrender allowances. However, this alternative has disadvantages compared to the option of aircraft operators. Before discussing these, however, some background on the definitions of these two terms is appropriate:

- An aircraft operator is the natural or legal person who has continual effective disposal over the use or operation of the aircraft. To operate an aircraft the operator needs an air operator's certificate (AOC), issued by the competent authority of the State where the aircraft is registered, which affirms that the operator has the professional ability and organisation to secure the safe operation of aircraft (Article 2 (c), Council Regulation No. 2407/1992). The so-called Insurance Regulation states more precisely that the natural or legal person in whose name the aircraft is registered shall be presumed to be the operator, unless that person can prove that another person is the operator (Article 3 (c), Regulation (EC) 785/2004).

- An air carrier is an undertaking with a valid operating licence (Article 2 (b), Council Regulation No 2407/1992). This licence authorises the undertaking to carry passengers, mail and/or cargo for remuneration and/or hire (Article 2 (c), Council Regulation No 2407/1992). Basically, all air carriers are also aircraft operators, but not all aircraft operators are air carriers. EUROCONTROL (2005) states that it levies route charges on an average of 3,300 aircraft operators per month. Only 600 of these operators are air carriers. However, they account for roughly 95% of the overall charges levied. In other words, air carriers are fewer in number but account for the bulk of the charges. One can assume that the same applies to emissions and climate change impacts caused by aviation.

Since air carriers are responsible for most of the aircraft emissions and climate impacts of aviation, an obvious solution in an ETS would be to oblige them to surrender allowances. However, that would exclude from the scheme emissions and climate impacts from aircraft of those operators who are not air carriers, for example, aircraft which are owned and operated by large companies but which do not provide commercial services. From an environmental and economic point of view it would not make sense to exempt such aircraft operators from the scheme. Restricting emissions trading to air carriers only would result in too narrow coverage of emissions and climate impacts of aviation. But since air carriers are a subset of aircraft operators, all air carriers would be included by definition if the emissions trading obligation were placed on aircraft operators.

Leasing of aircraft can also be dealt with adequately under the aircraft operator option since JAR-OPS 1.165 clearly defines under which AOC an aircraft is operated in the case of wet or dry leasing.

[21] For more details, see chapter 7 on legal analysis.

However, one disadvantage of the aircraft operator option would be that it would also cover several rather small aircraft operators. This would increase the administrative cost of the scheme and reduce its efficiency. But this could be avoided by defining a de-minimis rule, similar to the approach in stationary sources (for example, 20 MW thermal input capacity).

Such a rule should be compatible with already existing rules. Aircraft operators exclusively engaged in operations with, for example, aircraft of less than 8,618 kg MTOW (maximum take-off weight) could be excluded from the obligation to surrender allowances for the emissions and climate impact they caused (see Section 3.3.3 for a discussion of alternative cut-off points).

An alternative de-minimis rule that might be considered is the number of flights per year per aircraft operator. Some operators might enter the scheme less than once a week. For these operators the administrative burden would be substantially higher in relative terms than for those operating several thousand flights per year under the scope of the emissions trading scheme. Consideration might therefore also be given to cutting off all operators entering the scope of the scheme less than 53 times per year (frequency threshold). As with all operation-based thresholds, however, this might create unintended incentives to avoid the obligations of the emissions trading scheme, for example by splitting one aircraft operator with more than 52 flights a year into several smaller operators that do not exceed the threshold. Section 3.3.3 provides the impacts on the number of aircraft operators and emissions excluded from the scheme under various assumptions for a frequency threshold.

For stationary source the thresholds are clearly capacity-based and so do not create such incentives. However, some Member States currently suggest introducing additional thresholds based on CO_2 emissions or operating hours in order to exclude operators with rather small emissions. The Commission was always rather reluctant to adopt such suggestions and it is unlikely that such thresholds would be introduced for the period from 2008 to 2012. We therefore recommend refraining from frequency thresholds in the aviation sector unless operation-based thresholds are introduced for stationary sources.

2 Airport operators

In this option, airport operators on the territory of the European Union would have to surrender allowances. However, since the climate impact of aviation is not induced by airports as such but by aircraft, airport operators would have to surrender allowances for the emissions of the aircraft landing or taking off at their airports. This option would thus also require that aircraft operators be obliged to monitor and report their emissions and climate impacts to the airport operators. In other words, in this option aircraft operators would have to be actively involved even though they are not obliged to surrender allowances. The rules under which aircraft operators would have to report emissions to airport operators would have to be defined centrally and could not be left to the discretion of the airports[22].

3 Fuel suppliers

This option is quite different from the previous two. While the first two options can be characterised as 'downstream' approaches, this is an 'upstream' approach. The basic idea is that suppliers of aviation fuel would be obliged to surrender allowances according to the CO_2 emissions caused when the fuel is burned. To cover their costs for additional allowances they would increase their fuel prices

[22] These rules depend on the regional coverage of the emissions trading scheme and on the coverage of emissions and climate impacts (see Section 3.3 and Chapter 2, respectively).

correspondingly[23]. To the extent that operational or technical efficiency measures were less expensive than the additional cost caused by the price increase, airlines would realise these measures. Airlines would pass on the additional cost to their passengers and users of freight services, who in turn would have to decide whether to pay the increased price or reduce their demand for air transport services.

4 Air traffic managers

Under this option providers of air traffic management (ATM) would be obliged to surrender allowances for all flights that are covered by the emissions trading scheme. As with the option involving fuel suppliers, the ATM providers would need a mechanism to pass on the cost of purchasing allowances to their customers, the aircraft operators. They in turn would implement those mitigation measures that are less expensive than the additional charges imposed by the ATM providers.

5 Aircraft manufacturers

Finally, one might consider obliging aircraft manufacturers to surrender allowances. In this case the average climate impact caused by an aircraft would be calculated up-front. Aircraft manufacturers would be required to surrender the relevant number of allowances when they deliver an aircraft to their customers. Correspondingly, manufacturers would be given an incentive to develop and provide aircraft with specifically low climate impacts[24].

3.2.2 Comparative assessment

As initially mentioned, each of the above presented options has specific advantages and disadvantages. These *pros* and *cons* are discussed in the sections below.

1 Aircraft operators

Basically it is the aircraft that causes emissions and climate impacts of aviation. Therefore, aircraft operators would have direct control over all technical and operational measures to reduce aviation's climate impact and over the necessary monitoring data. This way it can be guaranteed that the emission reduction is achieved effectively and with an adequate incentive structure. This is the most important advantage of the airport operator option since most of the other require some kind of mechanism to pass on the incentives to the aircraft operators.

Under this option emissions trading in aviation can basically be extended to other climate impacts in the future even if the scheme is initially limited to CO_2 and

[23] From the airlines' point of view this option is rather similar to a tax or a charge, except that they would not transfer the funds to the state but to the fuel supplier.

[24] The climate impact of an aircraft depends on both the aircraft itself and the engine. In principle, any aircraft type can be fitted with different types of engine. Although the client can influence the engine type actually fitted, aircraft are still sold and delivered by aircraft manufacturers rather than engine manufacturers. Putting both aircraft und engine manufacturers under an obligation to surrender allowances would create no clear incentives and make the scheme more complex. If aircraft manufacturers only were subject to the obligation they could 'share' the incentives with the engine manufacturers, giving the latter an indirect incentive.

NO_X. Since this is not the case with some of the other options this has to be considered as another important advantage.

At present, EUROCONTROL charges about 3,300 aircraft operators with route charges for their air traffic management services. Basically speaking, under this option these same operators would also be covered by the emissions trading scheme. This might mean involving an overly large number of entities in emissions trading, particularly when it is borne in mind that the European trading scheme for stationary sources includes only some 11,700 installations. However, if a de-minimis rule is applied, the number of aviation entities can be reduced to an appropriate level. This is justified, firstly, because such de-minimis rules are also applied in the trading scheme for stationary sources and, secondly, because the group of small aircraft operators is large in number but accounts for only a marginal share of total emissions (see Section 3.2.1 and 3.3.3).

The feasibility of the aircraft operator option is based on the assumption that non-EU operators would be treated exactly like their EU counterparts. If this cannot be guaranteed, this option would create severe distortions in competition. The legal analysis has shown that equal treatment of non-EU and EU operators is feasible (see Chapter 7).

In the public consultation recently carried out by the Commission not only the aviation industry but also several NGOs and other players preferred the aircraft operator option to all others. A trading scheme based on this option will therefore enjoy greater political acceptance and bear less risk of not being implemented.

2 Airport operators

Under the airport operator option, coverage of climate impacts can also be extended to encompass the full range of impacts, even if the scheme starts with trading in CO_2 and NO_X. Apart from that, however, the airport option has several drawbacks compared to the aircraft operator option.

The most important disadvantage is that airport operators have neither direct control over the climate impacts of aviation, nor the data necessary to monitor those impacts. They would therefore have to pass the economic incentives of the trading scheme on to aircraft operators, by levying a charge, for example. In a competitive environment, airports would pass on these incentives to the airlines adequately. Given the monopolistic market status of many airports, however, it cannot be guaranteed that they will pass on the incentives. Even in the case of perfect competition, there is no guarantee that each airport would design an incentive structure that passes the price signal of allowances on to aircraft operators effectively and efficiently. It would therefore be necessary to introduce a harmonised mechanism, e.g. by regulation, for all airports, clearly a drawback compared with the aircraft operator option, where such a mechanism is unnecessary.

In addition, airports would have to involve aircraft operators to monitor the climate impact of their aviation operations. On the one hand this would result in higher administrative costs for this option, as both airports and aircraft operators would be involved in monitoring. On the other hand it may also create problems, as the private-entity aircraft operator would have to report sensitive data to another private entity, in particular if confidential ex post data on fuel consumption is to be reported (see Section 3.7.1).

The main attraction of the airport option is that it conceptually is closer to that of a fixed installation used in the current ETS. However, in reality this is not a major advantage as the current framework in any case would need to be adapted to include aviation, at which occasion the specificities of aviation could be taken into account.

3 Fuel suppliers

The major advantages of the fuel supplier option are that it basically covers all CO_2 emissions on intra-EU and outbound flights and that, of itself, it does not discriminate between non-EU and EU aircraft operators. Fuel suppliers would pass on the cost of surrendering allowances to all aircraft operators, independently of whether or not they are registered in an EU country. Correspondingly, not only intra-EU flights would be covered under this option but all outbound flights, too, unless tankering strategies are employed by aircraft operators. When asked, several airlines reported a fuel penalty of 2.5% - 3.5% per hour (depending on the stage length) for taking extra fuel on board. Assuming an allowance price of € 10 per tonne CO_2 and a fuel price of € 400 per tonne, this would imply that it would be profitable to take extra fuel on board from 'unregulated areas' for incoming flights to the EU with a flight time of less than 3.5 hours. If the allowance price remains at the recent level of well over € 20 per tonne CO_2, this flight time will double and thus double the potential tankering behaviour. Consequently, the major advantage of this option also brings with it a severe disadvantage, since it creates unintended avoidance strategies that not only reduce the coverage of the trading scheme, but also result – because of the fuel penalty – in additional emissions.

Another advantage of this option is that the administrative burden would be comparatively low. This is because the number of fuel suppliers is rather limited. Data on the market structure of fuel suppliers in Europe are not available. However, according to estimates by fuel suppliers, the global market is dominated by a few large suppliers: Exxon/Mobil 15%, Shell 12-13%, BP 12-13%, Chevron and Texaco some 9% each[25]. The market share of these large suppliers varies from country to country, but one can basically assume a rather similar market structure in all Member States and in the EU as a whole, with less than 10 large suppliers accounting for almost two-thirds of the market and up to about 100 smaller suppliers the rest. Given the fact that these fuel suppliers are already confronted with fuel taxation and pass on mechanisms for other mobile sources, one can assume that in this option the additional administrative burden would be comparatively low.

[25] Personal communication with BP/Aral Germany on 8 June 2005.

Of all the climate impact factors, only CO_2 and H_2O emissions can be attributed to fuel use and under this option it would therefore be rather difficult to cover the total climate impact of aviation. Even NO_X emissions cannot be covered by an upstream approach. This would not be a problem if the trading scheme were to cover only CO_2 at the start. However, introduction of an emissions trading scheme is limited to a window of opportunity that is open for a certain time frame but closed for a long time thereafter. In other words, even if scientific knowledge on other climate impacts of aviation improves in the future, it will be almost impossible to include these impacts in the scheme, as this would require a shift of the entity regulated. Choice of this entity is such a basic design option, however, that such a shift is not readily accomplished. If this option is selected, the aim to 'address the full climate change impact of aviation'[26] by including it in the existing emissions trading scheme will have to be abandoned unless the climate impacts of aviation that are not directly fuel-related are addressed using other flanking instruments.

Finally, it should be duly noted that from the airlines' perspective this option is rather similar to a fuel tax or charge, regardless of whether allowances are auctioned or allocated to fuel suppliers free of charge. In both cases fuel suppliers would pass on the cost of purchasing (additional) allowances to their customers. However, in as far as they also can pass on their opportunity costs for those allowances which they have received free of charge, fuel suppliers would benefit from windfall profits. Correspondingly, this option would not be welcomed by the aviation industry, which would have to bear the cost of abatement measures while not being able to benefit from the windfall profits. Although this would not disturb the economic efficiency of the trading scheme as such, it might still substantially reduce the political acceptance of emissions trading in the aviation sector if this option were selected.

4 Air traffic managers

Air traffic managers (ATM) already have dealings with aircraft operators when they provide their services and charge them accordingly. Hence, this option would create relatively lower transaction costs, as a mechanism for passing on costs is already established. As with the airport operator option, however, this option would require further involvement of aircraft operators, in particular if ex post monitoring is applied (see Section 3.7). Correspondingly, the administrative costs might be less than under the *airport* operator option, but are unlikely to be less than under the *aircraft* operator option.

As with the aircraft or airport operator option, total climate change impacts could, in principle, also be addressed under the ATM option. However, since the economic incentives must be passed on to the aircraft operators, this option would have the same disadvantages as the airport option.

[26] See title of the terms of reference to this project.

The most important drawback of this option, however, is the somewhat strange market structure: some ATM providers are public, others semi-public authorities. They serve regionally separated markets and do not compete with each other, but coordinate their services through EUROCONTROL. It is hardly conceivable that these entities would create a competitive market in a closed emissions trading scheme that is restricted to aviation entities only. Even in an open emissions trading scheme, though, ATM providers would be more like an authority that acquires additional allowances from other sectors and passes on those costs to aircraft operators. From their perspective this option would also be perceived as a tax, with all the disadvantages cited in the previous options.

5 Aircraft manufacturers

The only advantage of this option would be that it involves very few entities. Consequently, monitoring efforts would be fairly limited and so therefore would administrative costs. Apart from this, though, there are no other advantages to be identified. On the contrary, this option has several decisive drawbacks.
First, it would not be legally feasible to oblige manufacturers based outside the EU to participate. Accordingly, this would saddle EU-based companies with competitive disadvantages.

Second, only technical measures relating to aircraft technology would be addressed (fuel efficiency, aerodynamics, etc.), with incentives to introduce operational measures such as increasing load factors, improving maintenance or changing flight profiles being restricted. Third, it would not be possible to address the total climate impact of aviation.

3.2.3 Conclusions

This discussion of the pros and cons of the various options has shown that none is perfect. They each have their advantages and drawbacks. Several have major disadvantages, however, and these should be excluded from further consideration. This is clearly the case for the last two options: the aircraft manufacturer option would create severe market distortions and would not generate incentives for operational avoidance measures, while the air traffic management option should be excluded because the market structure is unsuitable for an emissions trading scheme.

The airport operator option, while in some respects similar to the aircraft operator option, has several disadvantages over the latter: it would require development of a sophisticated mechanism to pass on the costs of purchasing allowances; it would result in higher administrative burdens, as both airport and aircraft operators would be involved in monitoring; and it would require surrender of sensitive and potentially confidential data from one private entity to another. Since it has no specific advantages, but several disadvantages over the aircraft operator option, it should be also excluded from further consideration.

Each of the remaining two options, aircraft operators and fuel suppliers, has several advantages. The fuel supplier option is easier to administer and would thus result in less administrative cost. Furthermore, it would cover not only all intra-EU flights but all outbound flights as well and would less likely be legally challenged by non-EU operators since aircraft operators are not directly involved under this option. The major drawbacks, however, are that it would create unintended incentives to avoid the obligations of emissions trading by applying fuel tankering strategies and that total climate impact cannot be addressed under this option unless it is combined with other flanking instruments.

The aircraft operator option would directly affect the entities with control over technical and operational abatement measures and monitoring data. This would guarantee the most effective and efficient incentives for emission reduction. In addition, this option would allow non-CO_2 climate impacts to be addressed at a later stage, when scientific knowledge on these other impacts has sufficiently matured. However, since non-EU operators would be treated like their EU counterparts, this option bears the risk that this legal position might be challenged by non-EU operators at international courts, especially with regard to controlling emissions over the high seas. Potential legal obstacles are discussed further in Chapter 7 of this report.

Table 7 Pros and cons of options for different entities being obliged to surrender allowances

	Pros	Cons
1 Aircraft operators	• Direct control of abatement measures and monitoring data • Scope for including non-CO_2 impacts in the future • High political acceptance	
2 Airport operators	• Closer to concept of fixed installations used in sectors currently included in ETS	• Sophisticated mechanisms to pass on costs of allowances necessary • Risk of ineffective incentive structure established by airports • Transfer of sensitive or even confidential data between two private entities necessary
3 Fuel suppliers	• Low administrative costs • CO_2 of all intra-EU and outbound flights will be covered	• Unintended incentives for avoiding trading obligations through tankering • Only fuel-related climate impacts can be addressed
4 Air traffic managers		• Unsuitable market structure for trading
5 Aircraft manufacturers		• Not legally feasible to oblige manufactures outside the EU to participate; hence, competitive disadvantages for EU companies • Operational measures cannot be addressed

Table 7 summarises the major pros and/or cons of each option. It shows without a doubt that options 2, 4 and 5 have serious drawbacks and should be excluded from further consideration. Options 1 and 3 both have important advantages. In our analysis, however, the (major) disadvantages of the fuel supplier option are worse than the (major) disadvantage of the aircraft operator option. In particular, the incentive for fuel tankering may reduce the environmental effectiveness of emissions trading in aviation, particularly if the market price of allowances rises. Furthermore, there is broad support within the aviation sector for the choice of aircraft operators as trading entity. Our recommendation, therefore, is to oblige aircraft operators to surrender allowances rather than fuel suppliers.

3.3 Geographical scope

3.3.1 Introduction

The 'scope' of greenhouse gas emissions refers to the coverage of aviation emissions under the trading scheme. With regard to the scope to be defined under an EU emissions trading scheme, decisions must be made on two issues:
- Which countries, routes, and/or airspace are to be covered (geographical scope, reviewed in Section 3.3.2).
- Which type of flights/aircraft are to be covered (Section 3.3.3.).

The latter decision relates, for example, to the issue of whether or not very small aircraft or military aviation should be included.

These decisions will depend in part, at least, on the following:
- Amount of emissions captured under the scenarios considered (Section 3.3.4.).
- Number of airports and airlines involved in each scenario (Section 3.3.5.).
- Evaluation of pros and cons of the scenarios considered (Section 3.3.6).

3.3.2 Geographical scope: description of five scenarios

In relation to geographical coverage, various scenarios have been considered in this study, each specifying a different set of countries or routes to be included in the scheme. The following scenarios were examined:
- Scenario 1: Intra-EU routes.
- Scenario 2a: Intra-EU and 50% of emissions on routes to and from EU airports.
- Scenario 2b: Emissions from all departing flights from EU airports.
- Scenario 3: All emissions in EU airspace.
- Scenario 4: Emissions from all departing flights from EU airports plus remaining emissions in EU airspace.
- Scenario 5: Intra-EU and routes to and from third countries that have ratified the Kyoto Protocol.

The scenarios are described below[27].

[27] See Annex G for an overview of countries covered by the various scenarios of geographical scope.

Scenario 1: Intra-EU routes

Scenario 1 covers flights on the following aviation routes:

1 Domestic routes within the 25 EU Member States.
2 Routes between the 25 EU Member States.

Intra EU-routes, as defined for scenario 1, are strictly limited to the European part of the 25 EU Member States' territories. This implies that the following routes are *not* included:

- Domestic routes within Ultra Peripheral Regions (UPR)[28], Overseas Countries and Territories (OSCT)[29] and countries outside the EU but within the European Free Trade Association (EFTA).
- Routes between the EU and UPR, OSCT or EFTA countries.

However, as part of the emission calculations (see next chapter) the amount of emissions for these routes have been computed and presented separately, so that the implications for environmental effectiveness are clear in the event of these routes being ultimately included in an emissions trading system.
An overview of Ultra Peripheral Regions, Overseas Countries and Territories and the EFTA countries is provided in Annex H.

Scenario 2a: Intra-EU and 50% of emissions on routes to and from EU

Scenario 2a covers emissions of flights on the following aviation routes:

1 Domestic routes within the 25 EU Member States.
2 Routes between the 25 EU Member States.
3 Half of the emissions from international flights departing from one of the 25 EU Member States to 3rd countries (i.e. non-EU States).
4 Half of the emissions from international flights arriving at one of the 25 EU Member States from 3rd countries.

Scenario 2b: Emissions from all departing flights from EU airports

Scenario 2b also includes all emissions from Intra-EU flights. In addition, emissions for flights departing from the EU to 3rd countries are covered by the system. Emissions of flights flying from 3rd countries to the EU are not covered. It can be expected that the amount of emissions covered by this scenario will be close to that of scenario 2a.

Scenario 3: All emissions in EU airspace

Scenario 3 relates to the aviation emissions in EU airspace. An important issue in this scenario is how exactly to define 'EU airspace'. For this study the EU airspace was defined on the basis of the Flight Information Regions (FIRs) of the EU Member States, as specified in their Aeronautical Information Service publications and employed by EUROCONTROL. The FIRs employed by EUROCONTROL encompass not only the national territories of individual countries, but may also include particular areas of seas and oceans. For flights comprised in this scenario, the route section used for estimating emissions runs

28 See Annex H for an overview of these regions.
29 Ibid.

from initial entry into EU airspace (airport of departure if this is located in a EU25 Member State) to final exit from EU airspace (airport of arrival if this is located in a EU25 Member State).

Scenario 4: Emissions from all departing flights from EU airports plus remaining emissions in EU airspace

Scenario 4 is a combination of scenario 2b and scenario 3. As in scenario 2b, all emissions related to flights departing from EU airports are covered (i.e. including Intra-EU flights). In addition, scenario 4 covers all remaining emissions in EU airspace. These emissions relate to flights from 3rd countries to the EU and flights which do not depart or arrive at an EU airport, but which make use of EU airspace.

Scenario 5: Intra-EU + routes to and from third countries that have ratified the Kyoto Protocol

Scenario 5 is a route-based system that can be more readily tied to the Kyoto Protocol. More specifically, the idea is that all emissions on international routes between Annex B countries that have ratified the Kyoto Protocol (and are explicitly subject to the obligation contained in Article 2(2) thereof), are included in an emission trading scheme. For the EU Member States this would mean that under scenario 5, besides including emissions on Intra-EU routes, the scheme would also cover all emissions on routes between EU Member States and 3rd countries that wish to participate in the EU trading scheme. For the quantification of emissions under scenario 5 it is assumed that the Annex B countries that have ratified the Kyoto Protocol would participate in a route-based emission trading scheme (in this study these countries are referred to as 'Annex B countries'). An overview of these Annex B countries is presented in Annex H of this report.

Summary of emissions covered by the scenarios

Table 8 provides an overview of the percentage of emissions on various routes covered under each of the scenarios. The table shows that emissions on routes within the EU (both domestic routes within EU Member States and routes between EU Member States) are fully included in all scenarios. The scenarios thus differ only in the extent to which they include emissions on international routes between the EU and 3rd countries and international routes between 3rd countries.

In scenario 2a, 50% of the emissions on international routes between the EU and 3rd countries are included in the emission trading system. Scenario 2b covers the full emissions on routes departing from the EU. In scenario 3 the percentage of emissions included must be assessed for each individual route on the basis of the distance flown in EU airspace. Scenario 3 also includes international routes between 3rd countries insofar as these routes make use of EU airspace (overflights). Scenario 4 is equal to scenario 2b for the routes departing from the EU and equal to scenario 3 for the other international routes making use of EU airspace. In scenario 5 the emissions on international routes between EU States and Annex B countries (including the EFTA countries, as these countries have also ratified Kyoto) are fully included, while emissions on international routes between EU States and all other 3rd countries (termed 'Non-Annex B countries' in

Table 2) are fully excluded. Furthermore, scenario 5 in principle includes emissions on international routes between non-EU Annex B countries. Emissions on these routes have not been quantified in this study, however, because the flight data for these routes are incomplete.

Table 8 Percentages of emissions included for EU-related routes under various scenarios

Routes	Scenarios					
	Scen. 1	Scen. 2a	Scen. 2b	Scen. 3	Scen. 4	Scen. 5
Intra-EU routes						
Domestic EU States	100%	100%	100%	100%*	100%	100%
Between EU States	100%	100%	100%	100%*	100%	100%
International routes between EU Member States and 3rd countries						
EU – Annex B/EFTA	0%	50%	100%	Per route**	100%	100%
Annex B/EFTA – EU	0%	50%	0%	Per route**	Per route**	100%
EU – Non-Annex B	0%	50%	100%	Per route**	100%	0%
Non-Annex B – EU	0%	50%	0%	Per route**	Per route**	0%
International routes between 3rd countries						
Annex B/EFTA – Annex B/EFTA	0%	0%	0%	Per route**	Per route**	100%***
Annex B/EFTA – Non-Annex B	0%	0%	0%	Per route**	Per route**	0%
Non-Annex B – Annex B/EFTA	0%	0%	0%	Per route**	Per route**	0%
Non-Annex B – Non-Annex B	0%	0%	0%	Per route**	Per route**	0%

* Full route length is covered, also if use is made of airspace of non-EU States.

** Depending on distance flown in EU airspace. For international routes between 3rd countries only a limited part of the flights make use of EU airspace.

*** In this study emissions on routes between Annex B/EFTA countries have not been quantified, because the flight data for these routes are incomplete.

3.3.3 Which flights or aircraft types should be included?

An important question related to scope is whether the emissions of all types of flight and/or aircraft type should be included in the EU ETS. The background to this question is whether it is possible to exclude emissions of certain elements of air traffic in order to limit administrative complexity and transaction costs, while still capturing the vast bulk of total emissions. In this respect it is noted that the present EU-ETS for stationary sources also relates only to installations that exceed certain minimum capacity standards.

With respect to aviation, emissions could be excluded on the basis of:
1 Type of flight, based on flight rules.
2 Type of flight, based on flight purpose.
3 Aircraft weight.
4 Number of operations by trading entities.

Below, these options for ‘cut-off points’ are elaborated.

(1) Type of flights based on flight rules
With respect to flight rules a distinction is made between Instrument Flight Rules (IFR flights) and flights with Visual Flight Rules (VFR flights). VFR flights generally relate to short flights with small aircraft. Compared with IFR flights, emissions related to VFR flights are therefore limited. It is to be noted, furthermore, that IFR flights are centrally registered by EUROCONTROL. Flights

operated entirely as VFR are not registered by EUROCONTROL and are therefore also not included in the PRISME database of EUROCONTROL. Including VFR flights would require relatively large additional administrative efforts for capture of only limited additional emissions. It is therefore recommended that the EU ETS encompass only IFR flights.

(2) Type of flight based on flight purpose

In this respect the first distinction to be made is between military and civil flight purpose. In the terms of reference for this study it is indicated that military emissions are to be excluded from the emission trading scheme for the moment. Military flights can be distinguished in two ways:

- On the basis of a distinction between flights operating under military ATC flight rules versus flights operating at least in part under civil flight rules.
- On the basis of the flight coding of a flight, military flights having a separate code.

In this respect it is noted that not all flights with a military flight coding operate under military flight rules, and that some of these flights thus operate at least in part under civil flight rules.

In line with the terms of reference it is assumed that flights under military flight rules are excluded from the emission trading scheme. An additional argument for this choice, in the case of EUROCONTROL playing a role in monitoring and/or verification, is that these flights are not registered by EUROCONTROL and are therefore also not included in the PRISME database of EUROCONTROL. Military flights under civil flight rules are registered by EUROCONTROL, on the other hand, and these flights could be included in the emission trading scheme. In relation to the emission calculations made for this study it is noted that military flights under civil flight rules have been included in the computational results. If these flights were to be excluded for the Intra-EU routes, the amount of emissions captured by the emission trading scheme is estimated to decrease by 1.5%.

(3) Aircraft weight

The next question is whether and if so what weight level would be appropriate to use as a system boundary, with a mind to environmental effectiveness, availability of emission calculation methods for small aircraft and the transaction costs involved, taking into account existing weight thresholds used in international legislation. An important existing weight threshold in international legislation is the one of 8,618 kg established in Volume I of ICAO Annex 16 on the basis of which the distinction between chapter 3 and 4 aircraft versus chapter 6 and 10 aircraft is made. Chapter 6 and 10 aircraft are internationally regarded as small aircraft. Though the boundary of 8,618 kg in ICAO Annex 16 relates to noise regulation, the present emission charging systems in both Switzerland and Sweden also takes into account the boundary of 8,618 kg.

To be sure that on the basis of the above-mentioned weight boundary the environmental effectiveness of the system is still guaranteed (in terms of capturing the vast bulk of emissions), a comparison was made between the amount of emissions associated with aircraft with MTOW < 8,618 kg and aircraft with MTOW >= 8,618 kg. This comparison was made for the IFR flights operated in 2004 on the Intra-EU routes (scenario 1), and is presented in Table 9. The table shows that 10% of the IFR flights on Intra EU routes in 2004 were operated with small aircraft (i.e. MTOW category < 8,618 kg). In terms of emissions, however, the contribution of small aircraft is far more limited. Only about 0.5% of the emissions (both CO_2 and NO_x) are associated with small aircraft. The contribution of small aircraft to emissions is much smaller compared to their contribution to number of flights, because the average distance flown by small aircraft is much less and because fuel use per km is far more limited. It should be noted, moreover, that the numbers in the tables relate to Intra-EU routes only. The contribution of small aircraft to emissions on the other potential routes to be included (i.e. routes between the EU and 3rd countries) is even more limited, because these routes are generally operated by large aircraft only. The overall conclusion is thus that by excluding small aircraft on the basis of a threshold of 8,618 kg, environmental effectiveness is clearly guaranteed. An additional argument for setting a weight level is that the fleet mix for small aircraft is very diverse, and ex ante emission calculations are relatively unreliable.

Table 9 Comparison between number of flights, flight km and emissions for small versus large aircraft (for IFR flights on Intra EU routes in 2004)

	Unit	Aircraft MTOW category		Total
		< 8,618 kg	>= 8,618 kg	
Absolute quantities				
Flights	1000 flights	587	5,259	5,847
Flight Nm	million Nm	127	2,360	2,486
CO_2 emissions	million kg	309	51,875	52,184
NO_x emissions	million kg	1.02	204.56	205.58
Percentage per MTOW category				
Flights	%	10.0%	90.0%	100.0%
Flight km	%	5.1%	94.9%	100.0%
CO_2 emissions	%	0.6%	99.4%	100.0%
NO_x emissions	%	0.5%	99.5%	100.0%

Source: EUROCONTROL.

(4) Number of operations by trading entities

In Section 3.2 it was concluded that aircraft operators are the most suitable trading entities.

Excluding part of the air traffic on the basis of operator size is an option, with size then being defined, say, on the basis of annual number of flights executed. Thus, any operator with less then a certain number of flights executed on a yearly basis could be excluded from the EU ETS. This could be supplemental to the cut-off points, implying that only IFR flights under civil flight rules with aircraft MTOW >=8,618 kg are included in an EU ETS.

In the next section an overview is presented of the number of operators that might be involved as potential trading entities in an EU ETS (see Section 3.2). In Table 15 operators are categorised based on the number of Intra-EU flights in

2004. As the table shows, in 2004 over half the operators involved in Intra-EU flights flew less then 1 flight per day. Note that these flights include only IFR flights under civil rules with an aircraft MTOW >=8,618 kg. In scenario 1, if the criterion were that only operators with more than 1 flight a day would fall under an EU ETS, the number of potential trading entities would thereby be reduced by 55%, with only a limited number of flights (and associated emissions) left uncovered.

In Directive 2002/30/EC on the establishment of rules and procedures with regard to the introduction of noise-related operating restrictions at Community airports, the criterion is that only airports with over 50,000 movements per year of civil subsonic jet aircraft with an MTOW > 34,000 kg have to comply with the requirements of that directive. If the same criterion were applied to the EU ETS, the number of airports involved would fall to below 200 (see Table 14). However, although not calculated, the amount of emissions which would then not be covered is likely to be significant.

Summary of cut-off points

Table 10 provides an overview of the pros and cons of the various cut-off points discussed above, evaluating them with respect to the following criteria:
– Coverage of emissions.
– Administrative complexity.
– Leakages.

With the first criterion, the issue is the extent to which the amount of aviation emissions covered by the EU ETS is affected by introduction of the cut-off points. The second criterion is concerned with the question of whether administrative complexity (and related transaction costs) is significantly limited by adopting the various cut-off points. The final criterion relates to the scope created by the cut-off point for certain flights to avoid being subjected to the EU-ETS (leakages). If, for example, airports with <=50,000 movements a year were excluded from an EU ETS, it is conceivable that small airports would grow to just below this figure, although in the current situation such airports can get by with significantly less.

Table 10 Overview of pros and cons of cut-off points

Cut-off point by excluding	Coverage of emissions	Administrative complexity	Leakages
VFR flights	o / -	+ +	o / -
Flights under military ATC	-	+	o
Flights with military flight purpose	o / -	o / +	o
Aircraft with MTOW < 8,618 kg	o / -	+ +	o
Operators <=365 flights per year	o	+ +	o / -
Airports <=50,000 movements per year	- -	+ + +	- -

Legend: o = neutral; - = negative effect; + = positive effect

On the basis of the inventory of possible cut-off points and the overview of pros and cons, it is recommended that the following types of flight are excluded from the EU ETS:

- Flights with Visual Flight Rules (VFR flights).
- Flights under military ATC flight rules and flights with a military flight purpose.
- Flights operated by aircraft with an MTOW < 8,618 kg.

A further relevant option is to exclude operators (or airports) with a limited number of annual operations from the EU ETS. However, if the cut-off point were to be based on the annual number of operations indicated in Directive 2002/30/EC (per airport, 50,000 movements per year of civil subsonic jet aircraft with an MTOW > 34,000 kg), there would be a significant impact on the amount of emissions covered. Potential leakages would be introduced, moreover, as some of the flights from larger airports might be shifted to airports with less than 50,000 movements a year. To avoid this leakage effect, while still significantly reducing administrative complexity, it is recommended that only the very small operators (or airports) are excluded.

3.3.4 Amount of emissions under the five scenarios

The calculated amounts of emissions under the various scenarios serve several purposes:

1 They provide an indication of the amount of emissions captured under the respective scenarios.
2 Depending on the allocation criteria for allowances[30], they may give an indication of the number of allowances the aviation sector will need to acquire to cover its emissions and the marginal impact of the scheme on the existing system.

The text below summarises the findings with regard to the amount of emissions covered by the five scenarios. Annex G to this report provides a more detailed overview of emissions under each route group and underlying assumptions used. Furthermore, Annex G provides an overview of flight km and number of flights per route group within each geographical scenario.

Table 11 compares both the CO_2 and the NO_x emissions captured under the respective scenarios, doing so in both absolute and relative terms. For the comparison in relative terms, the emissions for the maximum scenario (i.e. that capturing most emissions) have been normalised to 100%. As the table shows, scenario 4 (emissions associated with flights departing from EU plus remaining EU airspace emissions) is the maximum scenario. Scenario 1 captures about 30% of the emissions under the maximum scenario. The emissions captured under scenarios 2a and 2b are very comparable (both about 80% of the emissions under the maximum scenario). The emissions under scenario 3 are

[30] If the aviation sector only need surrender allowances for emission growth above a certain baseline (e.g. historic base year), the results of this chapter will provide no indication. Under this allocation criterion, estimates of growth levels are required. See chapter 5 (environmental effects).

about 70% of the maximum scenario[31]. Scenario 5 captures about 40% of the maximum scenario. However, in relation to scenario 5 it is noted that under this scenario emissions on routes between non-EU countries participating in the ETS would also be captured. Emissions between non-EU countries have not been quantified, however, because not all of these flights are executed entirely or in part in the airspace for which EUROCONTROL is providing the central (air traffic) flow management service.

Table 11 Comparison of emissions captures in various geographical scenarios (based on the year 2004)

Substance / scenario	Absolute (in million kg per year)	% of maximum scenario (scenario 4)
CO_2 emissions		
1 Intra-EU	51,875	32.0%
2a Intra-EU +50% routes to/from EU[32]	130,287	80.4%
2b Departing from EU[33]	130,403	80.5%
3 Emissions in EU airspace	114,337	70.6%
4 Departing from EU + EU airspace	161,988	100.0%
5 Route-based system	72,449	44.7%
NO_x *emissions*		
1 Intra-EU	204.56	29.0%
2a Intra-EU +50% routes to/from EU	564.11	80.1%
2b Departing from EU	564.76	80.2%
3 Emissions in EU airspace	480.78	68.3%
4 Departing from EU + EU airspace	704.22	100.0%
5 Route-based system	294.93	41.9%

Source: EUROCONTROL flight data and emission calculations.

The growth of emissions (both CO_2 and NO_x) is presented in table 12. The table shows that it is above all the emissions associated with (longer) international routes that have grown significantly over the period 2002-2004. Emissions related to domestic routes have grown considerably less, in fact even declining a little between 2003 and 2004 in the case of CO_2. Table 12 indicates, furthermore, that the growth rates of CO_2 and NO_x emissions are very similar.

31 Scenario 3 includes the emissions in the Shanwick Oceanic FIR (EGGX). The airspace in this region does not 'belong' to any State, but has been included in the EU airspace scenario. In this FIR (west of the UK and Ireland) about 7,000 million kg of CO_2 is emitted. This is 6% of total CO_2 emissions in scenario 3.

32 Note that calculations have been based on the ANCAT methodology. This does not take account differences in fuel use due to jet streams between a flight from North America to Europe instead of the other way around. Therefore, differences between scenarios 2a and 2b may be underestimated.

33 Ibid.

Table 12 Increase of CO_2 and NO_x emissions over the period 2002-2004

Substance / route group	Annual % increase of emissions	
	2003 relative to 2002	2004 relative to 2003
CO_2		
Domestic routes	1.3%	-0.1%
Intra-European routes	4.7%	3.6%
Other international routes	8.1%	7.9%
Total	6.7%	6.2%
NO_x		
Domestic routes	1.4%	0.0%
Intra-European routes	3.8%	2.9%
Other international routes	8.1%	7.5%
Total	6.6%	5.9%

The relative share of non-EU operators in emissions varies widely per route group. In the year 2004 on domestic EU routes and routes between Member States, non-EU operators were responsible for only 1.2% and 2.9% of total CO_2 emissions, respectively, while on routes between the EU and 3rd countries they accounted for almost half of the total CO_2 emissions. As a consequence, the relative share of non-EU operators in emissions also varies widely across scenarios. In scenario 1 about 2.5% of CO_2 emissions are associated with non-EU carriers (year 2004). In scenarios 2 through 4 this percentage varies between 20% and 30%. In scenario 5 the contribution of non-EU operators to total CO_2 emissions is about 15%. Across all scenarios the relative share of non-EU operators in NO_x emissions is very comparable to the case for CO_2.

Finally, in Table 13, the CO_2 emissions computed for the various scenarios covering aviation emissions are compared with an estimate of the emissions allocated under the national allocation plans of the 25 EU Member States. These latter emissions relate to industry and electricity production, the sectors covered by the present European emission trading system. For the first trading period (2005-2007) the 25 Member States have allocated 2,190 megatonne of CO_2 emissions per year. As Table 13 illustrates, the CO_2 emissions covered in the various aviation scenarios for the year 2004 are between 2.4% and 7.7% of this amount.

Table 13 Comparison of CO_2 emissions under present EU Emission Trading System and aviation CO_2 emissions covered by geographical scenarios

	CO_2 emissions in million kg per year	% of present CO_2 emissions in ETS
CO_2 emissions under present Emission Trading System (2005-2007)[34]		
Allocated CO_2 emissions	2.200.000	100.0%
Geographical scenarios for aviation emissions (2004)		
1 Intra-EU	51,875	*2.4%*
2a Intra-EU +50% routes to/from EU	130,287	*5.9%*
2b Departing from EU	130,403	*5.9%*
3 Emissions in EU airspace	114,337	*5.2%*
4 Departing from EU + EU airspace	161,988	*7.4%*
5 Route-based system	72,449	*3.3%*

3.3.5 Number of airports and airlines involved

Apart from the emission calculation results for the various scenarios, in relation to administrative complexity it is of interest to know how many entities would participate in the emission trading scheme in the various scenarios. On the basis of EUROCONTROL data, the number of participating entities can be assessed for two alternative options:

- The trading entities are airports.
- The trading entities are aircraft operators.

Table 14 shows the number of airports per EU country involved in IFR operations, irrespective of route group (based on 2004 data). This is thus the number of airports involved in scenario 1. It is also the number of airports involved in the other scenarios. This because it can be safely assumed that there are no airports in the EU involved in international routes with non-EU countries but not with Intra-EU routes. In this context it should be borne in mind that Intra-EU routes are included in all the scenarios (see Table 14).

For scenarios 2a and 2b, it can be assumed that only EU airports would participate in emission trading (in the event of airports acting as trading entities).

For scenarios 3 and 4, the option of airports in the EU being the trading entities is not applicable if it assumed that overflights are also included. In this case both scenarios include flights which make use of EU airspace but which do not depart from or arrive at an EU airport.

Under scenario 5, the emissions on international routes from the EU to Annex B countries or EFTA countries can be assigned to the departure airport in the EU. Furthermore, in this scenario, as it is assumed that Annex B and EFTA countries are willing to participate, the emissions on international routes from these countries to EU member States can be allocated to the departure airport in the Annex B or EFTA countries. In this scenario, airports in Annex B and EFTA

[34] It should be noted that the overall amount of allowances issued for each year in the period 2008-2012 is likely to be smaller than the amount issued for 2005-2007. The comparison therefore mainly illustrates the order of magnitude.

countries are thus also involved. However, the number of airports involved in Annex B and EFTA countries under scenario 5 is not presented in Table 14.

Table 14 shows the number of EU airports involved in Intra-EU operations in 2004: a total of 829. This figure is based on the recommended cut-off points described in Section 2.3 (only IFR flights under civil ATC flight rules operated by aircraft with MTOW >= 8,618 kg). The airports are categorised on the basis of annual number of departures. As Table 14 shows, many airports have only a very limited number of departures annually; in fact, about half the airports have no more than 1 departure per week.

Table 14 Number of airports per EU country involved in Intra-EU operations (based on 2004 data)

	Country	Categorisation by yearly number of departures at an airport						Total
		>100,000	=<100,000 and >10,000	=< 10,000 and > 3,650	=< 3,650 and >365	=< 365 and > 52	=< 52	
1	Austria	1	1	4	1	3	2	12
2	Belgium	1	1	2	3	5		12
3	Cyprus		1	1	1			3
4	Czech Republic		1		4	5	4	14
5	Denmark	1	1	4	7	4	2	19
6	Estonia			1		2	3	6
7	Finland		1	4	17	2	1	25
8	France	2	13	17	83	35	16	166
9	Germany	2	15	11	34	38	32	132
10	Greece		4	6	18	13	6	47
11	Hungary		1			6	3	10
12	Ireland		3		7			10
13	Italy	2	16	9	26	13	2	68
14	Latvia			1		1	1	3
15	Lithuania			1	2	1		4
16	Luxembourg		1					1
17	Malta		1					1
18	Netherlands	1	2	3	3	4	2	15
19	Poland		1	5	4	9	10	29
20	Portugal		3		2	6	3	14
21	Slovakia			1	4	2	1	8
22	Slovenia		1		1	2	1	5
23	Spain	2	8	13	18	7	11	59
24	Sweden	1	3	11	27	11	3	56
25	United Kingdom	2	20	12	33	26	17	110
	Total	15	98	106	295	195	120	829

Source: EUROCONTROL

Table 15 shows the number of operators involved in the various scenarios if aircraft operators were to act as trading entities. For Intra-EU flights the table also provides a breakdown of operators according to the number of flights performed in 2004. Where data are available, a distinction is made between EU and non-EU operators.

As Table 15 shows, there is not that much difference between the various scenarios. Furthermore, if the figures are compared to those of Table 14, it can be concluded that the number of trading entities would be broadly similar whether airports or operators acted as trading entities.

There are a fair number of airports and operators with only a limited number of departures per year that could potentially be excluded on the basis of an additional cut-off point (see Section 3.3.3). With operators as trading entities, an additional cut-off point of 1 flight per day (365 flights per year) would reduce the number of operators involved from 774 airlines by 290 plus 139 (see Table 15). This would then imply inclusion of 345 operators (a reduction of 55% compared with the situation in which all 774 aircraft operators are included in the EU ETS). The additional cut-off point would have a limited effect on the percentage of flights and emissions captured. The maximum number of flights that would not be captured would be 365 x 429 = about 150,000 flights, which is only about 3% of the total number of flights under scenario 1.

Table 15 Number of operators involved in various scenarios (based on 2004 data)

Scenario	Operator nationality			
	EU	Non-EU	Unknown	Total
Number of operators involved in various scenarios				
Scenario				
1 Intra-EU	414	345	15	774
2a Intra –EU+50% of routes to/from EU	431	423	17	871
2b All departing flichts from EU	431	423	17	871
3 Emissions in EU airspace	442	467	18	927
4 Departing from EU + EU airspace	442	467	18	927
5 Route Based system	419	381	16	816
Number of operators for Intra EU flights by categori9sation of number of flights per year				
Number of flights per operator in 2004				
> 10,000 flights	n.a.	n.a.	n.a.	80
=< 10,000 and > 3,650 flights	n.a.	n.a.	n.a.	63
=< 3,650 and > 365 flights	n.a.	n.a.	n.a.	202
=< 365 and > 52 flights	n.a.	n.a.	n.a.	139
=< 52 flights	n.a.	n.a.	n.a.	290
Total	**n.a.**	**n.a.**	**n.a.**	**774**

Source: EUROCONTROL

3.3.6 Evaluation of the scope scenarios

In this section, the different scenarios for the geographical scope of the scheme are assessed[35]. Below, the main findings are presented.

[35] A legal evaluation is included in Chapter 7 of this report.

Environmental effectiveness

There are three 'routes' by which the scope of the scheme can influence its environmental effectiveness:

- The flights and routes covered.
- The part of the flights and routes covered.
- Leakages: the potential for avoiding the scheme.

The first two issues were presented in detail in Sections 3.3.2 to 3.3.5. Here, so-called leakages are discussed.

Leakages occur if airlines have scope for adjusting their behaviour so as to avoid falling under the system. Such avoidance behaviour may obviously undermine the environmental effectiveness of the scheme. Two possibilities are distinguished:

1 First, in a system based on airspace (scenarios 3 and 4), airlines may adapt their flight paths so as to minimise the distance flown in EU airspace. Arguably, this could result in longer flight distances and thus have an overall negative impact on fuel use and emissions. For airlines, the associated financial effects might be more than offset by a reduction of the distance flown in airspace subject to the system. This is a realistic possibility. On some routes airlines do in fact avoid the airspace of countries levying high route charges. Routes on which this might play a role with respect to emissions trading include Helsinki – Istanbul.
   There is a means of preventing avoidance behaviour that minimises the distance flown in EU airspace: by assigning flights a default amount of emissions based on aircraft type and a 'standard route' from departure to destination airport. If such a system were extended to allow airlines to show that in reality they had produced less emissions than attributed, incentives to take operational measures to minimise in-flight emissions would not be reduced. In the route-based scenarios (1, 2 and 5) the issue of minimising flight distance through EU airspace obviously plays no role.

2 Airlines can also avoid the system by planning additional intermediate landings on long-haul flights at airports falling just outside the scope of the system. In route-based scenarios, this has the advantage that the second stage of the flight no longer falls under the ETS. This kind of behaviour is very unlikely, however. Owing, among other things, to the additional landing and take-off charges and the fuel use associated with an extra LTO, the costs of an intermediate landing far outweigh the cost savings of avoiding payment of allowances (see Sections 5.3 and 6.4). In addition, passengers would not react favourably to the increased travel time. This kind of avoidance behaviour is therefore not to be expected.

Economic distortions

Economic distortions will reduce support for the system and hence feasibility of introduction. The analysis of this issue is described in-depth in Chapter 6 (economic impacts) of this report.

Operational feasibility
With respect to operational feasibility, the pros and cons of each scenario with respect to the scope for emissions monitoring are discussed. The results of this evaluation are included in Section 3.7 (monitoring and reporting methods).

Potential for wider implementation
Here we are concerned with the issue of symmetry, i.e. whether double counting of emissions would occur if the scenario were implemented by other states. In scenarios 1, 2, 3 and 5 there would be no overlap if other entities introduced schemes based on the same principle. In scenario 4 there would be overlap. The scheme could, however, be scaled down to scenario 2b or 3 at the time of introduction of other schemes.

Potential for global coverage
This criterion relates to the intuitively appealing idea that all flights would be covered fully if all states were to join the scheme or introduce similar schemes. As not all airspace has been attributed to a particular country or region, some gaps might remain if scenario 3 were to be expanded[36]. Depending on the exact definition of airspace, this might significantly affect the environmental effectiveness of the scheme. Expansion of the scope of any of the other scenarios would lead to global coverage.

3.4 Interplay with the Kyoto Protocol

Greenhouse gas emissions from fuel consumption in international aviation are not covered by the Kyoto Protocol. Accordingly, they are reported separately in national inventories as memo items (International Bunkers, Aviation). Greenhouse gas emissions from domestic aviation are, in contrast, covered by Kyoto and have to be reported under the common reporting format category '1 A 3 a ii Domestic aviation'. This category 'includes all civil domestic passenger and freight traffic inside a country. All flight stages between two airports in one country are considered domestic no matter the nationality of the carrier or the subsequent destination of the aircraft' [IPCC 1996, p. I.93]. All air traffic between two different countries is considered international aviation, including the entire LTO cycle of these flights. Military and private aviation are not included in either of these categories. Private aviation is a very minor contributor (usually below 1%) and military aviation in included under category '1 A 5 Other'. In the greenhouse gas inventories of Member States and the European Community flights between two European countries are considered as international aviation.

[36] In considering options for allocating responsibility for reporting emissions between Parties, the Subsidiary Body for Scientific and Technical advice under the UNFCCC has rejected the airspace-based principle for similar reasons.

3.4.1 Potential problems of integrating international aviation

Due to the exclusion of international aviation's greenhouse gas emissions from the national totals reported by Parties to the UNFCCC and thus from the quantified targets under the Kyoto Protocol, these emissions are not covered by Assigned Amount Units (AAUs) – at least not during the first commitment period, from 2008 to 2012. These AAUs are based on the commitments inscribed in Annex B of the Kyoto Protocol and define the amount of greenhouse gas emissions a country may emit during the first commitment period. They are measured in tonnes of CO_2 equivalent (tCO_2e). As the climate impact of aviation is included in neither the base year nor the target years, they basically are not covered by AAUs[37].

In particular, then, problems will arise if and when aviation sector emission rights are sold to sectors that are covered by the European emissions trading scheme (EU ETS). Before illustrating this, however, let us first look at trades from stationary sources to the aviation sector.

In the initial situation (Figure 6) EU ETS entities are endowed with European Union allowances (EUA), which are earmarked AAUs[38]. At the end of the commitment period, their aggregated emissions must not exceed the amount of allowances they possess. Aviation entities are endowed with aviation units which are not backed by AAUs. The non-EU ETS entities (private households, service sector, terrestrial transport, etc.) do not possess any allowances or emission rights. However, their emissions are covered by the AAUs of the respective Member State. All AAUs, those for the EU ETS and those for the non-EU ETS sectors, are stored in the Kyoto registry of that country.

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[37] In addition, the Kyoto protocol does not cover the entire climate impact of aviation. Since the protocol relates only to the so-called Kyoto gases (CO_2, CH_4, N_2O, HFCs, PFCs and SF_6), other climate impacts of aviation (NO_X, water vapour, contrails, cirrus clouds, etc.) are not covered.

[38] EUAs can be used for compliance under the EU ETS (Directive 2003/87/EC). AAUs are for compliance under the Kyoto protocol. They will be earmarked as EUAs when Member States issue the allocated allowances to operators holding accounts in their registries. The registries for the EU ETS at the same time serve as registries under the Kyoto protocol. Correspondingly, they contain all AAUs allocated to a country under the Kyoto protocol, some of them earmarked as EUAs. EUA transfers between two countries will all be checked automatically, for integrity purposes, by the Community Independent Transaction Log (CITL). The subset of EUA transfers occurring between registries will also be checked automatically by the UNFCCC Independent Transaction Log (ITL), as foreseen by the rules of the Kyoto protocol. The design of the EU registries system ensures that the tracking of EUAs is fully consistent with the tracking of Kyoto units.

Figure 6 Initial situation (before any trade)

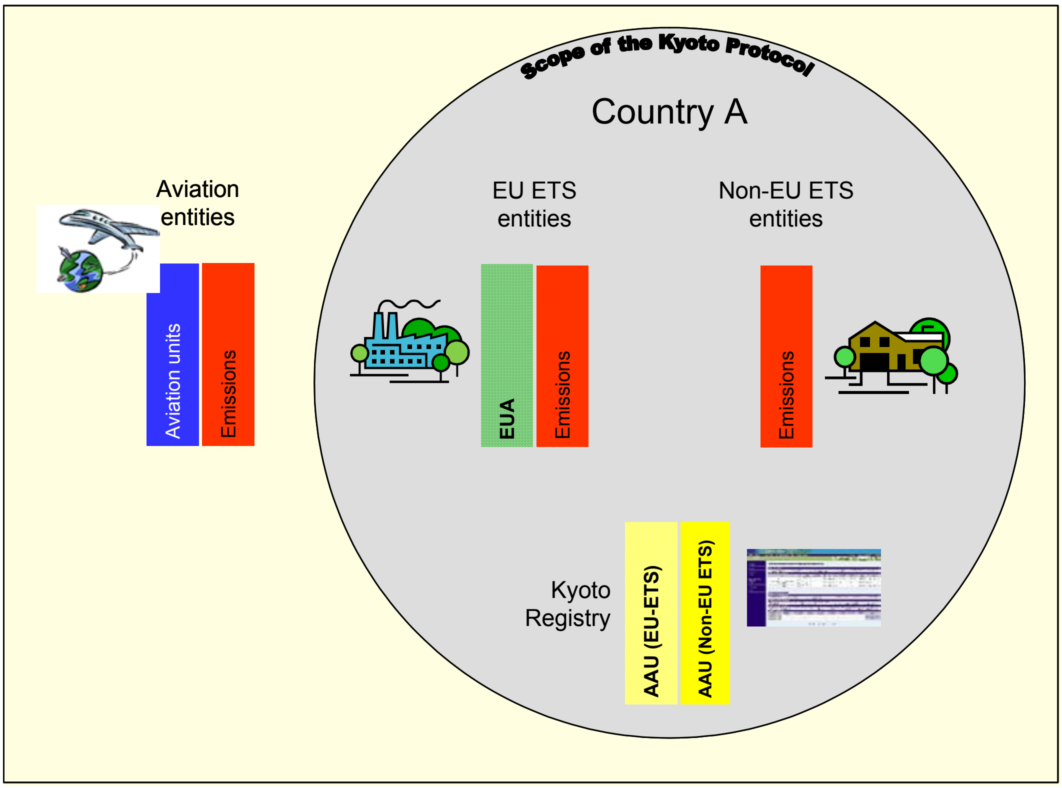
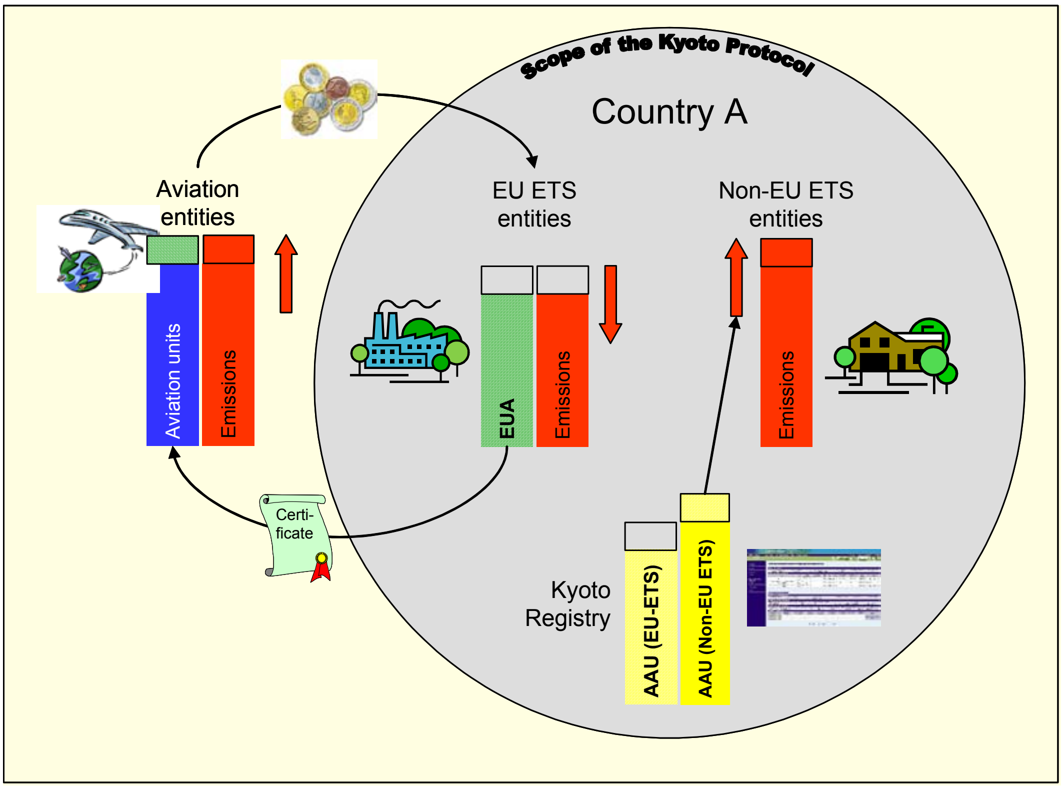


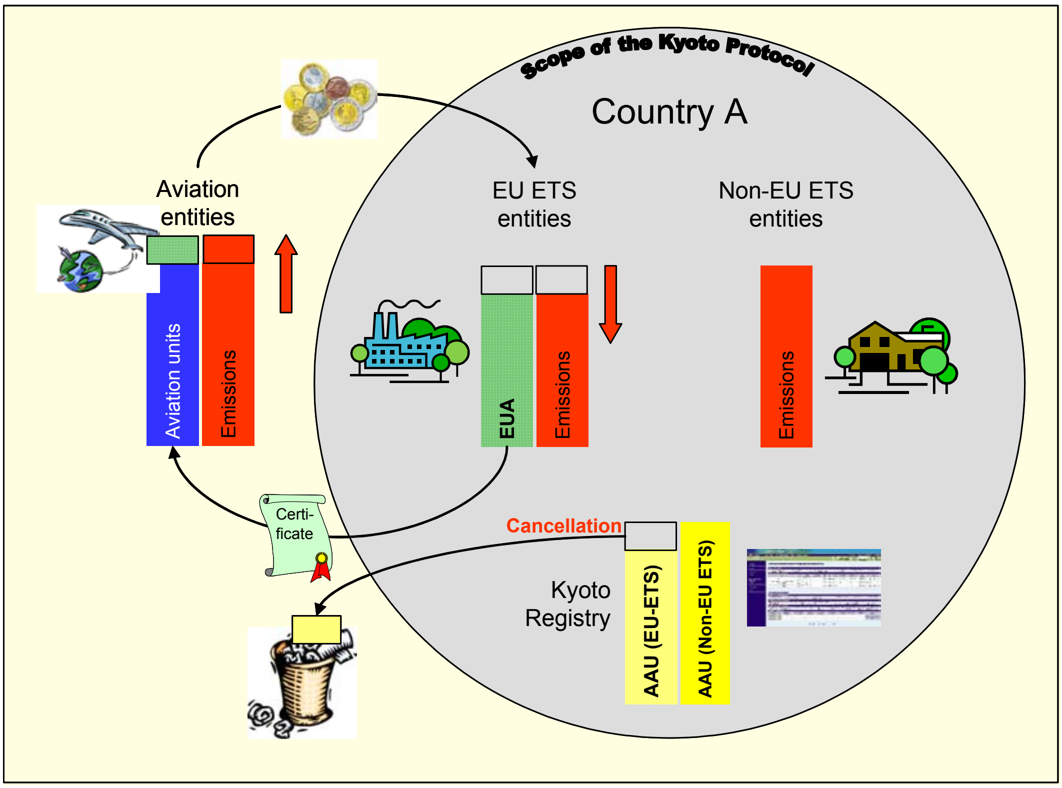
Figure 7 describes the situation after one EUA is sold by an EU ETS entity to an aviation entity. The EU ETS entity has decreased its emissions by 1 tCO_2e and can, accordingly, sell 1 EUA certificate to the aviation sector. This will result in 1 tCO_2e higher emissions in the aviation sector, i.e. outside the scope of the trading scheme. Through that transaction, the country in question now has 1 spare AAU in its registry, which might be used to increase emissions of non-EU ETS entities by 1 tCO_2e.

Figure 7 Sale of an EUA to an aviation entity without cancellation



Accordingly, this transaction would result in double counting of the reduction because emissions would be increased by 2 tCO_2e although only 1 tCO_2e was reduced. Obviously, such a trade would violate the integrity of the combined Kyoto Protocol and aviation cap unless the spare AAU is cancelled (Figure 8).

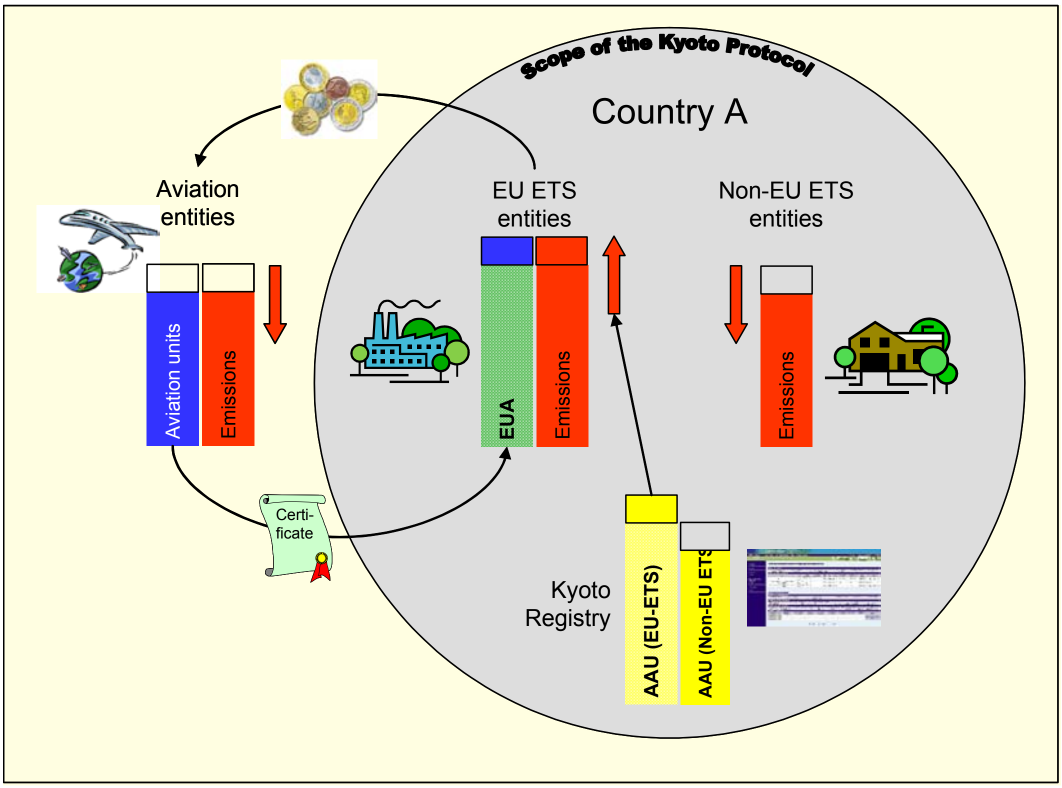
Figure 8 Sale of an EUA to an aviation entity with cancellation



In an open trading scheme Member States would therefore see themselves obliged to track net transfers of EUAs between EU ETS and aviation entities and cancel the corresponding amount of AAUs at the end of the commitment period to guarantee the integrity of the combined Kyoto Protocol and aviation cap.

Transactions in the opposite direction would cause even greater difficulties (Figure 9). If an aviation entity decreases its emissions by 1 tCO_2e, it can sell 1 aviation unit, not covered by an AAU, to an EU ETS entity. The latter entity will increase its emissions by 1 tCO_2e. Correspondingly, the country would need 1 more AAU to cover all the emissions of the EU ETS entities. But since the aviation unit is not covered by an AAU, the country can only cover all EU ETS emissions if it employs non-EU ETS AAUs for the EU ETS sector. As a consequence, non-EU ETS entities must reduce their emissions by 1 tCO_2e.

Figure 9 Situation 2: Sale of an Aviation unit to an EU ETS entity



Evidently, a transfer of 1 emission right from aviation to EU ETS entities would result either in a decrease of 2 tCO_2e or in under-compliance of the respective country with its obligations under the Kyoto Protocol. In other words, a trade from the aviation sector to an operator of an EU ETS installation would allow an increase in emissions in the EU ETS sector but as long as aviation allowances are not covered by AAUs, a tightening of targets for the non-EU ETS sectors. As the aviation sector will probably be a net buyer of allowances, however, this case is less likely – at least in a net perspective.

3.4.2 Possible solutions for the integration of international aviation

Several options are available for avoiding these problems:

1 *Extending the scope of the Kyoto Protocol:* abolishing the exemption of aviation from any quantitative obligation.

2 *Borrowing of AAUs from sectors not covered by the EU-ETS*
AAUs from sectors not covered by the EU ETS would be used temporarily to underpin international aviation emissions under the geographical scope with AAUs. Correspondingly, aviation entities would be allocated allowances that are fully fungible, i.e. the aviation sector would be free to buy and sell allowances within the sector and to trade with other sectors under the EU ETS without any restrictions. Since all allowances will be surrendered at the end of the commitment period, they are only “loaned” to the aviation sector.

3 *No allocation of allowances to the aviation sector:* aircraft operators would not be allocated allowances free of charge, but would have to buy all the allowances required for compliance on the market.
4 *Obligation to buy allowances for emissions growth above a certain baseline.*
5 *Semi-open trading for aviation:* aircraft operators can only buy allowances or Kyoto units (ERU, CER, RMU, etc.) from non-aviation operators, but are not allowed to sell any allowance or Kyoto unit to them.
6 *Gateway (trade restrictions):* aircraft operators can sell, at most, as many allowances as they, as a sector as a whole, have already bought from non-aviation agents during the trading period.

1 Extending the scope of the Kyoto Protocol

The first option would avoid any trade restrictions. However, it cannot be realised during the first commitment period from 2008 to 2012, because the Kyoto Protocol has already been ratified and can no longer be changed. In subsequent commitment periods, however, the scope of the protocol might be extended to include international aviation[39]. Rajendra Pachaur, chairman of the Intergovernmental Panel on Climate Change (IPCC), claimed at COP10 that aviation should be included in the Kyoto regime [AGE 2005, p. 13]. Since negotiations on the targets for the second commitment period are scheduled to start in 2005, it would be necessary to put the issue on the agenda, for otherwise it will even be difficult to realise this, the most appropriate option during the second commitment period.

2 Borrowing of AAUs from sectors not covered by the EU-ETS

Option 2 would make use of the AAUs allocated under the Kyoto Protocol to cover the non-EU ETS sectors of the economy e.g. households, road transport etc. Many of these AAUs are expected to be sitting in Party holding accounts in national registries without being used until the point of retirement under the Protocol (after 2012). Some of these AAUs could be used on a temporary basis in two different ways: Firstly, they could underpin all allowances allocated to the aviation sector. In this way, the aviation sector would be able to trade freely with the other EU ETS sectors. Secondly, a smaller number could be used to underpin a flexible inter-registry gateway system. In this way, an allowance arriving from an account owned by an existing EU ETS operator into an aviation operator's account would be stripped of its AAU. This AAU would be placed in a specific account, which would be drawn upon again when an aviation operator wished to transfer an allowance back to an account owned by an existing EU ETS operator. As with the first method, this system would mean that the aviation sector would be able to trade freely with the other EU ETS sectors. Making the second method operational would require software expertise, since transferring AAUs from allowance to allowance automatically would necessitate altering part of the registries system. However, this freedom for aviation operators would have the same implications for AAUs as options 5 and 6 if, at the end of a specific

[39] This would imply, on the one hand, including aviation as such in subsequent agreements or protocols and, on the other, extending the notion of 'Kyoto gases' to include the climate impacts of aviation that are not currently covered by the Kyoto protocol (NO_X, water vapour, contrails, cirrus clouds, etc.).

period of time, there had been a net transfer of allowances from the EU ETS sectors to the aviation sector i.e. cancellation of AAUs to avoid emission reductions being double counted and leakage from the system occurring. Under this option, there would also be the theoretical possibility, if in reality unlikely, of a net transfer of allowances flowing in the opposite direction: from the aviation sector to the other EU ETS sectors. Therefore, again, not all of the AAUs borrowed by the aviation sector might be able to be returned to the Member State.

3 No allocation of allowances to the aviation sector

The third option appears to be a straightforward solution, as it does not allocate allowances to the aviation sector at all. In this case, then, no earmarking of allowances as AAUs would be necessary. The aviation sector would have to buy all the allowances it needs from other sectors, with no additional aviation allowances being created. Emissions trading within aviation would be based on allowances from the EU ETS and Kyoto units only.

4 Obligation to buy allowances for emissions growth above a baseline

The previous option would increase the demand for allowances and Kyoto units substantially and put a higher financial burden on the aviation sector. It might also result in a higher allowance price and would thus affect stationary sources as well. To reduce these potential economic impacts, the obligation to surrender allowances might be limited to emissions growth relative to a base year or base period (baseline). If aviation sector entities only had to surrender allowances for additional emissions above the average of, say, the period 2000 to 2005, the financial burden would be much lower.

From an environmental economics perspective the aircraft operators would, in this case, be endowed with an unlimited right to cause the same climate impact they caused in the base period. Implicitly, the aircraft operators would be allocated emissions rights free of charge according to the so-called grandfathering principle (historic emission). However, these emission rights are not tradable and can only be used by the aircraft operator to which they were allocated.

Basically, the greater the scope of any emissions trading scheme, the greater its efficiency. Since this option does not cover the baseline emissions of the aviation sector, it is less efficient than options covering the total emission of the EU ETS and the aviation sector without applying any trade restrictions.

5 Semi-open trading for aviation

Option five is based on a strong restriction of trading from the aviation sector to stationary sources. Aviation entities would be allocated with allowances. However, these allowances would not be earmarked as AAUs and aviation entities would not be allowed to sell any allowance to the non-aviation sector. In order to avoid double counting of reductions and to guarantee the integrity of the combined Kyoto Protocol and aviation cap, at the end of the commitment period Member States would have to cancel as many AAUs as EUAs were sold from the EU ETS to the aviation sector.

Since it is generally assumed that avoidance costs for greenhouse gas impacts are much higher for aviation than in non-aviation sectors, the aviation sector is likely to be a net buyer of allowances. Accordingly, the restrictions embodied in this option will not have too great an effect on the efficiency of emissions trading within aviation. However, overall efficiency might be lower than in an entirely unrestricted trading regime, as the following example illustrates. If an aviation entity holds more allowances than needed – because of a slump in business, for example – selling of excess allowances might be restricted to sale to other aviation entities. Cognisant of their competitor's situation, entities interested in buying allowances would then only do so at a reduced price. Price differentials in a market for a basically homogeneous product such as allowances indicate inefficiencies. However, in a strongly growing market like the aviation sector, these inefficiencies will be rather small and might be accepted as a price for compatibility of the scheme with the Kyoto Protocol.

6 Gateway (trade restrictions)
Option six is rather similar to option four. Aviation allowances that are not earmarked as AAUs would be allocated to aviation entities, but the trading of those entities would be restricted to guarantee that, in net terms, no allowances are transferred from aviation to non-aviation entities. Option six is less restrictive, as it would limit trading only in those cases where the net trade balance between the aviation sector as a whole and the EU ETS sector is negative. Aviation allowances would basically be fully fungible, but specifically earmarked in the registries. AAUs of EUAs which are transferred from the EU ETS to the aviation sector would be separated from the allowance and put in a specific account (gateway). If an aviation entity intended to sell an allowance to the EU ETS sector, this transaction could only be completed to the extent there were sufficient AAUs available in the gateway. To guarantee integrity of the combined Kyoto Protocol and aviation cap, at the end of the period all the AAUs remaining in that gateway would have to be cancelled.

Basically, this gateway can be established either at the individual Member State registries or at the so-called Community Independent Transaction Log (CITL[40]). However, centralised administration would reduce restrictions to a minimum. In the case of Member State administration, a transfer from aviation to the EU ETS sector might be held back because the gateway is empty of AAUs, even though sufficient AAUs are available in other Member State's gateways. This kind of restriction can be avoided if the gateway is established centrally.

3.4.3 Conclusions

The first option would avoid any trade restrictions, as AAUs would be created for international aviation as well. However, international agreement on the incorporation of international aviation in the quantitative targets of the Kyoto Protocol is unlikely to be realised in advance of the first commitment period, from

[40] http://europa.eu.int/comm/environment/ets/welcome.do.

2008 to 2012. Consequently, at least until 2013 this option is deemed unfeasible for including aviation in the EU ETS.
Option two would also avoid any trade restrictions, as AAUs are used from sectors not participating in the EU ETS. However, this option requires a clearing house mechanism for optimal registry purposes as well as agreement by all member states on a mechanism in the event of not all borrowed AAUs being returned at the end of the commitment period. This situation may occur if there is a net flow of tradable units from the aviation sector to other sectors covered by the EU ETS.
As most of the emissions and effects of aviation are not underpinned by AAUs, all other options are designed to ensure continued integrity of the EU ETS. This implies either that no EU allowances are allocated to the aviation sector (options 3 and 4) or that trade restrictions are set (option 5 and 6).
If the aviation sector has high marginal abatement costs compared to other sectors, as is generally assumed, and in the absence of over-generous allocation of allowances, aviation would be a net buyer of allowances. Correspondingly, continuing this assumption, bringing aviation into the EU ETS would result in additional demand for allowances on the EU ETS market. This implies that it is to be expected that the special design features under options 2 to 6 (e.g. closing of the Gateway), required in the case of net selling by the aviation sector, may not be 'switched on'.

Domestic emissions
Another question concerning the interplay with the Kyoto Protocol is whether emissions and climate impacts of domestic aviation should be included in or exempted from emissions trading. Including them as well seems adequate, since domestic aviation is not yet covered by any regulation regarding climate impacts. Moreover, integration of domestic aviation would facilitate administration of the scheme for the regulated entities, as they would not have to differentiate between domestic and international aviation in their calculations of tariffs.

Keeping the climate impacts of domestic aviation separate might also cause distortions by creating incentives to re-route international flights to domestic airports in order to avoid the additional cost induced by emissions trading: flights from Munich to Brussels or Luxembourg might, for example, be re-routed to Cologne and flights from Barcelona to Lisbon to Badajoz, a Spanish airport close to the border to Portugal. However, such incentives would probably only be relevant in the larger Member States (France, Germany, Poland, Spain, etc.) and might also be avoided if domestic aviation were to be affected by other, equivalent measures such as fuel taxes.

Concerning allocation of allowances, another advantage of integrating domestic aviation would be that a share of the allowances would be covered by AAUs. This might alleviate the trade restrictions necessary to guarantee the integrity of the combined Kyoto Protocol and aviation cap (see above) because the aviation entities would have allowances which they could sell even before they have purchased EUAs. In this case, however, there would need to be clear differentiation between those aviation allowances covered by AAUs and allowances that are not covered. A mechanism would still be needed to guarantee that the aviation entities as a whole did not sell more allowances not covered by AAUs to the EU ETS sector than they have previously purchased. At the end of the commitment period, in addition, AAUs equivalent to the EUA purchase surplus must be cancelled to guarantee the integrity of the combined Kyoto Protocol and aviation cap (see above).

Integrating domestic aviation in the scheme might increase the administrative burden, but not significantly, because the clear differentiation between domestic and international aviation in monitoring, reporting and verification would also be necessary even if domestic aviation were not integrated. Finally, integrating domestic aviation would extend the overall scope of emissions trading, which is basically good for the liquidity and efficiency of the allowance market.

All in all, it seems more appropriate to integrate domestic aviation in the scheme.

3.5 Allocation

One of the central questions of any emissions trading scheme is how allowances are to be allocated to the relevant entities[41]. Basically speaking, this is 'simply' a decision on whether and if so how to distribute allowances. It must be taken either once and for all before the start of emissions trading, or on a regular basis before the start of each commitment period. Before scrutinising the methods of initial allocation, though, we discuss the level at which such a decision should be made.

3.5.1 Responsibility for the allocation decision

As in the case of emissions trading for stationary sources, key decisions should be taken at the EU level. Article 10 of the emissions trading directive (2003/87/EC) prescribes, for example, that 95% of allowances during the pilot phase and 90% of allowances during the first commitment phase are to be allocated free of charge. However, the number of allowances to be distributed to the emissions trading sector can be decided by Member States within their own national allocations plans, which are then scrutinised by the Commission against the 11 allocation criteria given in Annex III of the directive. Correspondingly, Member States have some degree of subsidiarity in their allocation decisions.

From one perspective, this degree of subsidiarity may be considered an advantage. Member States may take into account the specific situation of their aviation industry and its importance to their economy and allocate more or less allowances compared with other Member States. Initial experience with this approach shows that economic distortions can only be avoided by strong interventions from the European Commission, however, even though all Member

[41] The terms 'allocation' and 'issuance' of allowances will be used as in the emissions trading directive (2003/87/EC). Allocation of allowances refers to the decision as to how many allowances are to be granted to which entity and includes definition of the rules used to determine the number granted to each. Issuance, in contrast, is the administrative act of transferring the allowances allocated to an entity to its holding account in the registry.

States are obliged to adhere to the common allocation criteria of Annex III of the emissions trading directive (2003/87/EC)[42].

Since aviation has been internationally regulated for decades, however, one can assume that the economic conditions for players in the aviation industry are more homogeneous than for stationary sources. Aviation might, therefore, be better suited to harmonised allocation through a single EU decision than stationary sources. Such an approach would also avoid or at least reduce economic distortions as far as possible, as all the entities covered would be allocated allowances according to exactly the same rules. Obviously, there is a trade-off between the degree of subsidiarity and the potential for competitive distortion.

The most important argument against subsidiarity in the allocation decision for aviation is that it would require precise assignment of the emissions and climate impacts of aviation to individual Member States. Without assignment of emissions it will be impossible to determine whether a Member State has allocated more allowances than needed to its aviation entities. However, assignment of aviation climate impacts to individual Member States is a complex problem that has not yet been solved[43].

Another argument for defining the amount of allowances at the EU level and employing identical allowance distribution rules for all regulated entities in the aviation sector is that international aviation is not included in the EU's Burden Sharing agreement. This agreement, which established different emission reduction targets for each Member State, was an important reason for allowing a degree of subsidiarity on the quantity of allowances to be distributed to stationary sources. As international aviation is not covered by this agreement, however, in this sector there is no such barrier to harmonised allocation.

If the allocation decision were to be taken at the EU level, on the other hand, one single rule would be applied to all aviation entities within the EU, each of which would then be subject to the same effort to stabilise or reduce emissions. Assignment of emissions to individual Member States will now be less important[44] because it is not necessary to assess whether a Member State deviates too much from the joint stabilisation or reduction effort.

3.5.2 Methods of initial allocation

In theory, the efficiency of an emissions trading scheme is independent of the choice of allocation criteria and the design of the initial allocation scheme. However, the allocation of emission rights determines the financial burden to be

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[42] Additionally, the Commission provided a guidance document in which the provisions of Annex III are explained in more detail (COM(2003) 830 final).

[43] The lack any obvious and agreed solution to this problem was the main reason for aviation's greenhouse gas emissions being exempted from the obligations of the Kyoto Protocol.

[44] For flights beyond the borders of the geographical scope of the emissions trading scheme in aviation, the assignment of emissions is still needed. The options for how to assign these emissions are discussed in the section on geographical scope.

borne by the sector as a whole as well as by individual entities. Given these distributive implications, allocation of emission rights is a highly sensitive design issue which will be crucial for the acceptance of the emissions trading scheme.

While the emissions trading directive (2003/87/EC) allows Member States a great deal of latitude as far as initial allocation is concerned, this subsidiary approach must be questioned in the highly competitive and homogeneous aviation market. This aspect is not discussed in this section, however, but in Section 3.5.1. In this section several allocation methods are discussed and evaluated against several criteria, such as data availability, compatibility with the EU ETS and the polluter-pays principle, consideration of early action, etc. In this discussion it should be borne in mind, moreover, that the choice of allocation method is not independent of other design features of the emissions trading scheme, particularly the choice of entities obliged to surrender allowances.

1 Grandfathering

In the *grandfathering* approach, emission rights are allocated free of charge on the basis of past emissions. This approach fundamentally contradicts the polluter-pays principle. More, it strengthens vested interests and is therefore attractive from the perspective of the entities concerned and usually unfavourable for newcomers. In general, airlines using relatively old and polluting technologies will be relatively better off than operators that have already invested in cleaner technology[45].

The challenge in this approach is the decision on a fair distribution key establishing the financial burden of one entity relative to another. It is common practice to allocate emissions allowances in proportion to past emissions, with reference to the emissions of a single year, an average value for recent years or a maximum value of recent years[46]. The aviation sector is highly sensitive: the sector as a whole, as well as individual aircraft and airport operators, are very susceptible to economic circumstances in individual countries and regions and to isolated local and regional events such as terrorist attacks, epidemics and environmental disasters. Against this background it is therefore recommended – in order to have a sufficiently representative base period – to take a period of several years rather than a single year. In general, the earlier the base period, is the more early actions will be honoured. Accordingly, the base period should be as early as possible: 10 to 5 years before the start of the scheme, say. This would leave entities that enter the market after the base period without allocation, however, and in the EU ETS most Member States have therefore opted for grandfathering with a more recent base period (1998-2003, 2001-2003, etc.). Some of these states have introduced specific provisions for the consideration of early actions.

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[45] For a further, general evaluation of the grandfathering approach see [Cames/Deuber, 2004] and [IATA, 2001].

[46] Compare also National Economic Research Associates (2002): Evaluation of alternative initial allocation mechanisms in a European Union Greenhouse Gas Emissions Allowance Trading Scheme; prepared for DG Environment. European Commission, March 2002.

If the grandfathering approach is adopted, it is a prerequisite to have emissions data for the base period for all types of emissions considered in the basis for assessment. The flight and emission data must be of high reliability and comparability, moreover. EUROCONTROL – as an independent EU body – has at its disposal CO_2, H_2O and NO_x estimates for all individual flight relations within the European Airspace for the years 1995 to 2004. However, these emission data are generated by models that determine fuel consumption and NO_x emissions on the basis of aircraft/engine-dependent fuel flow data and on flight path data (cf. Section 3.7). Measured fuel consumption per flight is only available at the aircraft operators, while actual NO_x emissions are not yet routinely measured[47]. Although the EUROCONTROL CO_2 emission data can be assessed as fairly accurate at a route-group level (all Intra-EU routes), at the level of individual entities it is not generally reliable enough for the purpose of allocation. It is barely conceivable that in the grandfathering approach computed data should form the sole basis for allocation. One feasible strategy would be to oblige the affected entities to provide the data on fuel consumption for all flight relations. The data provided could then be verified against the computed EUROCONTROL data.

However, if a different basis for assessment than CO_2 were chosen or if it were intended to introduce a base period earlier than 1995, the grandfathering approach based on past emissions would not be suitable. Severe data constraints exist for contrails, cirrus clouds and, to a lesser extent, nitrous oxides. For cirrus clouds, at most globally aggregated estimates are available. These practical constraints argue for other allocation criteria[48].

2 Benchmarking

With *benchmarking*, emission allowances are distributed free of charge but, in contrast to grandfathering, on the basis of specific values – so-called benchmarks – relating to a typical output factor of a sector. The benchmark should refer to emissions per unit output[49]. While in the grandfathering approach emissions data must be available for a base period, in the case of benchmarking activity data must be collected and multiplied by a selected benchmark.

A clear advantage of the benchmark over the grandfathering approach is that it favours entities with new and low-emission aircraft, so that early action will be honoured. If designed properly, the benchmark provides strong incentives for investments in new technologies.

47 There is on-board measurement of NO_x emissions in a research context.

48 In [Trucost, 2004] some of the distributional effects for European airlines under a grandfathering regime based on CO_2 emissions between 1998 and 2002 are illustrated by way of examples. It is clearly demonstrated that the effect of an ETS is highly dependent on the base period adopted for allocating emission permits. The costs borne by airlines vary substantially, depending on the difference between their allocation and their actual emission level. Airlines with growing emissions are burdened by up to several million Euro, while those with declining emissions may enjoy benefits of up to several million Euro. If an early base period is adopted for allocation, the bandwidth of cost and benefit tends to be even larger.

49 Compare, for more details: [Price Waterhouse Coopers/ECN, 2003]: Allowance allocation within the Community-wide emissions allowance trading scheme. Utrecht, 6 May 2003.

The homogenous output of aviation can be summarised as transportation of payload[50] over a certain distance. The corresponding benchmark could be an average value of emissions per payload kilometre[51]. The denominator of the benchmark refers to the activity considered: the service provided by aviation. [Sentance and Pulles, 2001] suggest initial allocation of emission allowances on the basis of Revenue Tonne Kilometres (RTK)[52] with a benchmark referring to an average emission factor:

$$RTK_{total} = \sum_{i=1}^{n} RTK_i \qquad [1]$$

$$E_{total} = \sum_{i=1}^{n} E_i \qquad [2]$$

$$A_i = \frac{(E_{total} - T)}{RTK_{total}} * RTK_i \qquad [3]$$

n:	Total number of entities.
RTK_{total}:	Total revenue tonne kilometre of all flight relations in the base period considered in the trading scheme.
RTK_i:	Revenue tonne kilometre assigned to entity i[53] in the base period.
E_{total}:	Total emissions of flight relations considered in the base period.
E_i:	Emissions assigned to entity i in the base period.
T:	Emission reduction target.
A_i:	Amount of emission allowances allocated to each entity.

There are n entities covered by the scheme. In the base period, each entity is responsible for RTK_i and the corresponding emissions E_i. RTK_i and E_i sum to RTK_{total} [1] and E_{total} [2] respectively. The amount of allowances allocated to each entity is determined by multiplying the RTK_i by the average emission per RTK, taking into account the emission reduction or stabilisation target [3].

Regardless of the entity regulated, initial distribution of emission allowances will be based on the RTK of the aircraft. If aircraft operators are obliged to surrender allowances, the RTK of all flight distances under the emissions trading scheme will be taken into consideration.

In the benchmarking approach, several aspects argue for selecting a rather late base year. Contrary to the case of grandfathering, early action vis-à-vis efficiency and high load factors does not have to be explicitly considered by adopting an early base year, for once the benchmark is applied, entities that have made efforts in this regard are automatically better off. Another practical aspect arguing

50 Payload is the actual or potential revenue-producing portion of an aircraft's take-off weight. This includes passengers, free baggage, excess baggage, freight, express and mail [Boeing, 2003].

51 Alternatively, one could take a benchmark based on emission per unit output of the best available technology.

52 One passenger (including baggage) is assumed to weigh 100 kg. Ten passengers travelling or one tonne of cargo transported over one kilometre is one Revenue Tonne Kilometre.

53 The entities in question may be either airlines or airports.

for a late base year is data availability. Until now, data on RTK by flight relations in the European Airspace were not monitored by an independent institution. It is conceivable, however, that the entities will be obliged to provide their Revenue Tonne Kilometres – even for the past. Airlines determine the distance flown and payload by default and could provide such data with low transaction costs[54]. The distance flown could then be verified against EUROCONTROL data. Furthermore, it should be possible to verify the indicated payload by invoices on airport charges which are imposed, *inter alia*, on the basis of payload. [Sentance and Pulles, 2001] suggest the previous year as base period. This suggestion can be supported; but it would be more favourable to include several years in the base period, as this would level out unusual events and the effects of economic cycles (compare the argumentation in the grandfathering section).

Overall, data constraints are minor compared to the grandfathering approach, because only system-wide rather than entity-specific emission data are required. RTK can be monitored and reported by the regulated entities and verified by independent verifiers. Data on CO_2 and NO_X emissions can be monitored and reported according to methods described in Section 3.7. In the future, when the scientific understanding on contrail formation is robust and widely accepted (see Section 2.5.4) such data might also be included in the benchmark approach.

Taking the benchmark proportional to RTK, both passenger and cargo transportation are included in one and the same formula. From a climate policy perspective, the weight of goods transported is more important than the question of whether cargo or passengers are being transported. For political or distributional reasons, however, one might consider differentiation in Revenue Passenger kilometre (RPK) and Cargo Revenue tonne kilometre (CRTK)[55]. Alternatively – as such data is even more readily accessible – the benchmark could be indexed to Available tonne kilometre (ATK)[56]. However, in the latter approach aircraft operators with low load factors are relatively better off than those with high load factors. An additional unfavourable aspect is that even in the future this approach does not provide any incentive to increase load factors.

As a basic principle, a simple and uniform benchmark which can be easily monitored limits the administrative burden of initial allocation. Preferably, it should not provoke undesirable market strategies other than emission reductions. The approach outlined above – in the simple version described – suggests one benchmark for all flights, independent of distance flown. This approach leads to different reduction burdens for short-, middle- and long-haul flights, for emissions per RTK are greater on shorter than on longer hauls because of the relatively larger contribution of the LTO cycle. On the other hand, on very long hauls the fuel efficiency is also less owing to the effect of the fuel carried [Sentence and

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54 Several airlines, for example Lufthansa [Lufthansa, 2003/2004] and British Airways [British Airways, 2003/2004], indicate their RTK in their annual reports.

55 Cargo revenue tonne kilometres (CRTK) are a measure of cargo operation production, calculated as the product of cargo carried (revenue tonnes) and distance flown in revenue service [Boeing, 2003].

56 Available tonne kilometres (ATK) are a measure of airline or aircraft cargo capacity and production, calculated as the product of total cargo payload capacity and distance flown [Boeing, 2003].

Pulles, 2001]. Table 16 provides a rough quantitative overview of these effects. The figures are based on standard Airbus aircraft. Although, for lack of data, Available Passenger Kilometres have been used rather than Revenue Tonne Kilometres, the table gives an idea of the respective effects on short-, middle- and long-haul flights.

Table 16 Average carbon dioxide emissions per passenger seat (pax) and nautical mile (nm) for short-, middle- and long-haul standard Airbus aircraft

	Airbus 320-200	Airbus 330-200	Airbus 340-600
Flight distance (nm)	500	2,500	5,000
Trips/year	2,006	720	463
Fuel/trip (kg)	3,188	27,729	84,523
Pax	150	293	380
Flight distance/year (1,000 nm)	1,003	1,800	2.315
Pax * distance (pax * 1,000 nm)	150,450	527,400	879,700
t CO_2/year	20,209	63,089	123,664
g CO_2/(pax*nm)	134	120	141

From an economic point of view, a flight relation should be charged more heavily per distance if it is responsible for more emissions and therefore external effects per distance. Taking one overall average benchmark for all flights is in line with economic theory. Newcomers could receive an allocation on the basis of their flight plans[57].

3 Auctioning

From an economic perspective, *auctioning* – which is consistent with the polluter-pays principle – has a number of advantages, notably that permits are allocated on a non-discriminatory basis that also extends to new entrants. The revenue raised by auctioning could be substantial. Assuming an average price for allowances of € 10 per tCO_2e and taking into account only the climate impact of CO_2, € 600 million could be raised solely from intra-EU flights[58]. These revenues could in principle be used to reduce taxes elsewhere or to finance other climate control measures. Alternatively, they could be recycled to the aviation sector, in which case the effects would be similar to those of a revenue-neutral charge [IATA, 2001][59]. See also Section 6.6.2 for a discussion of options for the use of auctioned revenues.

57 Compare [Sentence and Pulles, 2001] for more details.

58 Correspondingly, auctioning leads to a significant financial burden on the individual aircraft operator. A rough estimate of the financial burden based on the annual CO_2 emissions figures of three airlines in Europe in 2002 given by [Trucost, 2004] sums to around € 30 million for BA, € 9 million for KLM and € 12 million for SAS, assuming a market price of € 10 per tCO_2e. An airline's profits may vary significantly from year to year. KLM, for example, had a pre-tax profit of € 622 million in 2002/2003, but only € 31 million in 2003/2004 [KLM, 2003/2004]. The relative share of auctioning revenue compared to profit can thus vary correspondingly and may be very significant (e.g. 30% of profits in the case of KLM in 2003/2004).

59 Further description of the auctioning approach can be found in [IATA, 2001] and [Cames/Deuber, 2004].

As the EU ETS limits auctioning of allowances to 10% of the national cap until 2008-2012, one option would be to allocate allowances for aviation according to the same principle and thus also free of charge. However, even in this case auctioning could be considered for the following cases:

a If fuel suppliers are selected as entities obliged to surrender allowances, it is recommended to adopt auctioning as allocation method because in the case of allocation free of charge fuel suppliers would receive tradable certificates without a direct quid pro quo. To the extent that fuel suppliers can pass on to aircraft operators not only the cost of purchasing additional allowances but at least some of the opportunity costs of these freely allocated allowances, they would benefit from windfall profits[60].

b If climate impacts caused by contrails or cirrus clouds are, at a later stage, also included in the scope of the emissions trading scheme, auctioning of allowances for these impacts would be appropriate, for the specific reason that reliable and consistent entity-specific historic data on contrails and cirrus clouds impacts are not available. By auctioning the share of climate impacts caused by contrails and cirrus clouds, a considerable incentive would be provided to avoid these impacts [Cames and Deuber, 2004].

c A hybrid system of auctioning (10%) and grandfathering (90%) could provide a starting point for a slow transition from allocation free of charge to an auctioning system. This hybrid proposal has the advantage of creating a reliable early pricing signal while still limiting the financial burden on the aviation sector. However, such a hybrid system has similar advantages and disadvantages to the 'pure' methods of grandfathering and auctioning, although often in somewhat alleviated form. Thus, unsolved allocation problems, such as how to guarantee newcomers market access, are still difficult but easier to tackle than with grandfathering. And though there is still a need for reliable data, the greater the share of auctioning, the less important this challenge becomes.

d Auctioning with recycling of revenues to the aviation industry is another option. The rationale behind this approach is that one can reap the benefits of auctioning on the one hand, while compensating the sector for the high financial burden on the other. With a revenue-neutral system, one could justify auctioning in an early stage of a trading system in aviation, even if other sectors receive allocated allowances free of charge.

  There are several options for the recycling of revenues [IATA, 2001]:

  - Recycling for projects in the air transport sector (e.g. scrapping aircraft purchased more than 20 years before 2010).
  - Reducing other environmental impacts (e.g. noise and NO_x).

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[60] From a theoretical perspective it does not matter whether fuel suppliers or aviation entities receive these windfall profits. From a political perspective, however, acceptance of an upstream system in which fuel suppliers are obliged to surrender allowances can be increased if allowances were auctioned. This is because in an upstream system aviation entities would always be confronted with the real or opportunity costs passed on by fuel suppliers. Aviation entities might put up strong resistance to such an emissions trading scheme if fuel suppliers benefited from the scheme, while they themselves were confronted only with extra costs. Acceptance by aviation entities would, however, be more important than acceptance by fuel suppliers, particularly when it is borne in mind that aviation entities are affected in their entire business, while for fuel suppliers aviation fuel is part, big or small, of their overall business.

- Investing in fuel efficiency in the air transport sector (e.g. R&D on emissions-reducing technologies).
- Funding improvements in air traffic control service provision.
- Recycling to entities involved in the emissions trading scheme according to their share of RTK.

In the last of these recycling options the financial burden of the entities is relatively low on average – comparable to allocation free of charge. In the case of the other recycling options, the financial burden is significantly higher. Although revenues are recycled within the sector and the entities can thus benefit from sectoral investments and improvements, the burden still remains high. And if revenues were controlled by Member States, this would require additional co-ordination efforts, particularly if the allocation decision was taken centrally. Finally, it should be stressed that in terms of economic efficiency it would be best if auctioning revenues were used to reduce distortionary taxes elsewhere in the economy (see also Chapter 6).

4 Baseline

With this method, entities are obliged to surrender allowances for emissions growth subsequent to a certain base period (baseline). In this alternative to the aforementioned 'classic' allocation methods, the first thing to be established is whether the surplus allowances are to be bought on the emissions trading market for stationary sources or whether they are to be auctioned. If they are bought on the emissions trading market, growth of aviation would increase demand for EUAs on the market of the EU ETS.

The obligation to surrender allowances for emissions growth only shows parallels with both allocation free of charge and auctioning. One parallel lies in the fact that existing entities do not have to pay for emissions within a certain baseline. Once the baseline is exceeded, they must buy allowances on the market. The same issues of data availability play a role in both approaches. Emissions in the base period must be identified – similar to grandfathering – in order to have a baseline against which emissions growth can be measured. As with grandfathering, entities with old, polluting technologies will be better off than those that have already invested in new technologies. The latter could compensate their growth by achieving large efficiency potentials, while entities that have already undertaken early action would have to buy surplus allowances to achieve growth.

The parallel to the auctioning approach lies in the fact that newcomers are obliged to buy allowances according to their emissions. Contrary to auctioning, however, existing entities are in a much better position than newcomers as they only have to buy allowances for surplus emissions. Positive in this approach is that there is a clear-cut allocation rule defined; the consequence of this rule, however, is a high financial burden on newcomers, which may prove a significant barrier to newcomers wishing to enter the market.

Additionally, this approach is unfavourable from the perspective of the entities themselves, as they have no scope for selling emission allowances if their actual emissions fall below the base period level. In other words, once they reach their base period emission level they have no further incentive to reduce emissions.

These restrictions might lead to significant efficiency losses for the trading system, which will tend to be larger the later the base period selected.

An alleged advantage of this approach could be included in the equation, though: entities losing market share will not be rewarded with revenues from selling emission allowances. However, in a cap and trade system it is not intended – and is not efficient from the economic perspective – to treat different forms of emission reduction (through reducing activity or increasing efficiency) differently. This seems to be unnecessary if the overall cap is maintained.

A characteristic of this approach is that the obligation cannot be broken down to the individual flight level, being valid only for the entity as a whole.

5 No allocation

In this option the aviation sector entities are allocated no allowances but must nonetheless surrender allowances for all the climate impact they induce. Accordingly, aviation industry entities must purchase all allowances or Kyoto Units to cover their climate impact on the market. From an environmental perspective this option would be welcomed, since it strengthens the mitigation target for the aviation sector as well as for stationary sources.

From an administrative angle this option is by far the simplest allocation method, for it obviates the need for both assignment of emissions and initial allocation. Neither will agreement on use of auctioning revenues be necessary. Moreover, interplay with the Kyoto Protocol will be fairly straightforward, as the aviation entities can only sell allowances they have previously purchased. Since all these allowances are covered by AAU, there is no need to establish any trade restrictions. At the end of the commitment period, nevertheless, AAUs equivalent to the aviation sector's purchase surplus of EUAs and Kyoto Units will have to be cancelled to avoid double counting of reductions and to guarantee the integrity of the combined Kyoto Protocol and aviation cap (see Section 3.4).

The main disadvantage of this option, however, is that it would create the greatest economic burden not only for the aviation industry but for the industries covered by the EU ETS as well. The burden would be higher than in the case of auctioning because of the more stringent mitigation target.

3.5.3 Assessment of initial allocation methods

The allocation methods described above will now be assessed against several key criteria.

1 Data availability

The practical applicability of any particular allocation method depends upon data being available to implement it with sufficient credibility. The aspect of data availability argues for no allocation at all or for auctioning rather than the other allocation methods. In the case of auctioning, only system-wide rather than entity-specific emission data are required to determine the overall cap. In the case of no allocation at all, this step can also be omitted. All the other methods require either entity-specific emission data or activity data. Basically it is rather difficult to obtain reliable entity-specific historic data, though most emission and activity data can be recalculated or derived from invoices and other records held by or on behalf of the entities. Common practice in such cases is for the entities to report the required data, which then has to be verified by officially accredited, independent verifiers. In addition, this data can be cross-checked with EUROCONTROL data.

However, determining historic emissions will be far more difficult if climate impacts not directly correlated to fuel consumption (NO_X, contrails, cirrus clouds) are included in the scope of the scheme, as this would require detailed examination of additional data (routes, flight profile, weather conditions, etc.). Data availability should therefore be somewhat better for benchmarking than for the grandfathering or baseline method, as it does not require entity-specific but only system-wide emission data.

2 Market access for new entrants

Definition of a new market entrant will depend on the entity regulated, being different if it is fuel suppliers rather than airport or aircraft operators that are obliged to surrender allowances. Here we will focus just on the last of these options because it was identified as the most appropriate option for the regulated entity (see Section 3.2).

In the EU ETS, new entrants are – pursuant to Article 3 (h) of directive 2003/87/EC – all installations which obtain a greenhouse gas emission permit after the submission of the national allocation plan. This concept is based on stationary installations and cannot be transferred directly to the aviation sector. An aircraft might be considered as an installation of the aviation sector. Since aircraft are mobile sources, they can be temporarily out of the scope of the emissions trading scheme if the scheme is geographically bounded. It would be definition of new entrants that would be particularly difficult, though, for instance in the case of leasing: should an aircraft leased from a company outside the scope be considered as a new entrant? If so, would it be necessary to apply for a permit even if the aircraft were leased just for several flights because the corresponding aircraft is out of service for whatever technical reason? What about new aircraft: should they be considered new entrants even if they replace old aircraft being taken out of service? These questions show that definition of a new entrant in the aviation sector is more complex than in the case of stationary sources.

In the case of no allocation or the auctioning or baseline approach, the question of how to deal with new entrants is soon resolved: they must buy allowances for their activities. Market access will also be guaranteed – even in the rather unlikely case of strong concentration and misuse of market power[61] – since new entrants can purchase units from project-based mechanisms. In the baseline

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[61] Strategies to restrict the access of competitors to the allowance market will be impossible on several sector-serving factor markets, as it would require edging out not only competitors on the own product market but also all those on the other product markets covered by the scheme.

approach, however, new entrants are in a worse-off position than existing airlines, which need only purchase a smaller share of the allowances they need.
In the grandfathering and benchmark approaches, however, the question of new entrants remains unresolved unless they must buy all their allowances on the market. Otherwise, the concept of new entrants has to be clearly defined, a rather complex matter. If the definition of new entrants is linked to the operating entities, these will have an incentive to create new subsidiaries in or outside the EU that can claim allocation as new entrants with allowances free of charge and thus circumvent the scheme. Linking the definition of new entrants to aircraft entering the scheme after the allocation decision has been taken would also create incentives to circumvent the scheme, for air carriers might sell their aircraft to carriers operating outside the scheme and buy their aircraft instead. Restricting the definition of new entrants to truly new aircraft would discriminate against newly established air carriers starting out with used aircrafts. Practical implementation would also be accompanied by data availability problems for the base period. In general, in the benchmarking approach, allocation free of charge to new entrants can still be more readily established than in the grandfathering approach, because it is only activity data that must be assessed or projected rather than activity, efficiency and emissions data[62]. However, the problems associated with clear definition of new entrants, a sine qua non for free allocation of allowances to these parties, are almost insurmountable. We therefore argue for no allocation of allowances free of charge to new entrants, even if the grandfathering or benchmarking approach is adopted. If all new entrants have to buy their allowances on the market, precise definition of new entrants becomes unnecessary and can be ignored[63].

3 Compatibility with the polluter-pays principle

This basic principle is of great importance when it comes to the fairness of environment policies. While no allocation and auctioning are fully in line with this principle, the growth obligation approach (obligation to buy allowances above a predefined baseline) is so at least for the future. Grandfathering is in strong violation of the polluter-pays principle. Benchmarking, however, concords in so far with that principle that entities using new, low-emission technologies must pay less than those using old, inefficient technologies. Nevertheless, it is obvious that the polluter-pays principle is not respected in so far as benchmarking is an allocation free of charge.

4 Credits for early action

One important design issue of national allocation plans within the grandfathering approach for stationary sources (Annex III) was the possibility of accommodating early action in order to guarantee fairness at the start of the EU ETS. This possibility is one of the greatest advantages of benchmarking compared with grandfathering. Although in theory early action can be also accommodated by

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62 This is also supported by the fact that in the current EU ETS most Member States have applied grandfathering to existing installations but benchmarking to new entrants.

63 Requate/Graichen (2003, p. 20f) argue that obliging new entrants to purchase all allowances on the market would result in efficient allocation, whereas free allocation of allowances to new entrants would be similar to subsidising them.

taking an early base year, data constraints preclude this choice. The baseline approach is fairly similar to grandfathering, because there is no way to take early action into account, in particular if a fairly recent base year is taken. Auctioning and no allocation at all would, in contrast, result in fair consideration of early action, because early actors would have to buy relatively fewer allowances than aviation entities with climate impacts above the average.

3.5.4 Conclusions

Table 17 provides an overview of the pros and cons of the different allocation methods described and discussed above.

Table 17 Evaluation of allocation methods

	Grand-fathering	Bench-marking	Auctioning	Baseline	No allocation
Data availability	-	-/+	+	-	+
Data needed					
entity-specific emission data	□			□	
system-specific emission data		□			
entity-specific activity data (e.g. RTK)		□			
Market access for new entrants resolved	-	-/+	+	+	+
			all entities must buy allowances	mainly new entrants must buy allowances	all entities must buy allowances
Compatibility with polluter-pays principle	-	-/+	+	-/+	+
Credits for early action	-	+	+	-/+	+

In general, the choice of allocation criteria in an emissions trading system involves weighing up numerous aspects such as fairness, transaction costs, data availability and political acceptance. In this sense no definite conclusion as to which allocation method is the most appropriate can be drawn. Nevertheless, based on the assessment summarised in the table above, we conclude that auctioning appears to be the most attractive option. From an economic perspective it can be considered the most efficient option. Other important advantages are the equal treatment of new entrants compared to existing operators, the credits for early action and the low administrative burden in connection with data requirements. In a relatively young and dynamic sector like aviation, fair treatment of new entrants can be considered an especially important advantage.

If auctioning is deemed to place too great a financial burden on the aviation sector, a second-best option is to start the scheme using benchmarked initial allocation. In general, it is preferable to base the trading scheme on a benchmarking rather than a grandfathering approach. The results of Table 12 show that benchmarking was evaluated as superior to grandfathering right across the board. The baseline approach, for its part, has significant drawbacks compared with benchmarking and is unfavourable for newcomers and entities achieving significant emissions reduction through abatement measures. It is therefore recommended to refrain from this approach, too.

3.6 Administrative tasks: role of Member states and the EC

As in the case of stationary sources, administration of emissions trading in the aviation sector comprises several tasks:

1. Issuance of permits.
2. Issuance of allowances, administration of registries.
3. Monitoring, reporting and verification of emissions.
4. Surrender of allowances and compliance control.
5. Enforcement in the case of non-compliance (penalties).

Most of these tasks can be carried out by individual EU Member States or by a central EU body. Whereas emissions trading for stationary sources is administered almost completely by Member States, in the case of aviation it may be appropriate to centralise certain elements of administration.

Even in the event of some central administration at the EU level, however, the corresponding Member State authorities will still have a role in the administration process. The distribution of administrative tasks between a central EU body and the national aviation authorities might be similar to the case of the European Aviation Safety Agency (EASA). The EASA is responsible for the airworthiness and environmental certification of all aeronautical products, parts and appliances designed, manufactured, maintained or used by persons under the regulatory oversight of EU Member States. It is intended to extend EASA's responsibility to the regulation of air operations, the licensing of flight crew and the oversight of third-country aircraft flying in the territory of Member States. It is expected that the certification costs will be reduced, particularly in cases where multiple certificates from different countries have been needed in the past. In the longer term, it is also envisaged that the Agency will play a role in relation to the safety regulation of airport operation and air traffic. To execute its tasks, the EASA relies on national aviation authorities, which historically have played this role[64]. The national authorities fulfil all tasks that must be carried out directly on-site, for instance all checks of aircraft or other technical units. Basically, the tasks are shared such that those promising synergies through harmonisation are carried out at the EU level, while those requiring presence at the various sites are carried out at the Member State level.

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64 http://www.easa.eu.int/home/easa_saferskies.html.

In the following, we start out by describing the administrative tasks and discuss, for each, the advantages of decentralised administration by Member States compared with central administration by an EU body. Subsequently, we assess the various options and draw conclusions on which option is the best fit for the different choices of regulated entity.

3.6.1 Tasks

1 Issuance of permits

To guarantee the integrity of the emissions trading scheme, operators under the scheme could be obliged to provide a trading permit[65]. This permit will be granted to entities covered by the trading scheme when they can prove they can comply with the necessary monitoring and other requirements. This task must be carried out before the start of emissions trading in aviation by all entities covered by the scheme. Later on, permits may be withdrawn if and when entities fail to comply with basic requirements. In addition, new permits will have to be granted to new entrants to the aviation emissions trading scheme. Accordingly, the bulk of the workload within this task will emerge before the start of emissions trading. However, surveillance of whether the entities in question are complying with the conditions on which the permit has been granted will be a continuous task.

Basically speaking, this task can be carried out either by Member States or by a central EU body. In the existing emissions trading scheme for stationary sources this task is carried out by Member States, in any cases by the administrative bodies responsible for the permits issued under the Integrated Pollution Prevention and Control (IPPC) directive. Since this directive, which came into force in 1996, already covers most of the installations included in the emissions trading scheme, this approach promised certain synergies in administration.

To achieve similar synergies in aviation, the issuing of permits should be carried out by those bodies issuing other permits and licences to the aviation sector (aircraft, airports, air carriers, etc.). National aviation authorities seem most fit for this task, because they already deal with the same entities that will be affected by emissions trading in aviation. However, such an approach would involve at least one additional national administrative body in emissions trading and requires some degree of coordination between the different bodies involved in the administration of that trading.

Issuance of permits might also be carried out by one central EU body. Which of these two approaches is more appropriate depends on the entities that are obliged to apply for permits and surrender allowances (see Section 3.2). If it is

[65] The terms 'permit' and 'allowance' will be used as in the emissions trading directive (2003/87/EC). An allowance is a tradable emission right that can be used for compliance control by those entities that are obliged to surrender such allowances. A permit cannot be transferred but is granted to entities obliged to participate in the emissions trading scheme when they have proved their compliance with all the necessary requirements. In particular, they must prove they can monitor and report their emissions, for instance by presenting a monitoring plan.

airports that are applying for permits, the decentralised approach would be more apt, because they would then have to deal with just one authority. If the permit obligation is on aircraft operators, however, the administrative burden might be far higher if they have to apply for a permit in each Member State where they operate. In this case a central body that can issue a permit for the entire trading system might be more appropriate.

However, Member States might also agree on mutual recognition of permits. This would require their agreement on rules as to where aircraft operators should apply for permits. For European aircraft operators the emissions trading permit might therefore be issued by the authority that had already granted the AOC. Non-EU operators might decide of their own accord in which Member State to apply for a permit. As at least the large fuel suppliers operate in several Member States, they would also gain from centralised administration or co-ordinated administration based on mutual recognition of permits.

2 Issuance of allowances, administration of registries

After allocation of allowances (see Section 3.5), these allowances must be issued to the entities covered. To guarantee the integrity of the emissions trading scheme it is also necessary to register the allowances and track all inter-entity transfers of allowances in an electronic registry. Issuance of allowances should be carried out on the same date allowances for stationary source are issued, i.e. by the 28th of February of each trading year (Article 11.4 2003/87/EC). Administration of registries, in contrast, will be a continuous task, since allowances can be transferred, cancelled, etc. at any time of the year.

Issuance of allowances to the aviation sector and administration of the registries can essentially be done either by individual Member States or by a central EU body. Generally speaking, issuance can best be carried out by the body administering the registry. As all Member States are under the same obligation and most of them have already set up such a registry for emissions trading for stationary sources[66], issuance and registration of allowances for the aviation sector could be carried out by the same administrative bodies.

However, the national registries report issuance, trading and cancellation of allowances to the Community Independent Transaction Log. It would therefore also be possible to carry out these tasks at the CITL or at a central EU registry for the aviation sector[67]. Similar to the granting of permits, central administration of this task would be more suitable if it is aircraft operators that are obliged to surrender allowances. This is because, in contrast to stationary sources, most air carriers operate in several EU countries[68]. Correspondingly, at least the larger air carriers would have to work with 25 different registries, creating comparatively

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66 The Member State registries are based on the so-called registries regulation: Commission Regulation for a standardised and secured system of registries pursuant to Directive 2003/87/EC of the European Parliament and of the Council and Decision 280/2004/EC of the European Parliament and of the Council.

67 The EU has already developed a registry system which can be used for that purpose.

68 Some operators of stationary sources covered by the EU ETS also operate in several countries. However, the vast majority of operators have installations in just one or a few of the countries.

high transaction costs for them[69]. In other words, one central administrative body responsible for issuance as well as registration of transfers and cancellations of allowances will be easier and more cost-efficient for all international aircraft operators. Should airports be obliged to surrender allowances, the picture is somewhat different. Since airports are located in just one Member State, they will have to cooperate with just one administrative body.

3 Monitoring, reporting and verification of emissions[70]

The basic idea of emissions trading is that all emissions should be backed up by allowances. Since the amount of allowances will be restricted, there will be a similar restriction of emissions. For the environmental integrity of such an emissions trading scheme it is therefore essential to monitor the emissions of the entities covered by the scheme. In the emissions trading scheme for stationary sources this task is carried out by the operators of the installations covered. Before they submit their emissions to the competent authority, however, the monitoring report must be verified by an independent verifier previously accredited by the competent authority.

In emissions trading for stationary sources the rules for monitoring are laid down in the so-called monitoring guidelines[71], which are community law and do not have to be transposed by the Member States. This will ensure that operators report their emissions in accordance with these guidelines (Article 14.3 2003/87/EC). Furthermore, Member States must ensure that verification is carried out in accordance with the criteria stated in Annex V of the emissions trading directive. They must therefore check the competences and knowledge of potential verifiers before accrediting them and carry out spot checks on both the monitoring of emissions and verification of emission reports. In essence, the rules for monitoring, reporting and verification have been articulated at the central level, while administration of these tasks is carried out at the Member State level.

For stationary sources, verified emission reports for the previous year have to be delivered by the 31st March. Correspondingly, the bulk of the work related to emission reports will pile up in February and March. Making spot checks and accrediting verifiers will, however, be a more continuous task, although the bulk of accreditation work will pile up before the start of emissions trading in aviation.

The appropriateness of centralised versus decentralised administration depends again on the entity regulated, but is rather similar to the issuing of permits. If it is airport operators that are obliged to surrender allowances, decentralisation would be the most obvious approach, since each airport would be confronted with just one authority. Internationally operating aircraft operators and fuel suppliers, in contrast, might have to deal with up to 25 different authorities unless agreement

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69 The situation is somewhat similar for fuel suppliers: large fuel suppliers operate in most of the Member States. Accordingly, they would also gain from central administration of this task.

70 Monitoring, reporting and verification methods for the aviation sector are discussed in Section 3.7.

71 Commission Decision of 29 January 2004 establishing guidelines for the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council (2004/156/EC).

was reached that each entity must submit its reports containing the total climate impact induced under the scope of the emissions trading scheme to just one authority. This authority should be the one granting the emission trading permit.

4 Surrender of allowance and compliance control

Once emission reports have been received by the respective authority, operators must surrender sufficient allowances to comply with their obligations under the emissions trading scheme. In the EU ETS, operators must surrender allowances for the previous year by the 30th of April at the latest (Article 12.3 2003/87/EC). The surrendered allowances are then cancelled and can no longer be used for compliance. In addition, the authorities must assess whether or not each covered entity has complied with its obligations.

In the emissions trading scheme for stationary sources, this task is carried out by the competent authorities in the Member States. If the scheme is extended to aviation, their competences might be extended to also having to check whether the aviation entities are complying with the regulations.

In general it would be appropriate to assign that task to the same authority responsible for the issuance and registration of allowances. Correspondingly, the appropriateness of administration at the Member State or EU level depends on whether the entities obliged to surrender allowances are airlines or airports. In the latter case, decentralised administration at Member State level would be feasible. If aircraft operators are the entity regulated, however, administration by a central EU body would be more appropriate unless unique ties of responsibility can be established between aircraft operators and national aviation authorities.

5 Enforcement in the case of non-compliance (penalties)

When the administering authority identifies an operator as non-compliant, penalties must be applied. Stationary sources must currently pay a fine of € 40 in the pilot phase and € 100 during the first Kyoto commitment period for each tonne of CO_2 emitted without surrendering an allowance. In addition, they must surrender the unaccounted-for allowances in the next year.

In the emissions trading scheme for stationary sources this task is carried out by the competent authority of each Member State. These are authorised to apply penalties in the case of non-compliance. If the operator in question also fails to comply with the penalties, more stringent sanctions are required. These might include withdrawal of the permit or even confiscation of property or imprisonment following a lawsuit. Since the agencies administering emissions trading are not authorised to confiscate property or send people to prison, they must rely upon judicial and executive powers.

The tasks of identifying whether or not an entity is in compliance with its obligations and applying the penalties provided by the directive in the case of non-compliance can be carried out either by the individual Member States or by a central EU body. Obviously this task would be best assigned to the authority running the registry. More stringent sanctions required when entities also fail to comply with penalties will have to be applied by national authorities.

3.6.2 Conclusions

Basically speaking, we can assume that the tasks described above will be carried out thoroughly and correctly at either the Member State or EU level. To the same extent, the environmental integrity of an aviation emissions trading scheme will be guaranteed independently of whether these tasks are carried out by Member States or a centralised EU body. However, the transaction costs might differ substantially in the two options, as these depend very much on the number of administrative duties to be carried out. Thus, the economic burden would be higher if the same administrative action had to be performed in parallel in several Member States. Consequently, transaction costs will be the main criterion against which administration options are assessed.

If airport operators are the party obliged to surrender allowances, it would be more appropriate for administrative duties to be carried out by the national aviation authorities, as each airport will then anyway be confronted with just one national authority. Accordingly, transaction costs cannot be reduced by transferring administration to a single, centralised EU agency. On the contrary, national administration would lead to lower transaction costs, as the link between airport operator and national authority is already established.

But the analysis above has also shown that almost all administrative tasks could be carried out at the EU level and that this option would be suitable if aircraft operators or fuel suppliers are obliged to surrender allowances. Implementing the central option would require assigning the various administrative tasks to an already existing EU institution (DG Environment, Eurostat, EEA, etc.), to EUROCONTROL, or to a completely new body. EUROCONTROL, for instance, already executes administrative tasks at pan-European level in coordination with its Member States and with the aircraft operators. The alternative option of a completely new international body has instead been recently applied with the setup of the European Aviation Safety Agency (EASA), which was established in June 2002. Currently it has about 100 staff. When fully operational it will have a staff of 350. The administration of emissions trading in aviation at EU level would also require additional resources (staff, office space, hard- and software, etc.).

Since there will be less overall administrative burden in the case of central administration, however, the cost at EU level will be lower than the aggregated cost at Member State level[72]. Nevertheless, the creation of a new EU body only makes sense if the majority of administrative tasks are carried out at the EU level. Even in this case, however, the central body will still have to rely on the support of national authorities in all the tasks requiring presence at the various aviation industry sites.

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[72] The expectation that certification costs will be reduced, particularly in cases where multiple certificates from different countries have been needed in the past, was one of the main motives for setting up the EASA after several years of fruitless efforts to harmonise the procedures and standards in the field of aviation safety through the Joint Aviation Authorities [EASA, 2005].

Nonetheless, decentralised administration might result in comparatively low transaction costs under certain circumstances, even if aircraft operators or fuel suppliers are the regulated entity. However, this would require, first, that a unique link can be established between each entity covered by the emissions trading scheme and one of the Member States; second, that the Member States agree on common rules for carrying out these tasks; and third, that the administrative actions carried out by other Member States are mutually recognised. Implementing this option would avoid the resource-intensive creation or extension of an entity at EU level at more or less the same or even lower transaction costs as under centralised administration. Accordingly, the decentralised option would also be more appropriate if aircraft operators or fuel suppliers are the regulated entity, unless mutual recognition of administrative acts is guaranteed.

3.7 Monitoring and reporting methods

3.7.1 Introduction

To establish monitoring and reporting protocols, emission inventory activities could rely either on self-reporting by participants or on third parties. For this purpose, data sources could thus include:

- 'Self-reported' data by airlines: under current legislation, trip fuel must be recorded in the mass and balance documentation that must be prepared before and after each flight. Many airlines store trip fuel data electronically in fuel management systems.
- Data from ATM authorities, who keep track of all flights undertaken in their airspace. For example, EUROCONTROL currently keeps track of distances, aircraft types, environmental data and origin-destination pairs for every flight handled.
- Data from current operations of bunker fuel suppliers: these suppliers are currently under no obligation to report to authorities; if they participated in a trading system this would obviously have to change.
- Combinations of these options might also be feasible: for example, ATM data could be used as a worst-case estimate, on which airlines could improve by self-reporting actual post-flight data.

Preferably, a monitoring method should not provide a disincentive for possible optimisation mechanisms (new technology, operational measures, optimisation of load factor, etc.) for reducing emissions. It should also preferably be transparent, based on officially accepted documents (e.g. aircraft mass and balance documentation, ICAO database, etc.) and its implementation should not place too high an administrative burden on the stakeholders concerned. Finally, the monitoring method should also have the ability to measure or calculate emissions in each of the (geographical) scope scenarios, as defined in Section 3.3.
There is an important distinction to be made between ***ex ante*** methods for calculating emissions and ***ex post*** methods. By *ex ante* calculation we mean that the emission level of a given flight is determined *before* the flight has taken place,

based on parameters like calculated distance and aircraft characteristics. By *ex post* calculation we mean that the emission level is determined *after* the flight has taken place, based on flight parameters like actual fuel use, or measured settings.

From the perspective of environmental effectiveness, *ex post* calculation of emissions is preferable to *ex ante* calculation, for it leaves operators a wider range of options to reduce emissions. For example, if the emissions of a certain flight are calculated *ex post*, there will be due incentive to optimise cruise speed for minimum fuel consumption during that specific flight, whereas this incentive will be lacking if emissions are calculated *ex ante*.

In this study we considered the following entities for the monitoring and reporting tasks:
- Aircraft operators monitoring their actual fuel consumption per flight and reporting periodically (e.g. monthly, quarterly or yearly).
- Monitoring and reporting by EUROCONTROL.

Below, we assess both possibilities.

3.7.2 Trip fuel by aircraft operators

Every civil transport aircraft has to comply with airworthiness requirements and operational rules. The most important sets of rules are the Federal Aviation Regulations (FAR) issued by the Federal Aviation Administration, an office of the Department of Transport of the United States of America, and the Joint Airworthiness Regulations (JAR) issued by the Joint Aviation Authorities (JAA) in Europe. Of these, FAR is the oldest and most of JAR is the same as FAR. These aviation regulations set out that operators have an obligation to prepare flight documentation relating to each flight and keep it filed for a certain period, generally 3 months. These flight documents can serve as a basis for monitoring and reporting of trip fuel by aircraft operators.

Flight documents
Regulations require the operator to record and store Mass and Balance documents and an Operational Flight Plan. JAR-OPS 1 regulates the minimum content and storage time of these documents[73]:
- Mass and Balance documentation: JAR-OPS 1.625.
- Operational flight Plan: JAR-OPS 1.1060.
- Document storage periods: JAR-OPS 1.1065.

The weight and balance documentation to be filled in by the aircraft operator after each flight includes information on the mass of fuel at take-off and the mass of trip fuel. Over and above the requirements of minimum data storage time, many

[73] JAR–OPS Part 1 lays down requirements applicable to operation of any civil aircraft for the purpose of commercial air transportation by any operator whose principal place of business is in a JAA Member State. JAR–OPS 1 does not apply to military aircraft, parachute dropping or firefighting planes.

operators collect information from these documents, including trip fuel data, and store it electronically in databases as part of company fuel management systems. Such systems enable detailed analysis of fuel consumption data, including disaggregation of the data according to whatever geographical or operational scope is necessary.

For example, in order to meet the monitoring and reporting requirements of the UK Emissions Trading Scheme, British Airways interrogates its fuel data management system to analyse and report CO_2 emissions from operations having their origin and destination within the United Kingdom. The raw data used to perform this analysis are the departure fuel and the pre-fuel quantity for the subsequent departure, as recorded in the departure documentation. British Airways perform a number of validity crosschecks and data cleaning processes within the system to ensure reliability and accuracy of the data[74].

3.7.3 Calculated emissions by EUROCONTROL

Because of the air traffic flow management service provided by EUROCONTROL's Central Flow Management Unit (CFMU) on behalf of participating states, EUROCONTROL receives and stores detailed traffic information on all flights operated entirely or in part in the ECAC[75] area. Furthermore, EUROCONTROL has developed in-house modelling capabilities in order to calculate estimates of aviation fuel use and related emissions. EUROCONTROL might therefore play a role in the monitoring, reporting and/or verification of emissions as part of a European emissions trading system.

In its PRISME data warehouse, EUROCONTROL currently stores the following data on each flight handled by the CFMU:
- Information from the (last) filed flight plan.
- Aircraft type.
- Airport of departure/airport of destination (city pair).
- The ICAO designator for the aircraft operating agency (see ICAO Doc. 8585) followed by the flight identification; *or* the registration marking of the aircraft; *or* the call sign determined by the military authorities if this is used to identify the aircraft during flight.

The PRISME data warehouse contains flight movement data. To calculate the CO_2 and NO_x emissions associated with flight movements in the PRISME database requires additional industry data or publicly available data (e.g. fuel use data per aircraft/engine combination).

74 Personal communication, Mr A. Kershaw (British Airways).

75 European Civil Aviation Conference (ECAC) is an intergovernmental organisation whose objective is to promote the continued development of a safe, efficient and sustainable European Air Transport System. ECAC liaises closely with the International Civil Aviation Organization (ICAO) and the Council of Europe. In addition, ECAC co-operates pro-actively with the institutions of the European Union and enjoys special relationships with EUROCONTROL and the Joint Aviation Authorities (JAA).

EUROCONTROL has developed a system to do so, known as PAGODA. PAGODA contains two operational models that can be used to calculate CO_2 and NO_x emissions:
- ANCAT 3, and
- The Advanced Emission Model (AEM).

Both models can be regarded as *ex ante* emission calculation methods. It should be emphasised, though, that some parameters[76] in AEM can be based on ex post data, while emission factors related to aircraft type are based on *ex ante* data.

The first model, ANCAT 3, is based on the EMEP/Corinair methodology and has been officially adopted by ECAC. In calculating fuel consumption and emissions in *LTO* and *cruise*, actual aircraft are modelled through 'conversion' to 19 generic aircraft representing the world's passenger jet fleet. This implies that all flight movements registered in the PRISME data warehouse will be linked to one of these 19 generic aircraft types of the ANCAT3 method. A description of the ANCAT calculation method is presented in Annex A.

The second model for emission calculation is the Advanced Emission Model (AEM). AEM has been developed by EUROCONTROL as a means to assess the environmental impact of future airspace and route network planning scenarios. In AEM the fuel burn and emission calculation for the Landing and Take-Off Cycle below 3,000 ft (LTO) is based on the ICAO Engine Exhaust Emissions Data Bank, which includes fuel flow data and emission indices for a large number of aircraft engines[77]. AEM links each aircraft appearing in the input traffic files to one of the engines in the ICAO Engine Exhaust Emissions Data Bank.

Above 3,000 ft, the fuel burn calculation is based on the ‘Base of Aircraft Data’ (BADA)[78] developed and maintained by EUROCONTROL itself. BADA is a collection of ASCII files specifying aircraft performance and operating procedure parameters for different aircraft types. The aircraft models are based on a Total Energy model of aircraft performance. BADA provides data on 267 different types of aircraft. For 87 of these the data have been developed using reference sources such as flight manuals, operating manuals, etc. from the aircraft and engine industry. These are the so-called directly-supported aircraft. For the other 180 types, the data is specified to be the same as one of the 87 directly-supported aircraft.

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76 The AEM model can make use of surveillance data for a large share of the flights in EUROCONTROL airspace. Currently, surveillance data can only be used for a some of the flights in the EUROCONTROL database. It is expected that this fraction will increase in the future.

77 For the LTO cycle, four modes are distinguished: i) take-off; ii) climb-out; iii) approach; and iv) idle (taxi). In the ICAO Engine Exhaust Emissions Data Bank the fuel flow and emission characteristics vary per mode. Furthermore, there are standard times per mode per aircraft type for the LTO. However, the idle time in particular can vary significantly per flight / airport. EUROCONTROL has no information on actual times spent in flight modes and therefore uses the standard mode times for emission calculations in AEM. At some airports information is available, e.g. taxi times at each airport.

78 For more information on BADA see: www.EUROCONTROL.int/eec/public/standard_page/ACE_bada.html.

In the AEM validation report it is stated that AEM fuel burn calculation results are close to actual trip fuel data [EUROCONTROL, 2004]. It is also concluded that, at the level of individual flights executed by a specific aircraft-engine combination, the AEM modelling data match actual trip fuel data much closer than the ANCAT3 computational results. The AEM model is therefore to be deemed the more suitable existing emission model available to EUROCONTROL for use in monitoring emissions[79].

Use of EUROCONTROL in different scope scenarios
In Section 3.3 of this chapter the following five possible scenarios were presented for the geographical scope of the emissions trading scheme:

1. Intra-EU.
2. Intra-EU + routes from and to the EU. Two variants are distinguished:
   a. Intra-EU and 50% of routes to and from the EU.
   b. Emissions from all departing flights from EU airports.
3. All emissions in EU airspace.
4. Combination of scenario 2b + 3.
5. Intra-EU + emissions of all departing and arriving flights from and to third countries that have ratified the Kyoto Protocol.

EUROCONTROL has the ability to carry out the monitoring and reporting tasks in all five scenarios. As EUROCONTROL does not use actual fuel use per flight, monitoring would be based on ex ante emission estimates. In addition, in scenarios 2, 4 and 5 EUROCONTROL would have to estimate the total distance flown by an aircraft, as flights from and to the EU will also fly in airspace not controlled by them[80].

EUROCONTROL's instruments seem to best suited to executing the monitoring task in the airspace-based scenario 3. In the first place this is because the EU airspace is fully covered by the CFMU area. Additionally, though, monitoring CO_2 emissions solely on the basis of actual trip fuel data might be a problem in relation to scenario 3, because in that case a distinction must be made between fuel use within and outside EU airspace. EUROCONTROL could calculate this by using its information on (i) city pair, (ii) time of take-off and arrival, (iii) aircraft type and engine and (iv) EU-airspace entry point data. Another possibility is to combine the trip fuel data reported by airlines with data from EUROCONTROL.

Monitoring of contrails?
At present, the only aviation emissions that can be potentially monitored are CO_2 and NO_x emissions. As indicated in Chapter 2 of this report, current state-of-the-art models are not able to robustly assess the contribution of individual flights to the formation of contrails and cirrus clouds. In this respect it is noted, however, that EUROCONTROL is participating in a research project to analyse the

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79 For a detailed description see EUROCONTROL (2004), Advanced Emission Model (AEM3) v1.5. Validation report. EEC Report EC/SEE/2004/004.

80 The distance flown outside the airspace controlled by EUROCONTROL can be estimated by using (i) the distance of the city pair, (ii) time of take-off and arrival and (iii) time in entry points of the EUROCONTROL airspace.

probability and magnitude of aircraft contrail formation. The research model used in this project to predict contrail formation is currently only in an experimental phase and it is uncertain how long it will be before it is fully operational and accepted.

At such time as scientific understanding of contrail formation becomes robust and widely accepted, EUROCONTROL may also have a role to play in administering possible flanking instruments. The most obvious example here is enforcement of flight procedures identified in the future as preventing or minimising contrail formation.

3.7.4 Conclusions on monitoring and reporting methods

Based on assessment of the positioning of aircraft operators or EUROCONTROL to fulfil the monitoring and reporting tasks, we here present the main conclusions regarding the potential of *ex ante* and *ex post* methods of calculating CO_2 emissions for use as a basis for the emission trading system variants considered.

The following conclusions can be drawn with regard to the possibilities of '*Trip fuel reported by aircraft operators'*:

- The most attractive option for arriving at accepted and specific *ex post* calculated emission figures for individual aircraft would be to base the CO_2 emission on the carbon content of the trip fuel, which airlines are currently obliged to register in the weight and balance documentation.
- The environmental effectiveness of the emission trading scheme would certainly benefit if actual trip fuel (*ex post* method) were used, as would its economic efficiency, for operational measures to reduce emissions would be duly rewarded (lower speeds, less steep climb angles, higher load factors, etc.).
- The Association of European Airlines (AEA) and a number of its members have expressed their preference for a monitoring and reporting method that is based on the actual trip fuel reported by aircraft operators[81]. They regard this as feasible and fairly straightforward to implement.
- Confidentiality of fuel data can be secured if aircraft operators report in terms of aggregated trip fuel over a pre-defined period. Another possibility for securing confidentiality of sensitive company data is that the competent authority only reports aggregated trip fuel data to the public domain.
- In order to avoid competitive distortions among aircraft operators, a uniform method for fuel data collection should be established and implemented by all participating aircraft operators. Currently, different methods are used. One possibility is to adopt a method developed by British Airways and currently used by them in the UK's domestic emission trading system. In this method

[81] See Working Paper on technical/legal issues for the inclusion in an emission trading scheme (ETS) (AEA, 7 March 2005) and a unanimous standpoint presented by seven European airlines during an AEA meeting on March 30, 2005 in Brussels, Belgium.

fuel burn on a flight is determined as Actual Departure Fuel minus Calculated Arrival Fuel[82].

- Based on the total trip fuel used by an aircraft operator within the boundaries of the geographical scope of the emission trading system, CO_2 emissions can be calculated by using an emission factor for the aviation fuel concerned. (As a formula: CO_2 emissions = fuel consumption [TJ] * emission factor [tCO_2/TJ]). An emission factor often used for kerosene is 3,154 kg CO_2 per kg fuel burned.
- The major European air carriers have indicated that they are able to monitor and report their actual trip fuel. However, some carriers might have capacity problems in organising this properly (e.g. operators from developing states). For these airlines it might be considered to use *ex ante* model estimates by EUROCONTROL, by the competent authority or by the operator, based on aircraft type and time or distance flown. This ex ante estimate should serve as a conservative (high) estimate in order to provide aircraft operators, on a voluntary basis, an incentive to report *ex post* data (actual trip fuel) if this is beneficial to them. The higher the *ex ante* emission estimate, the greater this incentive will be.
- if emissions are based on the carbon content of measured trip fuel, aircraft operators run the risk of paying emission penalties for delays resulting from ATM problems. This could be avoided by using an *ex ante* emission figure as a basis, to reward airlines if they do better, but *not* punish them if they do worse (owing to congestion, for example). Nevertheless, the major European air carriers expressed their preference for an ex post method[83]. Moreover, monitoring based on actual trip fuel (ex post method) may encourage aircraft operators under an emission trading scheme to request other stakeholders (ATM providers and governments) to do their utmost to reduce ATM-related delays.

Findings with regard to possible monitoring and reporting by EUROCONTROL imply the following:

- EUROCONTROL could fulfil the monitoring and reporting tasks, whereby emission calculations are based on ex-ante emission data and ex-post flight data.
- EUROCONTROL has two methods for calculating ex ante emission figures for individual aircraft. The first method is ANCAT3, which is based on EMEP/Corinair emission inventory methodology and which has been officially adopted by ECAC. The second emission calculation method is based on AEM (Advanced Emission Model), constructed by EUROCONTROL itself. To estimate emissions AEM uses generic industry data based on aircraft performance manuals, etc. Validation has indicated that AEM fuel burn calculation results are very close to actual trip fuel data.

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[82] Actual Departure Fuel is defined as the physical amount of fuel present in the aircraft's tanks once the uplift for a flight has been completed. Calculated Arrival Fuel is determined by subtracting the physical fuel uplift for the subsequent sector from the Actual Departure Fuel. This procedure ensures that the fuel burned in operating auxiliary units (APUs) is captured in the estimates.

[83] Ibid footnote 29.

- EUROCONTROL could execute monitoring and reporting in all the geographical scenarios defined in Section 3.3. However, monitoring by EUROCONTROL is most appropriate in the case of an EU-airspace-based scenario, as this requires specific data that are only available at EUROCONTROL[84].
- A disadvantage of using the ex ante emission calculations used by EUROCONTROL is that aircraft operators will not be given incentives to reduce their emissions through (operational) measures whose effects are not reflected in the models. Environmental effectiveness and economic efficiency can therefore be regarded as somewhat lower in the case of monitoring executed by EUROCONTROL.
- An advantage of monitoring and reporting by EUROCONTROL is that the administrative burden of the monitoring and reporting tasks is probably somewhat lower compared to trip fuel based monitoring by individual aircraft operators. EUROCONTROL already has its system in place and can base its task on the existing Route Charge infrastructure.
- EUROCONTROL can also play a role in implementing possible flanking instruments. The most obvious example is operation of flight procedures identified in the future as preventing or minimising contrail formation.

3.8 Verification

Verification procedures need to be defined to ensure the environmental integrity of the system and to protect participants. These procedures are primarily needed to help carriers identify and correct data and/or calculation errors. However, because there is always the risk in reliance on self-reporting that some participants might misrepresent their actual emissions, verification procedures are also needed to ensure equitable treatment of all participants [ICF *et al.*, 2004].

Trading systems tend to benefit from having multiple layers of verification[85]. This includes internal data checks by reporting entities, occasional third party audits and routine analysis of all reports submitted by participants to the competent authorities. We therefore recommend the following verification procedure in the case of monitoring and reporting of trip fuel by aircraft operators:
- Internal data and procedure checks by aircraft operators themselves.
- Independently designated external verifiers who check the internal data and procedures of the reporting aircraft operator.
- Routine checks by EUROCONTROL (in the role of verifier).

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84 In the case of flights from and to the EU it is required to calculate the emissions of the specific part of the flight flown in the EU airspace. Information is then needed on the fuel used during that part of the flight. EUROCONTROL could calculate this by using its information on (i) city pair, (ii) time of take-off and arrival, (iii) aircraft type and engine, and (iv) EU-airspace entry point data.

85 [Tietenberg et al., 1999], International Rules for Greenhouse Gas Emissions Trading: Defining the Principles, Modalities, Rules and Guidelines for Verification, Reporting and Accountability. Geneva. United Nations. UNCTAD/GDS/GFSB/Misc.6.

3.9 Phasing-in

Introducing emissions trading in aviation would place an additional financial burden on the aviation industry. The extent of that burden depends on the targets assigned to the aviation sector and the method adopted for initial allocation. Given that growth perspectives are stronger in the aviation sector than in most other industries, however, the financial burden may well even become quite substantial in the short term. To avoid drastic economic consequences for the industry, then, consideration might be given to implementation of a transitional phase.

The main aim of such a phase-in approach would be to alleviate the economic consequences of introducing aviation emissions trading for the aviation industry. Examples of scenarios could include:

1. *No phase-in*: the entities obliged to surrender allowances must surrender 100% of their allowances for the climate impact covered by the scheme in the first year.
2. *A 3 year phase-in*: the entities obliged to surrender allowances must surrender only 33% of their allowances in the first year, with the share being increased to 66% in the second year and full cost coverage being achieved in the third year.
3. *A 5 year phase-in*: the entities obliged to surrender allowances must surrender only 20% of their allowances in the first year with the share being increased every year by 20 percentage points so that the full cost coverage is achieved after 5 years.

Obviously, the economic frictions associated with introduction of emissions trading in aviation would be highest in the first scenario and lowest in the third.

From an administrative point of view, the scenarios are not that different. In all three scenarios monitoring, reporting and verification would be absolutely identical. The only difference would be in compliance control. Instead of checking whether an operator has surrendered 100% of his allowances for the climate impact he has reported, the administrating authority would check after the first year whether the amount of surrendered allowances is equivalent to 33% or 20% of the climate impacts caused by the operator during the first year. Correspondingly, data requirements are identical in all three scenarios.

This kind of phase-in does not basically interfere much with other design options. Each of the three scenarios can be applied independent of the option adopted for administration or the entity selected for surrendering allowances. The same applies to geographical coverage or coverage of climate impacts. Only with regard to initial allocation is there some degree of interference.

Scenarios two and three can easily be applied in the case of auctioning. The entity obliged to surrender allowances must surrender just one allowance for 3 or 5 tCO_2e emitted. During the phase-in period, however, the amount of allowances auctioned should be adapted to the reduced targets. Correspondingly, only 20% or 33% of the target-path emissions should be auctioned in the first year, increasing the share year by year to achieve 100% auctioning of allowances after three or five years, respectively.

The latter two scenarios can also be applied if it is only the emission growth since a certain base period has to be surrendered. In this case, the administrative authority would calculate the increase since the base year for each entity and multiply the result by 20% or 33% in the first year.

The situation is substantially different in the case of grandfathering and benchmarking, however, because then a phase-in approach can be implemented directly through allocation of allowances. Put differently, no specific phase-in strategy is necessary if allowances are allocated free of charge. If, for example, the climate aviation impact is to be reduced by 20% compared to business as usual over a 10 year period, 98% of the projected emission should be allocated in the first year, 96% in the second, 94% in the third, and so on. Aviation operators would have to surrender 100% of allowances for all the climate impact caused each year. However, due to the fact that the deficit of allowances is small in the first year and increases from year to year, they similarly have time to adapt to the new situation.

To summarise, if allowances are allocated free of charge, a smooth phase-in can be implemented directly through the allocation decision. However, a specific phase-in strategy is appropriate if other methods are adopted for initial allocation. Since the phase-in approach described above does not interfere with other design options, selection of one or other of the scenarios depends mainly on the normative or political decision as to the burden that can be borne by the aviation industry.

4 Selection of three system options

4.1 Introduction

The aim of this chapter is to select three policy options for including aviation in the EU ETS that can be implemented before 2012. In the design of such policy options there are many degrees of freedom with respect to (i) coverage of climate impacts, (ii) geographical scope, (iii) trading entity, (iii) allocation rules and methods, (iv) interplay with the Kyoto Protocol, etc. Within this broad 'playing field' the challenge is to identify a limited number of effective and feasible policy options for further assessment. In order to arrive at three policy options, this chapter discusses the following:

- Selection of feasible and most attractive choices within each key design element (Section 4.2).
- Overview of three policy options (Section 4.3).

4.2 Selection of feasible choices within each key design element

Based on the results of Chapters 2 and 3 we identified seven key design elements to be addressed if the climate impacts of the international aviation sector are to be included in the EU ETS:

- **Coverage of climate impacts** – besides CO_2 emissions, this refers to whether and by what metrics or instruments the non-CO_2 effects of aviation are to be addressed.
- **Geographical scope** – refers to the geographical coverage of aviation emissions under the trading scheme, i.e. specification of the countries, routes and types of flights/aircraft to be included.
- **Trading entity** – refers to the entities that would be obliged to surrender allowances for emissions generated and be allowed to trade.
- **Decision on allocation rules** – refers to the institutional level (EU or Member State) at which emission targets and methodologies for the distribution of allowances are to be set, i.e. the degree of subsidiarity granted to Member States with regard to the method used for allocating allowances.
- **Interplay with the Kyoto Protocol** – refers to the question how aviation can be integrated in the EU ETS, given the separate treatment of this sector under the Kyoto Protocol.
- **Allocation method** – refers to the method to be used for initial distribution of allowances among entities.
- **Monitoring method** – refers to the emission measurement or calculation method to be used and the agency responsible for monitoring and reporting emissions.

Table 18 reviews the main choices that were identified with respect to each of these key design elements.

Table 18 Key design elements and associated choices

Key design element	Choices (options)
Coverage of climate impacts	– CO_2 x multiplier to capture full climate impacts – CO_2 plus effect-by-effect approach to account for non-CO_2 impacts – CO_2 only, with flanking instruments (flight procedures, NO_x landing charge and NO_x en-route charge)
Geographical scope	– Intra-EU – Intra-EU routes and 50% of routes to and from EU airports – Emission of all flights departing from EU airports – All emissions in EU airspace – Emission of all flights departing from EU airports plus remaining emissions in EU airspace – Intra-EU and routes to and from third countries that have ratified the Kyoto Protocol
Trading entity	– Aircraft operator – Airport operator – Fuel supplier – Providers of air traffic management – Aircraft manufacturers
Decision on allocation rules	– Amount of aviation allowances defined at EU level and a uniform allocation approach – Amount of allowances set at Member State level and common allocation criteria
Interplay with Kyoto Protocol	– Extension of the scope of the Kyoto Protocol – Borrowing of AAUs from sectors not covered by the EU ETS – No allocation of allowances to the aviation sector – Obligation to buy allowances for emissions growth above a baseline – Semi-open trading for aviation – Gateway (trade restrictions)
Allocation method (allowance distributing mechanism)	– Grandfathering – Benchmarking – Auctioning – Baseline – No allocation
Monitoring method	– Measured trip fuel by aircraft operators – Calculated emissions by e.g. EUROCONTROL

Below we describe the selection process and clarify our arguments for the choice of the various key design elements in each of the three policy options, which are presented in the next section (4.3). These ultimate design choices are based mainly on an assessment of the pros and cons of a range of methods to address the full climate impact (Chapter 2) and a range of options for other design elements (Chapter 3). Some design elements are considered not to be *key* design elements and are therefore not discussed below. For example, the tasks associated with administration of emissions must be carried out in each policy option. In our opinion, the only major decision is then whether these tasks[86]

[86] Administrative tasks include: issuance of permits, issuance of allowance, administration of registries, compliance control and enforcement in case of non-compliance.

should be carried out by Member States (their competent authorities) or by a central body of the European Union and how this should be done.

In addition to the pros and cons of the key design elements, the criterion 'similar environmental impact' has also been used in constructing the three policy options. This means that we have tried to develop policy options (system concepts) for including aviation in the EU ETS that reduce CO_2 emissions by the same order of magnitude.

Coverage of climate impacts
This study examined three scenarios by which the 'full climate change impact' of aviation might be captured under the EU ETS without undermining the scheme's environmental integrity:

1 CO_2 × multiplier to capture full climate impacts.
2 CO_2 plus effect-by-effect approach to account for non-CO_2 impacts.
3 CO_2 only, with flanking instruments for non-CO_2 effects.

Scenario 1 may be feasible at some point in the future. In Chapter 2 the GTP (Global Temperature Potential) concept was proposed as a basis for the multiplier approach. Overall, it will require more work before this approach has sufficiently matured: an estimated 2 to 5 years. Given this time span we opted to include this scenario for climate impact coverage in one of the three policy options selected later on in this chapter. In line with the results of Chapter 2, a multiplier of 2 will then be applied to capture the full climate impact of aviation (without cirrus clouds).

Scenario 2 was judged to be unfeasible (see Chapter 2) at the present time.

Scenario 3 can be regarded as the most attractive scenario, as it can be implemented in the short term. As this scenario is based on a 'CO_2 only' regime, flanking instruments should be considered as safeguards against negative trade-offs and to mitigate the non-CO_2 climate impacts of aviation. With regard to NO_x, an LTO-based charge was deemed to be the most suitable flanking instrument, the general expectation within the sector being that a reduction of NO_x LTO-emissions will also reduce NO_x cruise emissions. Furthermore, NO_x-based landing charges can be based on a straightforward metric: kg NO_x/LTO. As an added benefit, NO_x landing charges might have a positive effect on local air quality. The feasibility of this instrument is reflected in some EU airports already having established NO_x airport charges, and the instrument has moreover been proven to be legally robust[87]. Based on these findings, we therefore decided to select scenario 3 for coverage of climate impacts in two of the three policy options.

[87] In Switzerland a charge was unsuccessfully challenged in the courts.

Geographical scope

In relation to geographical coverage several scenarios were considered in the study, specifying different sets of countries and routes for inclusion in the scheme, as follows:

- Scenario 1: Intra-EU routes.
- Scenario 2a: Intra-EU and 50% of emissions on routes to and from EU airports.
- Scenario 2b: Emissions of all flights departing from EU airports.
- Scenario 3: All emissions in EU airspace[88].
- Scenario 4: Emissions of all flights departing from EU airports plus remaining emissions in EU airspace.
- Scenario 5: Intra-EU and routes to and from third countries that have ratified the Kyoto Protocol.

Scenario 5 depends on the cooperation of countries outside the EU that have ratified the Kyoto Protocol and that wish to be linked to the EU ETS. This option can only be introduced in the long term. Furthermore, this option can be seen as a future extension of scenario 1 (intra-EU routes). Consequently, scenario 5 has not been selected. Scenario 4 is a combination of the route-based scenario 2b and the airspace-based scenario 3, which moved us to reject this option, as an impact assessment cannot show the effects of these scenarios separately. On balance, the first three scope scenarios have been included in the selection in order to show differences in impacts. Although the pros and cons of these scenarios differ, all three have been assessed as feasible (see Section 3.3).

Trading entity

In our opinion aircraft operators are the most attractive entity for surrendering allowances and engaging in emissions trading. This option provides the best guarantee of achieving the most effective and efficient incentives for emissions reduction, as it is aircraft operators that have greatest control over abatement measures and monitoring data. All the other options for trading entities have one or more decisive disadvantages that led us to reject them as inferior. Below, these disadvantages are summarised for each of the rejected trading entities.

Fuel supplier: disadvantages

- Fuel tankering is a crucial obstacle. Different airlines cited to us a fuel burn penalty of 2.5% - 3.5% per hour for taking extra fuel on board (depending on stage length). Assuming an allowance price of € 10 tonne/CO_2 and a fuel price of € 400 per tonne implies that it would be profitable to take extra fuel on board from areas outside the scope of the scheme for flights with a flight time less than 3.5 hours that are flying into the EU. If the allowance price rises, this flight time threshold will increase and, with it, this potential for tankering behaviour.

[88] In this study the EU airspace is defined on the basis of the Flight Information Regions (FIR) of the EU Member States as employed by EUROCONTROL and officially agreed on with ICAO. The FIRs employed by EUROCONTROL encompass not only the national territories of individual countries, but may also include particular areas of seas and oceans. For all intra-EU routes it is assumed that the full route length is covered, even if the airspace of non-EU States is used.

– This option closes off the possibility of including non-CO_2 climate impacts from aviation in a tradable metric in the future. This disadvantage need not be a problem if flanking instruments are chosen to mitigate non-CO_2 climate impacts of aviation.

Airports: disadvantages

– Airports have no control over the majority of the mitigation measures.
– It is uncertain whether airports will pass on the costs of allowances to aircraft operators by means of an effective and efficient incentive structure. If airports are the trading entity, they must pass on the costs of the allowances they surrender to competent authorities. This would require an additional mechanism (e.g. a charge) at all EU airports, which might be arranged through introduction of a separate EU regulation. Obviously, this requires a very sophisticated designed mechanism in order to give the 'right' incentives to airlines to mitigate climate impacts. If this mechanism is not harmonised among EU airports, each airport might use different and sometimes ineffective incentives.
– Given the monopolistic market situation of most airports, it is questionable whether the price signal will be passed on uniformly. This may not be a problem from an internal market perspective (every airport employing its own strategy for maximising profits), but may decrease the environmental effectiveness of the system.
– Another rather important disadvantage of this option is that one private entity (airline) may have to report sensitive information to another private entity (airport). In particular, this might be an obstacle if monitoring is based on actual fuel and/or flight data, in which case confidential data would have to be reported to airports by airlines. A monitoring system based on data calculated *ex ante* will be less a problem from the angle of confidentiality, but lacks certain incentives (to implement operational measures, for example).

ATM providers: disadvantages

– An additional mechanism (e.g. charge) is needed to pass on the price signal (and provide effective incentives).
– A major obstacle is the market structure: ATM providers are sometimes public or semi-public.

Aircraft manufacturers

– It would not be legally feasible to oblige manufacturers based outside the EU to participate. This would create competitive advantages for such companies.
– No incentives will be created for operational measures or short-term technical measures (e.g. re-engining, retrofits, etc.).

Decision on allocation rules

One of the pivotal issues of an emissions trading scheme is the level – EU or Member State – at which the total amount of allowances is to be decided and the rules according to which allowances are to be allocated among the entities covered. In essence, this task comprises decisions on whether and eventually how to distribute allowances.

This study identified has two convincing arguments for defining the amount of allowances at the EU level and employing uniform allowance distribution rules for all regulated entities in the aviation sector:

– *International aviation is not included in the EU's Burden Sharing agreement*
  An important reason for allowing a degree of subsidiarity on the quantity of allowances to be distributed to stationary sources was the Burden Sharing agreement, which established different emission reduction targets for each Member State. As international aviation is not covered by this agreement, no such barrier to harmonised allocation exists for this sector.
– *Prevention of competitive distortions and administrative costs*
  A uniform EU allocation method would prevent competitive distortions, as all the entities covered would be allocated allowances according to exactly the same rules. For Member States it might also reduce the administrative costs associated with allocation decisions.

Interplay with the Kyoto Protocol

Including international aviation in the EU ETS may create leakages in the system and in the Kyoto Protocol, because the emissions of international aviation are not underpinned by the AAUs used for compliance control under the Kyoto Protocol. Problems may arise, particularly if aviation sector emission rights are sold to sectors already covered by the European emissions trading scheme (EU ETS). This study identified and assessed several options for avoiding these problems:

1. *Extension of the scope of the Kyoto Protocol*
   Repeal of the exemption of aviation from quantitative obligations.
2. *Borrowing of AAUs from sectors not covered by the EU ETS*
   AAUs from sectors not covered by the EU ETS are used temporarily to underpin international aviation emissions under the geographical scope. Correspondingly, aviation entities are allocated allowances that are fully fungible, i.e. the aviation sector can buy and sell allowances from and to other sectors under the EU ETS without any trade restrictions.
3. *No allocation of allowances to the aviation sector*
   In this option the aviation sector must buy all the allowances required for compliance from other sectors, with no additional allowances being granted to aviation. Emissions trading in aviation is based on allowances from the EU ETS and Kyoto units (ERU, CER, RMU, etc.) only.
4. *Obligation to buy allowances for emissions growth above a baseline*
   This option is similar to the previous one, but limits the obligation to surrender allowances to those for emissions growth relative to a base year or base period (baseline).
5. *Semi-open trading for aviation*
   Aviation entities are allocated allowances. They can buy allowances or Kyoto units from non-aviation operators, but cannot sell allowances to these parties.
6. *Gateway (trade restrictions)*
   Aviation entities are allocated allowances and can, as a maximum, sell as many allowances as they have already bought during the trading period from non-aviation sectors.

The first option would avoid any trade restrictions, as AAUs would be created for international aviation as well. However, it cannot be realised during the first commitment period, from 2008 to 2012, because the Kyoto Protocol has already been ratified and can no longer be changed. Consequently, we deem this an unfeasible option for including aviation in the EU ETS before 2012.

As aviation is not underpinned by AAUs, all the other options are designed to ensure continued integrity of the EU ETS. This can be done by not allocating EU allowances to the aviation sector (options 3 and 4) or by means of trading restrictions (options 5 and 6). An alternative is option 2, which also allows trade within the aviation sector and between the aviation and other sectors without any constraint. However, there is a risk that at the end of the commitment period more allowances will have been sold by the aviation sector to other sectors than bought from other sectors. In that case there will be a shortage of AAUs and correspondingly not all AAUs can be returned to the Member States that 'loaned' them at the beginning of that commitment period. In that case, Member States and the EC would have to find alternative ways of settling this AAU deficit, for example by buying additional AAUs from third countries outside the EU. This kind of AAU deficit seems an unlikely probability, however, as the aviation sector as a whole is expected to be a net buyer of EU allowances (EUAs) (and thus the linked AAUs), it being generally assumed that the aviation sector has high marginal abatement costs compared to other sectors.

In selecting attractive options, we decided not to select option 3 (buy allowances for all emissions) as it will lead to a relatively high *extra* demand on the EU ETS market. It must be borne in mind, however, that option 3 has many advantages compared with option 4, because (i) it requires no allocation of allowances, (ii) it provides reduction incentives for all emissions, not only above the baseline, and (iii) it guarantees equal treatment to new entrants.

Option 5 (semi-open trading) has not been selected, furthermore, it being deemed less efficient than option 6 (Gateway) because no allowances can be sold to other sectors. On balance, option 2 (borrowing AAUs), option 4 (buy above baseline) and option 6 (Gateway) have been selected for further the design of three policy concepts for inclusion of aviation into the EU ETS.

Allocation method
Auctioning appears to be the most attractive option for allocation. From an economic angle it is to be considered the most efficient. Other important advantages are simplicity with respect to equal treatment of new entrants compared with existing operators and crediting for early action, and the lower administrative burden associated with data requirements. There is also a significant degree of flexibility regarding the extent to which auction revenues are recycled.

A second-best option would be to start off with benchmarked initial allocation. In general, it is felt that benchmarking is to be preferred over a grandfathering approach, the latter being less favourable to new entrants and those companies that already operated relatively energy-efficient aircraft in the baseline year.

Monitoring method
To establish monitoring and reporting protocols, emission inventory activities could rely either on self-reporting by participants or on third parties such as EUROCONTROL. For CO_2, the most accurate monitoring option is for aircraft operators to measure the actual fuel used on each trip flown within the chosen geographical scope of the emission trading system. CO_2 emissions can then be calculated from the carbon content of that fuel. Under current international regulations, the amount of fuel used on each flight must already be registered by airlines. Monitoring by EUROCONTROL is most appropriate in the case of an EU-airspace based scenario, as this requires specific data which are only available at EUROCONTROL[89].

4.3 Selection of three policy options

Based on the assessment of the pros and cons of the individual key design elements and the selection process described above, three policy options were selected for further examination, which we shall refer to as Option 1, 2 and 3 (see Table 19). Configuration of these options was based on the wish for consistent combinations of the design elements, for broadly comparable environmental outcomes, for avoidance of extreme options and for coverage of each of the main feasible choices per key design element. Note, however, that none of these is necessarily 'the optimum', even though the results of the evaluation below may show one option to be less attractive than another because of a sub-optimum combination of key design elements.

[89] In the case of flights to and from the EU the emissions occurring on the specific part of the flight flown in EU airspace would have to be calculated. Information is then required on the fuel used during that part of the flight, which EUROCONTROL could calculate using its information on (i) city pair, (ii) time of take-off and arrival, (iii) aircraft type and engine and (iv) EU-airspace entry point data.

Table 19 Overview of the three selected policy options for including aviation in the EU-ETS

Design element	Option 1	Option 2	Option 3
Coverage of climate impacts	CO_2 and multiplier for non-CO_2 climate impacts	CO_2 only (with flanking instruments for other impacts)	CO_2 only (with flanking instruments for other impacts)
Geographical scope	Intra-EU	Emissions of departing flights from EU airports	EU airspace
Trading entity	Aircraft operator	Aircraft operator	Aircraft operator
Decision on allocation rules	Uniform approach set at EU level	Uniform approach set at EU level	Uniform approach set at EU level
Interplay with Kyoto Protocol	Aviation buys allowances from other sectors above a historic baseline	Unrestricted trading based on AAUs borrowed from other sectors	Trading with other sectors based on a Gateway mechanism
Allocation method	Baseline	Benchmarked allocation	Auctioning
Monitoring method	Actual trip fuel reported by aircraft operator	Actual trip fuel reported by aircraft operator	EUROCONTROL data (*ex ante* and radar surveillance)

The idea behind **Option 1** is to start with an intra-EU scheme that can be later extended with regard to routes to and from the EU. Furthermore, Option 1 includes the multiplier of 2 (to capture the full climate impact) in order to achieve a balance in terms of environmental effectiveness compared with the other two options, which have a much broader scope in terms of the flights covered. The choice for the 'baseline' approach to allocation in policy Option 1 is to examine the impacts of this approach in the remainder of this report. However, according to the assessment of pros and cons (see Chapter 3), auctioning or benchmarked allocation would be preferable. This might be a reason to optimise policy Option 1 with respect to this particular design element.

Option 2 has a much broader geographical scope compared with Option 1, 100% of emissions from flights departing from EU airports being covered by the system. This means that about 130 Mt CO_2 emissions are covered instead of about 52 Mt under the intra-EU based Option 1. With regard to the interplay with the Kyoto Protocol, administrative registration with respect to the underpinning of allowances by AAUs will be based on a 'pool' of AAUs that are 'borrowed' from other sectors in the EU that are not covered by the EU ETS. This implies there will be no trade restrictions in place, because allowances sold by the aviation sector to other sectors can be underpinned by AAUs from the 'pool' borrowed at the beginning of the commitment period. Obviously, aircraft operators can also buy or sell (initially auctioned) allowances to and from one another.

Option 3 can be characterised as a more centralised policy option in which the EC or a specialised EU body operates the system with support from EUROCONTROL. The geographical scope of Option 3 is based on EU airspace, while the first two options are route-based. Option 3, the airspace-based approach, requires the involvement of EUROCONTROL in the monitoring and reporting tasks. Another feature of this option is the Gateway mechanism, meaning that the aviation sector can, as a maximum, sell as many allowances as they have previously bought from non-aviation sectors. Since it is generally assumed that the marginal costs of greenhouse gas abatement are much higher for aviation than in non-aviation sectors, one can expect the aviation sector to be a net buyer of allowances. Accordingly, these restrictions will not influence the efficiency of emissions trading in aviation too much. If domestic aviation emissions were also included, potential trade restrictions would be further alleviated because some AAUs would then be available in the 'aviation pool' from the start of the scheme. This implies that aviation could even be a net seller at the end of the commitment period. As in Option 2, aircraft operators can also buy or sell (initially grandfathered) allowances from and to one another.

5 Environmental impacts

In this chapter we review the potential environmental benefits of the three policy options selected for including aviation in the EU Emissions Trading Scheme. Although the international literature provides a certain amount of insight into the potential environmental benefits of applying economic policies in the aviation sector, we opted to conduct an entirely fresh analysis. There are two main reasons. First, the available information resources were not aimed at assessing the environmental effectiveness of emissions trading for aviation linked in various ways to the existing EU ETS. Second, in our opinion, these resources lack the scope and depth for drawing solid conclusions.

This chapter presents the following:
- Assumptions and the 'Business as Usual' scenario (Section 5.1).
- Incentives provided by the various policy options (Section 5.2).
- Impacts on operating costs and ticket prices (Section 5.3).
- Quantitative environmental impacts of three policy options (Section 5.4).
- Effects of a 'CO_2-only' regime and negative trade-offs (section 5.5).
- Impacts of flanking instruments (section 5.6).

5.1 Assumptions and the 'Business as Usual' scenario

Throughout the analysis in this chapter, the environmental effects of the three policy options selected in Chapter 4 are compared to a 'Business as Usual' (BaU) scenario, with 'no policy change'. This comparison will be based on the following assumptions and specifications:

1 A quantitative impact analysis has been carried out for the period 2008-2012, thereby taking 2008 emission levels as an historical baseline. Under Option 1, aviation must buy allowances for all emissions above this baseline. In Options 2 and 3, the total amount of emissions grandfathered or auctioned, respectively, to aircraft operators is assumed to be equal to the 2008 emissions level.

2 The impacts are computed and presented for the year 2012. The impacts are shown by comparing the BaU situation in 2012 with the situation after implementation of each of the three policy options.

3 Under option 1, a multiplier of 2 is applied to account for non-CO_2 climate impacts. This figure of 2 is based on a preliminary estimate of the Global Temperature Index (GTI) presented in Chapter 2 (see Section 2.4). This implies that for each tonne of CO_2 emitted by the aviation industry, two allowances must be bought from other sectors. Vice versa, for each tonne of CO_2 reduced by the aviation sector, the sector can sell two allowances to other sectors. Under Option 3, effects associated with possible flanking instruments are not taken into account.

4 In the BaU scenario, the CO_2 emissions computed for the various geographical scenarios (see Section 3.3.4) are assumed to grow by 4% a year in the period 2004 – 2012. We have assumed here that an average growth of 5% in air traffic is partly offset by a reference fuel efficiency

improvement of 1% annually. This assumption seems to be very much in line with projections of [ICAO, 2004] and [Airbus, 2005] and the AERO2K [Eyers, 2004] results.

5 The effects of the three Options have been calculated assuming two alternative market prices for allowances. These are exogenous factors in our calculations and were set at € 10 and € 30 per tonne of CO_2.

6 It is assumed in Option 3 that the average price of initially auctioned allowances equals the price on the open market of the EU ETS. This seems a plausible assumption given the relatively high marginal abatement costs in the aviation sector compared with other sectors and expected scarcity due to air transport growth expectations.

7 It is assumed that the aviation sector is a net buyer of allowances, which would be the case if it has high marginal abatement costs for CO_2 emission reduction, as is generally assumed, and in the absence of 'over-generous' allocation.

8 It is assumed that the policy-induced cost increases to airlines are passed on to consumers by increasing fares on those routes subject to the EU ETS. We assume no cross-subsidising over and above the current level of cross-subsidisation with routes not subject to the scheme. Consequently, it is only demand on the routes under the EU ETS that will be affected. This seems a plausible assumption, as competition on other markets would remain unchanged and thus create no scope for *additional* cross-subsidisation (see also Section 5.3.3).

9 Regarding the opportunity costs of grandfathered rights, two scenarios are presented. In the first, opportunity costs are not passed on, while in the second it is assumed that aircraft operators pass these costs on to customers in their entirety. See Section 5.3.4 for a detailed description of the concept of opportunity costs and Section 6.6.1 for a discussion of the revenues generated by aircraft operators as they pass on these costs to customers.

10 Impacts on operating costs and ticket prices for some flight stages have been calculated using spreadsheets models. The assumptions and calculations are clarified in this chapter and in Annex E to this report. Impacts on demand and supply-side responses by the aviation sector have been estimated using the AERO model. A brief description of the AERO model and references to a full description can be found in Annex F.

5.2 Incentives provided by the various policy options

For a proper understanding of how including aviation emissions in the EU ETS would lead to improvements in the environmental performance of the air transport sector, we here describe the incentives that are likely to be provided by the three selected policy options. In other words, we clarify which emission abatement measures are likely to be triggered by each of the policy options.

By bringing international aviation into the EU ETS, a price is set indirectly on emissions. This price consists partly of abatement costs in the case of supply-side responses, and partly of the cost of emissions for which allowances must be purchased on the market. Under Option 2, opportunity costs are additionally involved for those emissions for which allowances are grandfathered (see also Section 5.3.4). Clearly, the share of financial costs and opportunity costs depend on the distribution of allowances. Whatever the case, though, there will be benefits for aircraft operators that reduce emissions, either because they can sell grandfathered allowances, or because they need to purchase fewer allowances. We can therefore state broadly that there will be costs associated with emissions. The expected impact on aircraft operation costs and ticket prices is discussed further in Section 5.3.

Aircraft operators are expected to respond to allowance prices on the market in one of two possible ways. If the allowance market price exceeds what it costs a particular aircraft operator to reduce emissions, that operator will probably decide to reduce emissions. He can now either sell his excess allowances, or need buy fewer allowances on the market. In the alternative case, with the market price below what it costs the aircraft operator to reduce emissions, he will probably not reduce emissions but buy allowances on the market instead (or sell fewer). Which of the two possibilities is in fact the case has no influence on the environmental impact. In the first case, the aircraft operator himself takes measures to reduce emissions. Alternatively, in the second case he purchases allowances on the market and the selling party will have to cut emissions. In either case, the environmental impact is the same (assuming that emission reductions per unit are fully fungible).

Below we discuss the various kinds of emission abatement measures that aircraft operators may or may not be encouraged, or 'incentivised', to implement. We thereby distinguish:

1 Measures to the fleet mix.
2 Technical measures:
   a To existing aircraft (short term).
   b To new aircraft (long term).
3 Operational measures:
   a At individual flight level.
   b At network level.

These measures all take place on the supply side. Given the envisaged rise in the price of air transport, however, demand-side effects are also to be expected, viz.:

1 Substitution of air transport to other modes.
2 A net loss of total transport demand.

Demand-side impacts will depend on airlines' fare-adjustment behaviour (discussed below in Section 5.3).

We first elaborate on each of these demand-side measures and on effects more generally and then discuss the exact incentives provided by each of three Options for bringing aviation into the EU ETS.

1 Fleet mix measures

This category of possible measures implies a shift in fleet composition towards more fuel-efficient aircraft, but only includes technologies that would also have been in the marketplace if the incentive had not been present. We can distinguish two different mechanisms.

Accelerated fleet renewal

As new aircraft generally have lower emissions than older, old aircraft may be replaced sooner if there are costs associated with emissions.

Shifts in sales of new aircraft

Apart from accelerated fleet renewal, environmental characteristics may become more important in the choice of new aircraft. Aircraft with relatively few emissions will have lower operating costs, as fewer emission allowances need be surrendered. These aircraft may therefore become more popular than is presently the case relative to aircraft with high emissions.

2 Technical measures

A To existing aircraft (short term)

There are various market options available for reducing the fuel consumption of existing aircraft. These options, such as retrofitting of winglets, riblets and possibly engines, will also reduce CO_2 emissions.

B To new aircraft (long term)

This category includes technologies that are not currently available but development and introduction of which could be accelerated. If there are costs associated with CO_2 emissions, demand for fuel-efficient aircraft will increase. Aircraft operators will then be willing to pay more for fuel-efficient aircraft and aircraft manufacturers therefore further incentivised to develop such aircraft and accelerate their introduction.

Development of more fuel-efficient aircraft can take one of three forms:

- Development of airframes with lower drag / lower design speed. Reduction of aircraft drag can be achieved by improving technologies or by lowering the design speed of aircraft.
- Development of lighter airframes. Aircraft with a lower weight are, *ceteris paribus*, more fuel-efficient.
- Development of more fuel-efficient engines.

3 Operational measures

A At individual flight level

There are several operational measures that can be applied at the individual flight level:

- Changes to flight path and flight speed to minimise emissions. Apart from changes to flight path to avoid EU airspace in Option 3, flight paths (especially altitude) and speed can be adapted to reduce emissions. For any particular aircraft and route, a minimum-emissions speed leads to a 15-25% reduction in CO_2 emissions compared to a maximum-emissions speed[90].

- Reduction of empty weight (e.g. lower on-board service levels, less tankering). While reduction of *airframe* weight is a technical measure that may be incentivised, *aircraft* weight can also be influenced by scaling down on-board service levels.

B At network level

This category includes operational measures, such as changing frequencies, networks, destinations and so on, the impacts of which extend beyond individual aircraft. We can distinguish two types of measure:

- Increases in load factor (larger aircraft or lower frequencies). The costs associated with emissions increase the direct operating costs (DOC), thus leading aircraft operators to 'bundle' their passenger and freight streams[91].
- Changes in flight distance to improve environmental efficiency. Long-distance transport is relatively hard hit, as the relative CO_2 emissions per $/euro ticket price are higher. This incentive is not present under policy Option 1 (Intra-EU flights only). In this option, shorter (EU) flights are relatively worse off than intercontinental flights. Option 1 can therefore be regarded as favouring long-haul flights over short-haul, intra-EU flights. This follows from the demand effect, as discussed in Section 6.2.

So far, all the measures discussed are supply-side responses to bringing aviation into the EU ETS scheme. As already mentioned, however, if the costs associated with emissions are passed on (in whole or in part) to customers via ticket prices and freight tariffs, demand-side effects are also to be expected.

It is clear that the measures discussed above are not new and are largely or partly already incentivised by existing costs under the Business as Usual scenario. For example, because fuel costs are a significant element of operating costs, aircraft operators already take the fuel efficiency of aircraft into account at time of purchase. However, the additional costs associated with emissions will change the cost-benefit ratio of airline companies investing in fuel efficiency measures compared to the 'no policy change' scenario. This implies that more fuel efficiency measures become cost-effective as a result of introducing an economic incentive such as emissions trading or emissions charges. It should be emphasised here that some measures, such as development of new aircraft technologies, only become available in the long term.

We now discuss, for each of the three policy options, to what extent incentives for abatement measures and the aforementioned demand-side effects are increased relative to the reference scenario. First, though, Table 20 summarises the main features of each option once more.

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[90] [CE, 2002].

[91] At first sight it might appear counterintuitive that both a reduction in empty weight and an increase in load factor (de facto making the aircraft heavier) improve fuel efficiency. However, both measures would reduce fuel use per tonne or passenger transported.

Table 20 Main features of policy Options 1 to 3

	Option 1	Option 2	Option 3
Coverage of climate impacts	CO_2 and multiplier for non-CO_2 impacts	CO_2 only and flanking instruments	CO_2 only and flanking instruments
Geographical scope	Intra-EU	100% of departing flights	EU airspace
Allowance distribution mechanism	Above historic baseline, purchase from other sectors	Benchmarked allocation	Auctioning
Monitoring method	Actual trip fuel reported by airline	Actual trip fuel reported by airline	EUROCONTROL data (*ex ante* and surveillance)

Measures concerning the **fleet mix** are incentivised under all three Options. The effect on emissions of both accelerated fleet renewal and shifts in sales of new aircraft would be picked up under both monitoring methods, and aircraft operators would be 'rewarded' by a reduction in emission allowances to be surrendered.

The extent to which technical measures to existing aircraft are incentivised depends on how CO_2 emissions are monitored. Actual trip fuel data records the benefits of such measures on fuel use and emissions. Under Option 3, with calculation of emissions by EUROCONTROL, whether such measures are incentivised depends on the exact calculation method used. If the adopted method does not account for such measures (e.g. retrofit measures), there is no increased incentive to apply them. EUROCONTROL's current, *ex ante* monitoring method of (see Section 3.7.3) does take into account aircraft type. However, engine type as well as some retrofits (such as wingtip devices and riblets) are not included and thus no incentive is provided for these fuel efficiency measures in the case of monitoring by EUROCONTROL.

Technical measures relating to *new* aircraft are, in general, incentivised under all three Options, provided that EUROCONTROL duly accounts for more fuel-efficient types of aircraft in monitoring calculations under Option 3.

Aircraft operators will have an additional incentive for taking operational measures to increase fuel efficiency if monitoring is based on actual (measured) emissions. Policy Options 1 and 2 are based on actual trip fuel used and would thus provide this incentive, while Option 3, based on *ex ante* emission calculation methods, would not. This implies, for example, that monitoring by EUROCONTROL would not provide an incentive to increase aircraft load factors.

In general, whether or not particular measures are incentivised depends largely on how CO_2 emissions are monitored. If actual trip fuel data are used, there will be an incentive for any and all measures that increase fuel efficiency, while if monitoring is based on calculation, incentives will depend on the measures accounted for in the calculation methodology applied. However, even if the calculation methodology does takes account of the measures, the incentive may be reduced as particular aircraft operators may not be able to directly relate the results of the particular measures taken to the results of a generalised and anonymised calculation[92].

Size of the incentive under the three policy options

Above, we have discussed the *direction* of the incentives provided under each policy option, concluding that there is little difference in the respective structure of the incentives created. The three Options do differ significantly in their environmental effectiveness, however, in terms of the strength of the incentive created. That strength depends on the incentive 'at the margin' (i.e. the change in an aircraft operator's marginal costs associated with production of one extra tonne of CO_2) and on the amount of emissions for which allowances must be surrendered, since it is these emissions that are associated with costs, either effective or opportunity. This amount depends on the choices made regarding three key design elements.

- **Coverage of climate impacts**. If a multiplier were applied to CO_2 emissions to account for non-CO_2 impacts, the strength of the incentive would be proportional to the multiplier. With a multiplier of two, for example, the incentive created in Option 1 would be twice as great as in Option 2. Clearly, flanking instruments would provide incentives of their own, possibly reinforcing the incentives provided by the EU ETS for CO_2 emissions.
- **Geographical scope**. The strength of the incentive to the aviation sector depends on the geographical scope of the option. If more routes are included, environmental effectiveness will increase. Moreover, the greater the share of a route, the stronger the incentive, which will rise in direct proportion to the CO_2 emissions falling under the scheme. In addition, options with a limited scope, such as Intra-EU (Option 1) and to a lesser extent EU airspace (Option 3), benefit long-haul more than short-haul flights, as only the latter are (fully) covered by the scheme.
- **Allocation method**. Although the strength of the incentive for operators does not depend on whether allowances are grandfathered or auctioned[93], it does depend on the amount of emissions for which allowances must be surrendered. Option 1 differs from a standard baseline and credit system, because aircraft operators are accountable only for emissions above their historic baseline. Therefore the scheme provides no incentives for reductions beyond this baseline.

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[92] Although aircraft operators will monitor fuel use, they may be unsure about the extent to which their efforts are also reflected in the amount of emissions attributed to them.

[93] In either case it pays to reduce emissions, either by being able to sell allowances or by having to purchase fewer allowances.

5.3 Impact on operating costs and ticket prices

5.3.1 Introduction

In this section the impact of the three policy options on costs for aircraft operators and on ticket prices is assessed. The impact on operating results, ticket prices and, more generally, air fares depends crucially on whether operators will be able to pass the costs associated with the EU ETS on to their clients and, if so, whether they will do so. The fare adjustment behaviour of operators coupled with the receptiveness of the market will determine the impact on demand.

Under the EU ETS, CO_2 emissions from aviation become a factor of production that has to be paid for, in the same way as fuel, labour and capital. Inclusion of aviation into the EU ETS involves the following potential cost factors:

- **Cost of auctioned allowances***:* if the initial distribution of the total quantity of allowances available is through an auction, rather than be freely allocated, then these costs are equal to the amount of allowances bought through an auction multiplied by the auction clearing price.
- **Opportunity cost:** if the initial distribution of the total quantity of allowances available is distributed for free, these allowances still have an associated cost ("opportunity cost") when they are used for covering the emissions of the operator [Nentjes et al., 1995]. This is because, even though the allowances have been received by the operator for free, the operator is foregoing the opportunity to sell these allowances on the market when they are used instead to cover its emissions.
- **Abatement costs:** costs of operational and technical measures to reduce the climate impacts of aircraft. In a trading scheme, these measures are taken if they cost less than the price of allowances on the market.
- **Cost of purchasing allowances** on the EU ETS market: if the operator needs to purchase additional allowances, these costs are equal to the amount of allowances bought on the market multiplied by the prevailing market price.
- **Administration and transaction costs** of administering emissions (monitoring, reporting and verification) and trading (opening registry accounts, brokerage or exchange charges, etc.).

Besides administration and transaction costs, all of the above costs will be dealt with in this study. Administration and transaction costs are not discussed because, as yet, there is little information available that gives robust indications of the magnitude of these running costs for participating in the EU ETS. However, this category of costs would not be expected to be a major component of total costs. This issue may require further research.

The structure of this section is as follows:
First, Section 5.3.2 analyses fare adjustment behaviour. Some general remarks on this subject are followed, in Section 5.3.3, by an analysis of the likelihood of increased cross-subsidisation by non-EU carriers. Next, in Section 5.3.4, the concept of opportunity costs is discussed and the likelihood of aviation

companies passing these costs on to their customers is analysed. Finally, based on conclusions in the previous sub-sections, the initial impact on operating costs at individual flight level and the effect on ticket prices is analysed.

The environmental impact of including aviation in the EU ETS is the subject of a separate Section 5.4.

5.3.2 Fare adjustment behaviour

A core area considered in the assessment of the environmental and economic impacts of the three policy options relates to the extent to which airlines adjust fares to reflect the costs of participating in the EU ETS. For example, if airlines were to fully absorb the cost increase resulting from each of the options through lowering their profit margins, ticket prices would remain unchanged and so there would be no impact on demand.

Below we argue why we assume in this study that airlines will generally pass the cost increase resulting from each of the policy options on to their customers.

First, it should be stressed that all carriers, both EU and non-EU, are assumed to be subject to exactly the same system. This study considers only non-discriminative options, meaning that all carriers providing a service on the same route are treated in the same way. This implies that both EU and non-EU carriers would face the same cost increase per tonne of CO_2 emitted on the same flight stage[94]. In a situation of perfect competition in the international markets for air transport, both EU and non-EU carriers would then pass on the whole of that cost increase to their customers. The reason for this is that in a perfect market there is no scope for airlines to absorb the cost increase (and reduce their fares) by reducing their profit margin or by cross-subsidising[95].

However, perfect competition and demand-driven supply is not applicable to all routes of the airline industry. Rather competition may be restricted by legal agreements or by capacity constraints (particularly limited slot availability at congested airports) [Oxera, 2003]. On those market segments prices are higher than marginal costs and in the present context the market power of airlines enables them to set their prices accordingly. In deciding whether to pass on an increase in marginal costs in their ticket prices, airlines operating in imperfect markets do make some allowance for the likely impact on demand, however. Thus, companies may absorb an increase in operating costs resulting from the three policy options by reducing profit margins, in order to mitigate the negative impact of rising costs on demand.

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94 There will be variations regarding the total cost per flight, even if the cost per tonne of CO_2 is the same: airline companies with relatively old and inefficient aircraft will have to surrender more allowances per flight and thus will have higher total costs per flight.

95 Cross-subsidising is defined as the situation whereby an airline company uses profits earned with activity A to finance a reduction of the fares of activity B.

Literature and interviews in this area indicate that charter and low-cost carriers are likely to pass on the entire cost increase resulting from the three policy options to customers. The main reason is that these markets are highly competitive and consequently have small profit margins that do not permit higher costs to be absorbed without reflecting in ticket prices. This is confirmed by two studies[96]: one on the impact of abolishing intra-EU duty- and tax-free allowances on charter airlines and another on the impact of such a move on low-cost scheduled airlines. In both studies a majority of airlines surveyed believed it would not be possible for them to absorb any increased costs. This is also confirmed for low cost airlines by a more recent study [Oxera, 2003], concludes that, in general, low cost airlines are more likely to apply marginal cost pricing than other carriers.
A questionnaire survey of scheduled carriers carried out by [Alamdari and Brewer, 1994] indicated that the dominant response, besides improvement of environmental efficiency, would be to increase fare levels.

5.3.3 Cross-subsidisation

In the current situation with markets not yet all liberalised and indeed monopolistic or oligopolistic markets in existence, the question remains whether non-EU carriers would be encouraged by an emissions trading system at EU level to engage in **extra** cross-subsidising of flight stages to and from the EU. If this were to happen, EU carriers would then be forced to reduce air fares as well and not pass on the whole of the charge to customers in order to hold their market share. Obviously, cross-subsidisation is common and is widely practised in all international air markets. Here, the question is not whether cross-subsidisation occurs but whether the policy options allow for *additional* cross-subsidising by non-EU airlines competing with EU airlines.

Including aviation in the EU ETS will make flights within the relevant scope of the policy option more costly. This holds for every carrier, irrespective of its nationality. Some EU carriers will have a substantial share of their flights included in the EU ETS, whereas non-EU carriers will generally have only a small fraction of their flights included. Precisely because of this difference, it is often argued that non-EU carriers will be able to cross-subsidise their flights in the scheme. In that case, the cost increases on EU flights may be spread over all their flights, including those not falling under the scope of the scheme. The advantage to non-EU carriers would be that they would be able to limit air fare increases on the EU flights they operate, whiles EU carriers have little if any such scope if all or a large proportion of their flights fall under the scheme. Consequently, non-EU carriers would be able to increase their market share on EU flights. According to this argument, the additional profit generated in the EU market would outweigh the loss[97] on the non-EU market and overall profits would increase.

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[96] SH&E International Air Transport Consultancy (June 1997); Symonds Travers Morgan (June 1997).

[97] Due to cross-subsidising, air fares on non-EU flight would have to increase. The market position on these flights would therefore deteriorate and the carrier would lose market share to competitors on the non-EU market. This results in a loss on the non-EU market.

However, from an economical perspective it is not that simple. One crucial assumption behind this argument is that non-EU carriers would indeed be able to increase their overall profits by raising air fares on flights not falling under the scheme in order to cross-subsidise EU flights. First, it should be borne in mind that, on markets outside the EU, nothing changes. To that extent, increasing air fares on these markets will certainly reduce the profits of non-EU carriers. The question is then whether non-EU carriers can offset their losses on third markets by earning additional profits on the EU market through cross-subsidisation. Whether this is indeed possible depends on the competitive position on each of the markets and on price elasticities of demand[98].

In general, one can say that if the above argument holds true and non-EU carriers were indeed able to increase their overall profits through cross-subsidisation, then **it would be true irrespective of inclusion of aviation in the EU ETS**. That is, non-EU carriers would already be able to increase their market share on EU flights and increase overall profits by cross-subsidisation. It is to be anticipated that all air carriers are already cross-subsidising up to the level that profits are maximised. Including aviation in the EU ETS should, in general, not lead to a change in the optimum level of cross-subsidisation.

One theoretical reservation should be made, however. The above reasoning presumes price elasticity functions that are more or less linear. For small distortions in costs, they may be assumed to be linear without any reserve. However, in the case of large changes in cost levels, price elasticity functions may not be linear and incentives for additional cross-subsidisation may indeed be created. Given the relatively modest potential impact on ticket prices of including aviation in the EU ETS (see later in this section), however, price elasticities can safely be assumed to be linear.

Conclusion
Summarising, a strong argument for not expecting any *extra* cross-subsidising by non-European carriers appears to be that the three policy options defined provide no extra incentive for it. This is mainly because including European aviation in the EU ETS will not affect the profits of non-EU airline companies on routes outside Europe, thus freeing up no extra funds for cross-subsidising from non-covered routes.

5.3.4 Opportunity cost and effects on ticket prices

The allocation of allowances by means of grandfathering, i.e. granting aircraft operators allowances free of charge, is a form of transferral of wealth: the emitters receive valuable assets without payment. In order to answer the question of whether a transfer of wealth would affect ticket prices, one must analyse its effects on marginal costs and mark-up [Mannaerts and Mulder, 2003].

[98] These indicate the demand response for a one percent change in air fare.

Not only auctioning, but also free allocation entails costs for firms: freely allocated allowances have an opportunity cost when they are used for covering emissions of the permit owners [Nentjes *et al.*, 1995]. The cost of using an allowance is the opportunity cost of not selling it on the allowance market. It can be concluded, therefore, that the production of passenger kilometres (pkm) or tonne kilometres (tkm) is always accompanied by sacrifice of the opportunity to sell the allowances on the market.

The question then arises whether opportunity costs will be passed on to customers. The characteristics of the product market will determine whether firms pass on the total increase in marginal costs in product prices. In a market with perfect competition, the price rise will be equal to the increase in marginal costs. In other words, in a competitive market aircraft operators will pass on each *additional* unit of cost increase to passengers in the price of a ticket. Similarly, in the freight market, operators will pass on costs in freight tariffs. Given the low profit margins that characterise competitive markets, operators have only limited scope for absorbing cost increases (see also [Trucost, 2004]). In markets with imperfect competition, however, prices are higher than marginal costs and in the present context the market power of airlines enables them to set their prices accordingly. In deciding whether to pass on an increase in marginal costs in their ticket prices, airlines operating in imperfect markets do make some allowance for the likely impact on demand, however. Thus, companies facing linear demand curves will probably slightly decrease their mark-ups in order to mitigate the negative impact of rising costs on demand.

Hence, economic theory suggests that companies would pass on the vast bulk of opportunity costs in their ticket prices. Obviously, there is, however, as yet no conclusive *empirical* evidence (from the impact of the EU ETS on electricity prices, for example) that can confirm economic theory. At the same time it should be noted that if operators choose to pass on opportunity costs, they will generate so-called windfall profits (see Section 6.6.1). See for example [Carbon Trust, 2004; Oxera, 2004] which anticipate a substantial passing on of opportunity costs for different sectors in the UK.

Conclusion
Although economic theory suggests that companies would pass the majority of opportunity costs through to ticket prices, there is no empirical evidence regarding whether this would actually occur in practice, and if so, what proportion of opportunity costs associated with freely allocated allowances would be passed on to customers. In addition, the inclusion of opportunity costs into an impact analysis could be deemed misleading, since such an increase in ticket prices would not reflect a rise in actual operational costs for aircraft operators but would instead directly reflect windfall profits.
In the absence of empirical evidence as to whether or not opportunity costs will indeed be passed on, in the impact analysis in the remainder of this study we work with two alternative assumptions: in the first case, opportunity costs are not passed on at all, while in the second they are passed on in their entirety.

5.3.5 Impacts on costs and ticket prices

Taking into account the assumptions discussed in the sections above regarding administrative and transaction costs, cross-subsidisation, and opportunity costs, this section elaborates on the potential costs increases, both per flight and per passenger ticket, for each of the three policy options.

We analyse potential cost increases for three exemplary flights. The exact calculation methodology is described in Annex E, so that other calculations for different aircraft or flight distances can be readily made. The exemplary flights are the following:

- Short-haul flight: Amsterdam – Paris Charles de Gaulle, 480 km (259 nm).
- Medium-haul flight: Munchen – Palma de Mallorca, 1,402 km (757 nm).
- Long-haul flight: London Gatwick – Newark, 6,404 km (3,458 nm).

We assume that both the short- and medium-haul flight fall within EU airspace and emissions are covered fully under each of the three options. For the long-haul flight, 1,000 km of the stage length of 6,404 km is assumed to fall within EU airspace.

For the analysis of cost increases at flight level and in ticket prices, we assume no cross-subsidisation with flights outside the scope of the emission trading scheme. This issue was discussed above: the main argument is that no additional funds are freed up from flights outside the scope of the system to finance (additional) cross-subsidisation, on condition that the 'business as usual' market structure continues for flights outside the scope of the system. Of course, for flights falling under the scheme, some cross-subsidisation of the price increase may be expected, just as there is currently some degree of cross-subsidisation between 'hub and spoke' flights. Also, given the differences in price elasticities between business class and tourist class passengers, aircraft operators may choose to spread the cost increase unevenly over these categories (cf. [Trucost, 2004]). However, in our analysis the *average* cost increases for three typical flights assume no cross-subsidisation.

Since future allowance prices cannot be forecast with much precision, we have opted to use a range from € 10 to € 30 per tonne CO_2 equivalent to estimate the potential effects on operating costs and ticket prices[99]. The same value was assumed for both the price of allowances on the EU ETS market and the auction price under Option 3, as evidenced by auctions that have taken place in other emissions trading schemes. Note that the price range is based on the assumption that the flexible mechanisms of CDM and JI are also available to aircraft operators, meaning that operators can invest in sectors not covered by the EU ETS in order to generate cost-effective emission reductions.

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99 The figures of € 10 and € 30 reflect potential prices on the allowance market. They differ from the values of € 10 and € 50 representing external cost estimates in [CE, 2002]. It should be noted that potential allowance market prices are an entirely different concept from external cost estimates.

Aside from the assumptions discussed so far, in calculating impact on aircraft operating costs and ticket prices we made use of the data presented in Table 21. Data on fuel use have been taken from the Corinair database[100].

Table 21 Data assumptions for impact calculations

	Aircraft type	Seats / Occupancy rate	Trip fuel (kg)	CO_2 emissions trip (kg)
Short haul	Airbus A320	150 / 70%	2,539	8,024
Medium haul	Boeing 737-400	150 / 70%	4,998	15,793
Long haul	Boeing 777	340 / 70%	49,694	157,033

Under the aforementioned assumptions, the average impact on aircraft operating costs and ticket prices can be estimated for the three exemplary aircraft types. Table 22 presents the results of these calculations for the case in which it is assumed that opportunity costs are *not* passed on to customers.

Furthermore, an average emissions growth rate of 4 per cent annually has been assumed. Operators with a different growth rate will obviously face different cost increases. For example, if a certain operator's emissions do not grow between 2008 and 2012 he will suffer no cost increase under Options 1 and 2, because there is no need to purchase allowances. Operators growing more rapidly than the 4 per cent assumed will face higher cost increases.

Table 22 Impact on aircraft operating costs and ticket prices (in € per round trip) **with no opportunity costs passed on**

Aircraft operating costs	Option 1	Option 2	Option 3
Short haul	47 – 140	23 – 70	160 – 481
Medium haul	92 – 275	46 – 138	316 – 948
Long haul	0	228 - 684	546 – 1,638
Ticket prices	Option 1	Option 2	Option 3
Short haul	0.4 - 1.3	0.2 - 0.7	1.5 - 4.6
Medium haul	0.9 - 2.6	0.4 - 1.3	3.0 - 9.0
Long haul	0	1.0 - 2.9	2.3 – 6.9

Note: Number range indicates the expected increase in aircraft operating costs and ticket prices for round trips in 2012, based on the assumptions discussed in the text and those summarised in Table 21. The first figure is the increase at an allowance price of € 10 per tonne CO_2, the second at an allowance price of € 30 per tonne.

The methodology and formulae used for calculating increases in operating costs and ticket prices are to be found in Annex E to this report.

[100] Emep-Corinair Emission inventory guidebook – 3rd edition, September 2004 Update.

Illustration of cost impact calculations
We illustrate these results with the calculations for a short-haul flight under Option 1, assuming no passing-on of opportunity costs and an allowance price of € 10. Total CO_2 emissions are estimated at 8,024 tonnes (see Table 21). The baseline is set at the 2008 emission level. Emissions are assumed to grow by 4% annually, based on the assumption of 5% annual growth of air traffic and a 1% annual improvement in efficiency. On this scale, emissions in 2012 are therefore estimated at (1.04)^4 times emissions in 2008. Under these assumptions the baseline emissions are estimated to be 85.5% of Business as Usual (BaU) emissions in 2012.
The potential growth in emissions beyond baseline levels under the BaU scenario will have to be covered by allowances purchased from other sectors or by additional emission reductions within the sector. If all allowances were purchased from other sectors, the associated financial costs would be 2 (the multiplier representing non-CO_2 climate impacts) times 14.5% of 8,024 tonnes times € 10, which equals about € 23 for a single flight and correspondingly € 46 for a round trip.
The cost increase per ticket can be calculated by dividing the cost increase at flight level by the average number of occupied seats, which in this case is 105 (70% of 150).
Because of demand effects and the scope for reducing emissions within the sector at a cost below the allowance price, the actual cost impact may be somewhat lower than the presented initial cost increases in table 22.
The full calculation methodology for various types of flights and for Options 2 and 3 is to be found in Annex E.

Under the assumption that opportunity costs are *not* passed on, we see in Table 22 the following effects on aircraft operating costs and ticket prices. Under Option 2, ticket price increases range from about € 0.20 for a short-haul flight and an allowance price of € 10 per tonne to € 2.90 for a long-haul flight and an allowance price of € 30. Due to the multiplier, price increases under Option 1 are twice as large for short- and medium-haul flights. Long-haul flights are not intra-EU and do not fall under the scheme in Option 1. Ticket price increases under Option 3 range from € 1.50 for a short round trip to € 9 for a medium haul round trip ticket.

The impact on ticket prices is relatively small, for several reasons. In the first place, under Options 1 and 2, aircraft operators receive allowances equal to their 2008 baseline for free, and therefore only need to purchase allowances for their growth in emissions above the 2008 baseline. Second, it is assumed that aircraft operators will not pass on the opportunity costs associated with their grandfathered permits below the baseline. Third, the costs of purchasing allowances above the 2008 baseline are expected to be spread over all tickets for flights falling under the scheme.

Increases under Option 3 are generally larger, because allowances are auctioned instead of freely distributed. Per kilometre, cost increases under option 3 are about 7 times larger[101] than under options 1 and 2. However, since Option 3 is based on airspace, only a small part of the long-haul flight is subject to the scheme.
The figures for all policy three policy options assume that aviation does not make emission reductions but instead covers the increase in emissions by purchasing

[101] Under options 1 and 2, financial costs are related to about 14% of emissions in 2012. Relating costs to the other 86% would lead to costs approximately 7 times higher (1/0.14).

allowances representing emission reductions in other sectors. In reality, however, there exists some potential for the aviation sector to reduce its emissions at a cost lower than that of purchasing allowances, i.e. operators can save money by implementing measures to improve fuel efficiency, which would cost less per unit of emissions saved than the allowance price. Therefore, in this respect, all of these figures are potentially slight over-estimates. Demand effects have not been incorporated into the calculations: these would be expected to slightly decrease the emissions and passenger numbers proportionally, and could also mean that the figures are slight over-estimates.

100% of opportunity cost pass-through to passengers' ticket prices

The potential impacts under the assumption that opportunity costs *are* passed on, in their entirety, are presented in Table 23. If operators opt to fully reflect their opportunity costs in their ticket prices, the potential cost increases under Options 1 and 2 would be about 7 times larger[102] than if opportunity costs were not passed on. This would lead to higher demand effects, but it should be noted that the passing on of opportunity costs will generate additional revenues (windfall profits) for aircraft operators (see Section 5.3.4 and 6.6.1). Since opportunity costs play no role in Option 3, the results for this option are not influenced by this assumption.

As already remarked, inclusion of opportunity costs will not increase total costs of aircraft operators, since such an increase in ticket prices would not reflect a rise in actual operational costs for aircraft operators but would instead directly reflect windfall profits.

Table 23 Impact on ticket prices (in € per round trip) **with opportunity costs passed on fully**

Ticket prices	Option 1	Option 2	Option 3
Short haul	3.1 – 9.2	1.5 – 4.6	1.5-4.6
Medium haul	6.0 – 18.0	3.0 – 9.0	3.0-9.0
Long haul	0	6.6 – 19.8	2.3-6.9

Note: Figures indicate the expected increase in ticket prices for round trips in 2012, based on the assumptions discussed in the text and those summarised in Table 21. The first figure is the increase at an allowance price of € 10 per tonne CO_2, the second at an allowance price of € 30 per tonne.

Conclusion

In this impact analysis, ticket price increases are estimated to be in the range of: € 0.2 to € 9 for a round trip. This range depends on allowance prices and flight distances assumed. Furthermore, these figures represent the average ticket price increase for a particular flight route, assuming an average growth rate of emissions of 4% annually and assuming that all passengers on a flight pay equally for aviation's participation in the EU ETS.

[102] Under options 1 and 2, financial costs are related to about 14% of emissions in 2012. Relating costs to the other 86% would lead to 1/0.14 is about 7 times higher cost.

In reality, there would be variations around an average figure depending on the exact nature of the allocation methodology, the (cost)structure and network operated by individual aircraft operators. Under option 1 where allowances are distributed freely in accordance with historic emissions ("grandfathering"), an operator with an older, more inefficient aircraft fleet would receive relatively more allowances than an operator owning a more modern fleet. Conversely, an operator with a more modern fleet would receive relatively more allowances under option 2 where allowances are distributed freely in accordance with an efficiency benchmark. If an operator's business was growing at a rate faster than the average, then under options 1 and 2 its relative position would depend on how frequently the reference data in the allocation methodology was updated. Under option 3, where allowances are auctioned, all operators are treated equally.

The reality might also be that certain passengers e.g. in business class pay proportionately more of the cost increases than a passenger in e.g. tourist class, depending on price adjustment behaviour of aircraft operators and price elasticities of demand of the market segment.

5.3.6 Indicative impacts on operating costs *of individual flights* in case of a longer time horizon: 2008 - 2017

Clearly, a different choice for the historical baseline (now 2008) or for the year of evaluation (now 2012) would results in a different impact on direct operating costs. The main determinant of the impact on direct operating costs is the growth in emissions in relation to the baseline emissions. The larger the growth has been, the more allowances have to be purchased from other sectors. The growth in emissions over the historical baseline will for a large part be determined by the time lap between the baseline year and the year of evaluation. For illustrative purposes, we will present some results for a baseline year of 2008 and an evaluation year in 2017. All other assumptions remain as they were, this included the allowance prices of € 10 and € 30.
Under the assumption that opportunity costs are not passed on, direct operation *costs of a round trip* will increase under options 1 and 2, but not under option 3. Since we assume auction and market prices to be identical, the level of the historical baseline does not matter for the operating costs of a round trip under option 3. Under options 1 and 2, the share of emissions for which allowances have to be purchased from other sectors will have risen in 2017 to about 29.7% (= [emissions 2017 – emissions 2008] / emissions 2017 = [1.04^9 – 1] / 1.04^9). This is slightly more than two times the share of emissions in 2012 (14.5%) for which allowances had to be bought. Therefore, the impact on direct operating costs per round trip in 2017 will be slightly more than two times the impact in 2012, ceteris paribus. The same holds for the ticket price increases under options 1 and 2 in 2017.
Alternatively, assuming opportunity costs to be passed on, effects on ticket prices in 2017 will be identical to the ticket price increases in 2012 for all options. If opportunity costs are fully passed on, the level of the historical baseline does not influence the impact on ticket prices. Irrespective of whether allowances are grandfathered or purchased from other sectors, costs are passed on.

The results for the situation in which opportunity costs are fully passed on, provide an upper limit for the impact on ticket prices of incorporation of the aviation in the EU ETS. The results coincide with the impact for the case in which the baseline is set at zero emissions. In that case, all allowances have to be purchased from other sectors and there are no opportunity costs. Note that this resembles the situation for a reference year in the far future, with a baseline at 2008 emissions. The share of emissions for which allowances have to be bought from other sectors will come close to a 100%[103].

5.4 Quantitative environmental impacts of three policy options

This section starts out by presenting the quantitative results of an environmental impact analysis of the three selected policy options using the AERO Model[104]. In addition, these results will be compared with other, limited quantitative findings in the literature. Potential trade-offs of CO_2 optimisation will be presented in the next Section 5.5. A description of the AERO Model and the price elasticities used in the analysis are included in Annex F to this report.

As noted in Section 5.3.4, two alternative scenarios will be assumed for the extent to which opportunity costs of grandfathered allowances (Options 1 and 2) are passed on in ticket prices. Below, first the environmental impacts compared with the BaU scenario are presented under the assumption that aircraft operators do not pass on opportunity costs to customers. Then follows the case of opportunity costs being passed on fully.

5.4.1 Impacts on CO_2 emissions (opportunity costs *not* passed on)

Table 24 indicates to what extent the aviation sector will actually reduce its CO_2 emissions and to what extent allowances will be bought from other sectors in order to cover those emissions. As the table shows, in all three policy options emission reduction will be achieved largely through purchase of allowances from other sectors (i.e. this part of emission reduction is thus actually achieved within these other sectors). Reduction of CO_2 emissions within the aviation sector itself is related to both demand- and supply-side effects, in a proportion of about 80% demand-side and 20% supply-side. That the effect on the supply side is relatively low stems mainly from the short time horizon considered.

The estimated CO_2 emissions under the Business as Usual scenario for the three policy options are based on the 2004 figures of EUROCONTROL (see also Section 3.3.3) and the assumed 4% annual emissions growth for the period 2004-2012. For each of the options, Table 24 presents CO_2 emissions quantities for 2004 and BaU-related emissions for 2008 and 2012.

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[103] Obviously, some assumptions are very unlikely for that situation. Allowance prices are likely to be higher and growth rates may have be lower.

[104] The AERO Modelling System has been developed by the Dutch Ministry of Transport. Amongst other analyses, AERO-MS has been used for analysis of market-based options in ICAO/CAEP/4 and by the Forecast and Economic Support Group (FESG) of ICAO/CAEP/5.

In addition, Table 24 shows how the 2012 BaU emissions for the three options would be covered. In the first place, under all three options a limited fraction of the emissions would not take place at all because of CO_2 reductions within the aviation sector. The sector's remaining CO_2 emissions would then have to be covered by either grandfathered or auctioned allowances or by allowances bought from other sectors.

Although the geographical scope of Option 1 is limited to Intra-EU routes only, the number of allowances bought under this option is relatively high. This is because of the multiplier of 2 for non-CO_2 climate impacts. In Option 1, for every tonne of CO_2 emitted, two CO_2 emission allowances must be bought from other sectors in the EU ETS or from JI/CDM project-related emission reduction credits.

Table 24 The BaU scenario in 2008-2012, the initial allocation and the impacts of the three policy options in terms of CO_2 reduction within the aviation sector and allowances bought from other sectors under the EU ETS or using JI/CDM credits (based on AERO-MS). **(Under Options 1 and 2, opportunity cost are assumed to be *not* passed on)**

Effect	Unit	Policy options		
		Option 1*	Option 2	Option 3
Aviation CO_2 emissions in the BaU scenario				
2004 CO_2 emissions	Mt	51.9	130.4	114.3
Projected 2008 CO_2 emissions	Mt	60.7	152.6	133.8
Projected 2012 CO_2 emissions	Mt	71.0	178.5	156.5
Covering of CO_2 emissions in 2012				
Allowance price: €10 per tonne				
Number of allowances not required	Mt	60.7	0.0	0.0
Reduction CO_2 within aviation sector	Mt	0.3	1.1	2.0
Allowances grandfathered	Mt allow.	0.0	152.6	0.0
Allowances auctioned	Mt allow.	0.0	0.0	133.8
Allowances bought from other sectors	Mt allow.	20.0	24.8	20.7
Allowance price: €30 per tonne				
Number of allowances not required	Mt	60.7	0.0	0.0
Reduction CO_2 within aviation sector	Mt	0.7	3.2	5.6
Allowances grandfathered	Mt allow.	0.0	152.6	0.0
Allowances auctioned	Mt allow.	0.0	0.0	133.8
Allowances bought from other sectors	Mt allow.	19.3	22.7	17.1

* Under option 1 a multiplier of 2 is applied for non-CO_2 climate impacts. This implies that for every tonne of CO_2 emitted, two CO_2 emission allowances must be bought from other sectors in the EU ETS or from JI/CDM project-related emission reduction credits.

Table 25 summarises the total absolute and relative CO_2 emission reduction impacts of the three policy options compared with emissions in the Business as Usual (BaU) scenario in 2012. It should be borne in mind that for each policy option the percentage share of reductions shown in the table is based on different scenarios of geographical scope. For example, assuming an allowance price of € 10 per tonne, Option 1 would reduce CO_2 emissions by about 29% of total intra-EU emissions in the BaU scenario, while Options 2 and 3 would reduce CO_2 emissions by some 15% of all emissions of flights departing from the EU and 15% of all emissions in EU airspace, respectively. As already remarked above, it should be noted that the largest share of the reduction in CO_2 emissions (20.3, 25.9 and 22.7 Mt CO_2 equivalent) for Options 1 to 3, respectively, at a market price of € 10 per allowance), as shown in Table 25, is achieved through emission reductions bought from other sectors under the EU ETS. Only a minor part of these emissions reductions are due to demand and supply-side responses in the aviation sector itself.

Table 25 Absolute and relative CO_2 eq. emission reduction impacts of the three policy options in the period 2008-2012 compared to BaU scenario in 2012 based on AERO-MS. **(Under options 1 and 2, opportunity cost are assumed to be *not* passed on**)

	Option 1	Option 2	Option 3
BaU emissions in 2012	71 Mt	178.5 Mt	156.5 Mt
Allowance price: €10 per tonne CO_2 eq.[105]			
Reduction of CO_2 eq.	20.3 Mt	25.9 Mt	22.7 Mt
Share of 2012 aviation emissions under the scope considered	29%	15%	15%
Allowance price: €30 per tonne CO_2 eq.			
Reduction of CO_2 eq.	19.9 Mt	25.9 Mt	22.7 Mt
Share of 2012 aviation emissions under the scope considered	28%	15%	15%

5.4.2 Impacts on CO_2 emissions (opportunity costs fully passed on)

Table 26 indicates to what extent the aviation sector will actually reduce its CO_2 emissions and to what extent allowances will be bought from other sectors *if aircraft operators pass on their opportunity costs in ticket prices in their entirety.* As the table shows, in all three policy options a larger proportion of emission reductions will be achieved within the aviation sector itself compared with the situation in which opportunity costs are not passed on. Correspondingly, the aviation sector buys fewer allowances from other sectors. Obviously, this shift towards greater reductions in the aviation sector itself can be clarified by greater demand effects in the aviation sector if aircraft operators pass on full opportunity costs to their customers. It should be stressed that under each of the policy options aggregate emissions reductions will remain the same, regardless of whether opportunity costs are fully passed on or not.

[105] The term CO_2 *equivalent* applies here because some of the allowances bought from other sectors may be based on emission reductions of other gases covered by the Kyoto protocol (e.g. methane, F-gases) which are achieved under the EU ETS in other sectors.

Table 26 The BaU scenario in 2008-2012, the initial allocation and the impacts of the three policy options in terms of CO_2 reduction within the aviation sector and allowances bought from other sectors under the EU ETS or using JI/CDM credits (based on AERO-MS). (**Opportunity cost are *fully* passed on under option 1 and 2**)

Effect	Unit	Policy options		
		Option 1*	Option 2	Option 3
Aviation CO_2 emissions in the BaU scenario				
2004 CO_2 emissions	Mt	51.9	130.4	114.3
Projected 2008 CO_2 emissions	Mt	60.7	152.6	133.8
Projected 2012 CO_2 emissions	Mt	71.0	178.5	156.5
Covering of CO_2 emissions in 2012				
Allowance price €10 per tonne				
No allowances required	Mt	60.7	0.0	0.0
Reduction CO_2 within aviation sector	Mt	1.4	3.2	2.0
Allowances grandfathered	Mt allow.	0.0	152.6	0.0
Allowances auctioned	Mt allow.	0.0	0.0	133.8
Allowances bought from other sectors	Mt allow.	17.8	22.7	20.7
Allowance price €30 per tonne				
No allowances required	Mt	60.7	0.0	0.0
Reduction CO_2 within aviation sector	Mt	3.9	9.2	5.6
Allowances grandfathered	Mt allow.	0.0	152.6	0.0
Allowances auctioned	Mt allow.	0.0	0.0	133.8
Allowances bought from other sectors	Mt allow.	12.8	16.8	17.1

Comparison of CE (2002)[106] supply-side results with AERO-MS results

In CE (2002) estimates of the impacts of an extensive supply-side analysis were compared with those in the AERO model. This comparison concluded that the AERO model leads to CO_2 reductions due to supply-side measures of around 0-2%, depending on a charge level from 10 to 50 €/tonne CO_2, compared with the figure of approx. 1-6 % calculated in [CE, 2002].

Because the mechanisms through which the emission reductions arise cannot be identified from the output of the AERO modelling system, the differences between the two approaches cannot readily be explained. To judge from the qualitative descriptions of the mechanisms addressed in AERO-MS, however, the differences are probably due to two factors [CE, 2002]:

- AERO-MS takes fewer emission reduction mechanisms into account than [CE, 2002]. More specifically, impacts on aircraft technology, cruise speeds and load factors are taken into account in the calculations in CE [2002] but not in the AERO-MS.
- The effect of accelerated fleet renewal is estimated in [CE, 2002] to be more substantial than in AERO-MS. This is probably due to the fact that AERO-MS airlines have only one, quite radical option to change aircraft technology (from

[106] *Economic Incentives to mitigate greenhouse gas emissions from Air Transport in Europe* [CE, 2002]. See also http://www.ce.nl/pdf/02_4733_10_rep.pdf.

'old' to 'new'), which is not feasible in many cases, whereas in practice airlines have numerous options for arriving at a younger fleet.

For these reasons the emission reductions that may be achieved within the aviation sector itself, as illustrated in Table 25, can be regarded as an underestimate. [CE, 2002] suggested that, over a period of about 10 years, economic instruments would have an approximately equal demand-side and supply-side impact. This would imply that a somewhat larger part of CO_2 reductions will be achieved within the aviation sector (about an additional 0.3 Mt, 0.2 Mt and 0.6 Mt under Options 1, 2 and 3, respectively, assuming €10/tonne) mirrored by a lower amount bought from other sectors. Given the relatively short period of 2008-2012 considered, however, we expect no substantial supply-side responses on top of the AERO results. More substantial supply-side impacts may be expected from long-term technical developments (new engine and aircraft concepts).

5.5 Effects of a 'CO_2-only' regime and negative trade-offs

This section considers the effects of a CO_2-only trading regime on atmospheric impacts. It is important to be clear about what is being compared. There is currently no regulation impinging on aircraft emissions other than the ICAO LTO certification standards for NO_x, HCs, CO and smoke. These have already been briefly reviewed (Section 2.7) and are examined in far greater depth elsewhere [Lister and Norman, 2003]. While air quality standards do thus impinge on aviation, it is only one of many sources affecting air quality and is mainly an issue in the vicinity of airports.

The cases that are compared here are: a 'business as usual' (BAU) scenario in which aviation is not subject to any regulation or economic instrument ('market-based option') targeting climate impacts via CO_2 emissions, for example; and a scenario in which European aviation is included in the European emissions trading scheme (ETS+Av).

From a 'system' perspective, incorporating aviation in the EU ETS puts extra pressure on the system to achieve reductions of CO_2 emissions. The question of 'leakage' from the relatively poorly quantified non-CO_2 effects of aviation raises the important issue of negative trade-offs, i.e. unintentional increases in one or more pollutants or effects as a result of efforts to reduce another.

CO_2 and NO_x trade-off?
To analyse the impact of CO_2 optimisation requires a distinction between, on the one hand, the short and medium term and, on the other, the long term in which environmentally superior engine and aircraft technology innovations will emerge.

Short- and medium-term impact (up to about 8 years)
Model calculations [CE, 2002] show that in the short and medium term, for a given level of engine technology, overall fleet reductions in CO_2 emissions that might arise from emissions trading go more or less hand in hand with NO_x

emission reductions. This is because on this timescale the total amount of fuel used by all European air traffic can, to a large extent, only be reduced by fuel efficiency measures that also reduce NO_x, such as operational measures (network, load factor, speed, climb angle, etc.) and reduced demand for air transport.

Long-term impact
In the long term, there is less certainty about the impact of CO_2 optimisation on NO_x emissions. The NO_x emissions index (NO_x emissions per unit fuel) might increase *faster* if aviation were incorporated in the European Emissions Trading Scheme on a CO_2-only basis. That is, the EI NO_x of the aircraft fleet might increase compared with a BaU scenario owing to the higher combustor temperatures and pressures resulting from technological innovations to increase the fuel efficiency of gas turbine engines. This will be elaborated on below.

The best understood trade-off with regard to engine technology is that between CO_2 and NO_x, stemming from the technological trend towards higher engine pressure ratios and combustion temperatures and pressures that improve fuel efficiency but, perversely, generate more NO_x. This trend was established with the move to high by-pass engine[107] in the early 1980s. Advances in combustion technology have meanwhile managed to more or less offset this trend towards increased NO_x, as illustrated in Figure 10.

[107] High-bypass ratio engines are those in which the majority of the flows around rather than through the engine core and thrust are produced more by the engine fan than by the exhaust jet. Today this is the prevailing design, superseding early engines, which were less efficient pure jet or low-bypass ratio engines.

Figure 10 Schematic representation of changes in overall pressure ratio, specific fuel consumption (SFC) and NO_x emissions index ($EINO_x$) (courtesy of P. Madden, Rolls-Royce)

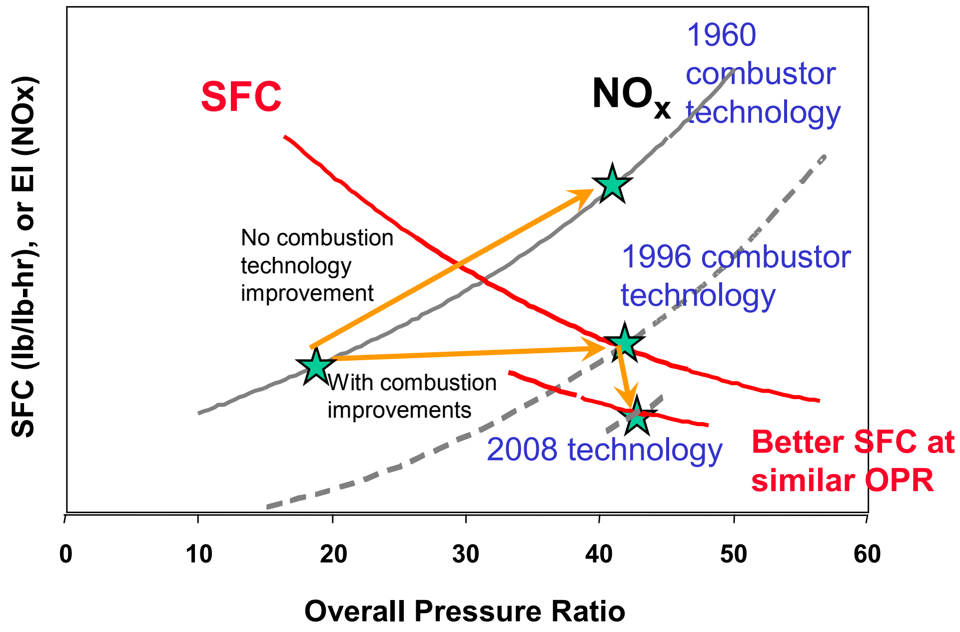
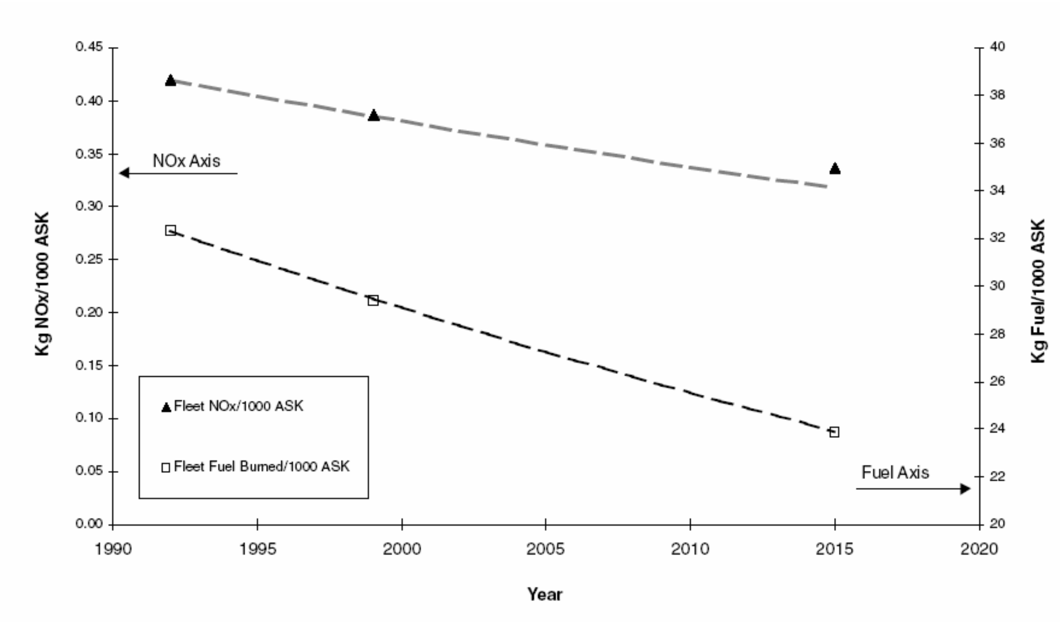


Figure 10 shows that as the overall pressure ratio (OPR) increases the specific fuel consumption (SFC) tends to decrease, but at the same time the $EINO_x$ tends to increase. With the development of higher OPR engines, primarily turbofans that have facilitated better fuel economy (and lower noise), SFCs have decreased. These higher pressure ratios engines require higher flame temperatures, which increase NO_x formation. As the figure shows, if improved combustion technology had not been developed, the $EINO_x$ would have been substantially higher. Despite improvements in combustion technology, however, the $EINO_x$ is still higher today than it was. The complexities of trade-offs extend to noise and safety/airworthiness issues, too. In evaluating changes in combustion technology, it is also necessary to consider aspects such as engine relight at altitude. Another way of looking at the change in NO_x performance over time is shown in Figure 11.

Figure 11 Trends of global scheduled fleet NO_x/ASK and fuel burned/ASK derived from NASA emission inventory and scenario work



Source: Sutkus et al., 2001

Figure 11 shows that according to the inventory calculations of [Sutkus *et al.*, 2001], trends in NO_x per 1,000 ASK (available seat kilometres) are not keeping pace with traffic efficiency (kg fuel/1,000 ASK). In other words, changes in NO_x per ASK are not decreasing at the same rate as fuel per ASK. This can be explained by the fact that although a reduction in fuel use per ASK will also lead to a reduction of NO_x emissions, this is partly offset by higher OPRs, giving rise to lines of different gradients.

Elsewhere in the report it is argued that the ETS-Av scenario will put extra pressure on manufacturers to increase fuel efficiency. There is therefore a possibility that manufacturers will respond by increasing pressure ratios, with an inherent tendency to increase NO_x *per unit fuel* in the absence of any changes in combustion technology to ameliorate this. The higher temperatures and pressures that result from increased pressure ratios will ultimately reach material limitations where cooling becomes a major problem. In Europe the ACARE targets[108], which have been adopted by Rolls Royce, among others, aim for an 80% reduction in specific NO_x emissions by 2020 and a 50% reduction in specific CO_2 emissions. These are technology targets, applicable to best new available technologies not to the average fleet or operations. In other words, these target figures would not be reflected in actual emissions until the existing fleet has been fully replaced using the technologies in question. However, these are challenging targets and it is not yet clear whether or how manufacturers will achieve them.

108 http://www.acare4europe.com/.

On balance, there seems to be a risk of NO_x emissions *per unit fuel* (EI NO_x) increasing through extra pressure on fuel efficiency compared to the BaU scenario, although it is not possible to speculate how great this risk will be.

It should be noted that the risk of a higher EI NO_x is from an engine perspective only. Clearly, it is the aggregate amount of NO_x emissions from the fleet as a whole that matters here, not just the EI NO_x. From the fleet perspective, there are other CO_2 reduction measures that might offset this potential increase due to engine optimisation. In addition to the short-term operational responses already cited (network changes, speed, load factor, flight path), CO_2 and NO_x emissions may both decline owing to demand effects, changed airline practices and airframe innovations (e.g. weight reduction). According to [Babikan *et al*., 2002], regional jets are 40 – 60% less fuel-efficient than larger narrow and wide-body jets and regional jets are 10 – 60% less fuel-efficient than turboprops. One possible response by airlines might therefore be a change in the airframes used. However, influences on choice of airframe are not confined to fuel efficiency, although this will be a major driver.

The key question for the long term, then, is whether an *additional* EI NO_x increase, due to incorporating aviation in the EU ETS, is expected to be offset by other measures and effects increasing fuel efficiency, such as operational measures, demand effects and airframe innovations (e.g. weight reduction). This question cannot be answered with any certainty. However, at least one aircraft manufacturer[109] has indicated that CO_2 reduction objectives would not adversely impact on NO_x emissions overall. In addition, a group of major European Airlines has also expressed the opinion that, overall, NO_x emissions would not increase as a result of further CO_2 optimisation[110].

Based on the above findings, we conclude that a CO_2-only based scheme would most probably reduce both CO_2 and NO_x emissions in the long term, but that the uncertainties with respect to this long-term impact suggest that a precautionary approach to NO_x emissions is appropriate.

Effects of CO_2-only regime on contrail formation

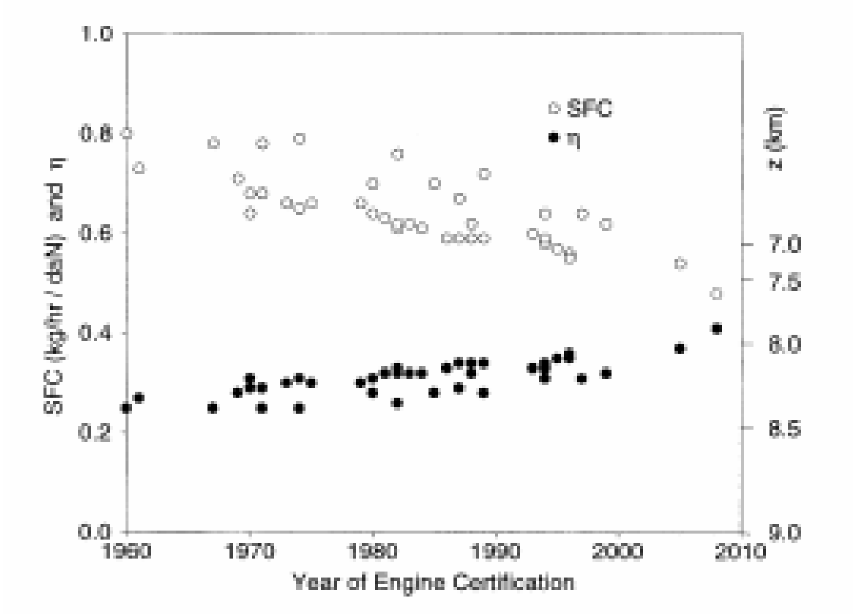
The production of contrails, as described earlier, is primarily a function of environmental conditions, ice supersaturation and temperature being the principal determinants. A second-order effect is the exhaust gas temperature, which can affect the entire depth of the atmosphere in which contrails are produced [Schumann, 2000].

On the basis of theoretical calculations, [Schumann, 2000] has shown that as the propulsion efficiency (η) of aircraft has increased, contrails can be produced by modern aircraft over a larger range of flight altitudes. This theoretical prediction was subsequently borne out by observation, when an older-technology B707 was flown alongside a modern A340 [Schumann *et al*., 2000]. The observations

[109] Personal communication, Airbus Industries.
[110] Meeting with AEA and several members (Brussels, March 2005).

clearly show that the newer-technology A340 produces contrails, while the B707 does not. This effect of propulsion efficiency was introduced as a factor in the calculation of contrail coverage for future scenarios [Gierens *et al*., 1999].

Figure 12 Trend in the overall efficiency of propulsion η (solid circles), computed from aircraft-specific fuel consumption data SFC (open circles) over the years 1960-2010. The solid circles also denote the critical altitude z (right-hand axis) above which contrails form (for 100% relative humidity and the temperature profile of the mid-latitude standard atmosphere)



Source: Gierens et al., 1999

From Figure 12 it can be seen that as η increases and SFC decreases, contrails tend to form at progressively lower altitudes under the same atmospheric conditions. [Gierens *et al*., 1999] has estimated a fleet-average value of η of 0.4 by 2015 and 0.5 by 2050. [Gierens *et al*., 1999] tested the sensitivity of this by calculating global and regional contrail coverage for 2050 (Fa1) using values of η of 0.3 (assumed present-day) and 0.5: they found corresponding figures for global contrail coverage of 0.38 and 0.46, not an insignificant difference.

If the trend in increasing η is assumed to continue, this implies production of contrails over a progressively greater depth of the atmosphere, which is a very real 'negative trade-off'. However, critical to this assertion is the precise impact emissions trading is anticipated to have on technological developments. Elsewhere in this report it is concluded that the extra pressure on engine and airframe manufacturers would result in an increase in fuel efficiency in the future, over and above that which might be expected from BaU. The magnitude of this increase will therefore affect η. Unfortunately, this effect cannot be readily quantified as the projected change in η in the global fleet would need to be known (or hypothesised) and contrail coverage calculations need to be performed. Currently, the only quantification comes from the sensitivity study of [Gierens *et al*., 1999], who found a 21% increase in global contrail coverage for a change in η from 0.3 (present-day) to 0.5 (projected in 2050).

Since we have no quantitative evidence for a change in η being induced by ETS-Av relative to BaU, it is not possible to speculate on the magnitude of this effect, merely to take the above sensitivity as an order-of-magnitude estimate for the effect of a change in η.

With respect to cirrus clouds, as a first-order approximation it can be said there is a relationship between persistent linear contrails and enhanced cirrus. As this relationship is not understood in a quantitative sense, however, to predict any changes arising from a change in η would be speculative.

Conclusions on potential trade-offs

The crucial question with a CO_2-only scheme is whether it would lead to any *negative* trade-offs. This is an extremely difficult issue to evaluate, because of its speculative nature and also for lack of technological documentation in the public domain.

CO_2 - NO_x

The above considerations indicate that, overall, emissions trading based on CO_2 only would not adversely impact on NO_x emissions. In the medium term, at a constant level of engine technology, overall fleet reductions in CO_2 emissions that might arise from emissions trading go more or less hand in hand with NO_x emission reductions. This is because, in the short and medium term, the total amount of fuel used by all European air traffic can, to a large extent, only be reduced by fuel efficiency measures that also reduce NO_x, such as operational measures (network, load factor, speed, climb angle, etc.) and reduced demand for air transport.

In the longer term, it is more uncertain whether CO_2 optimisation would also reduce overall NO_x emissions. The NO_x emissions index (NO_x emissions per unit fuel) might increase *faster* if aviation were incorporated in the European Emissions Trading Scheme on a CO_2-only basis. That is, the EI NO_x of the aircraft fleet might increase compared with a business-as-usual scenario owing to the higher combustor temperatures and pressures resulting from technological innovations to increase the fuel efficiency of gas turbine engines. However, although still uncertain, any *additional* EI NO_x increase is expected to be offset by other measures and effects increasing fuel efficiency such as operational measures, demand effects and airframe innovations (e.g. weight reduction). Moreover, there is a European commitment (ACARE) to improve NO_x performance (bearing in mind that not all aircraft flying in Europe have European-manufactured engines/airframes).

Based on the above findings, we conclude that a CO_2-only based scheme would most probably reduce CO_2 *and* NO_x emissions in both the shorter and the longer term, but that the uncertainties of the impact in the longer term suggest that a precautionary approach to NO_x emissions would be appropriate. This implies that ‘flanking’ instruments focusing on NO_x might be considered in addition to the inclusion of aviation in the EU ETS on a CO_2-only basis.

CO_2 - contrails
Whilst environmental conditions of ice supersaturation and temperature are the primary determinants of whether a persistent contrail is formed, more modern technology has been reported to have a higher propensity to cause contrails because of a cooler exhaust, causing contrails over a greater depth of the atmosphere than was the case with older technology. Based on assumptions regarding the likely increase in propulsive efficiency (η), this trend is expected to continue in the future. This effect and whether it will increase relative to a BaU situation (as in he case of NO_x) is rather speculative. However, that there is an effect of more modern engines has been demonstrated by observations and theoretical calculations. If pressure on fuel efficiency increases as a result of including aviation in the ETS, then η will also increase, with a consequential impact on contrail production. As an illustration of the potential effect, sensitivity calculations from the literature suggest that a value of η of 0.5 in 2050 will result in 20% greater contrail coverage than an approximate estimate for the 1990s η of 0.3.

5.6 Impacts of flanking instruments

It should be noted that this study includes no impact analysis of flanking instruments (e.g. NO_x cruise standards, NO_x airport charge, flight procedures or NO_x en-route charge). Only Section 2.6.4 includes some indicative results related to potential impacts of regulation of flight altitudes to limit contrail production. An impact analysis of flanking instruments falls outside the scope of this study. However, although flanking instruments are aimed primarily at mitigating non-CO_2 emissions and their climate impacts, they may have significant impacts on CO_2 as well. These impacts may be positive or negative, depending on the type of flanking instrument and its precise design. We therefore recommend further research into the optimum design and quantitative impacts of various flanking instruments.

6 Economic and distributional impacts

The potential economic and distributional effects of the policy options considered may be largely dependent on the geographical scale on which the incentive is applied. One important potential effect of an emissions trading scheme imposed at EU level only is that it may lead to distortions in competition in the aviation industry as well as in other sectors of the economy. In the aviation industry the competitive position of EU airlines might be adversely affected compared to non-EU airlines. Other areas of the European economy where air transport plays an important role, such as tourism, might also be adversely affected by an emissions trading scheme with a geographical scope limited to the European Union.

This chapter focuses on the potential economic distortions and distributional impacts resulting from the three proposed options to include climate impacts from international aviation in the Emissions Trading Scheme of the EU.

The impacts on transport volume under the three selected policy options defined in Section 4.3 have been quantified using the AERO modelling system. In addition, several interviews were carried out with airline company representatives and experts. Reference was also made to the scarce international literature of relevance to this topic.

This chapter presents the following:
- A definition of what, in this study, is considered to be an economic distortion (Section 6.1).
- Impacts on transport volume (Section 6.2).
- Analysis of the change of the competitive position of EU carriers compared with non-EU carriers (Section 6.3).
- Potential economic distortions between airports (Section 6.4).
- Potential economic distortions between tourist areas (Section 6.5).
- Revenues from grandfathering (windfall profits) and auctioning and options to use the auctioned revenues (Section 6.6).
- Marginal impact on the EU ETS and the allowance price (Section 6.7).

In all sections, relevant differences between the three policy options have been made explicit.

6.1 Definition of economic distortion

Economic distortions are defined in this study as distortions in competition between European and non-European airline companies caused by the limited geographical scale of the policy options. This definition implies that changes in the competitive position of companies that would also be prompted by a *global* aviation emission trading system are not considered to be economic distortions in this study.

It is important to note that this study discusses two types of economic impact on competition of an emissions trading system, each with possibly different policy implications. Thus, including aviation in the EU ETS could:

- Distort fair competition among airlines, airports or other sectors. This will **reduce** economic efficiency and the appropriate policy response is to select options that minimise such distortions.
- Change the relative competitive position of different suppliers in favour of those that are environmentally efficient (and against those that are environmentally inefficient). This will **increase** economic efficiency; there will clearly be winners and losers, however, and the appropriate policy response may therefore be to give companies sufficient opportunity to adapt to the new circumstances, e.g. by early announcement or by gradual phase-in, as already discussed in section 3.9.

Examples of the first type of impact (distortions to fair competition) arise in circumstances where it is not possible to apply the emissions trading scheme equally to all potential competitors (e.g. holiday suppliers inside and outside Europe if the scope of a scheme was limited to intra-EU flights only). Examples of the second type of impact (changes in relative competitive strength) will arise when a charge applied uniformly to all competitors has a differential impact on them (e.g. between airlines with more (or less) environmentally efficient aircraft or between holiday suppliers making more (or less) use of air transport).

6.2 Impact on transport volume

In all three policy options, Intra-EU routes are included in the EU ETS. However, the extent of the price increases introduced on these routes varies significantly between the three options. If an allowance prices of € 30 per tonne of CO_2 is assumed, in the case of Option 1 for every tonne of CO_2 an airline must in fact pay € 60. This is because of the assumed multiplier of 2, to account for non-CO_2 climate impacts. In Option 2 the cost increase on Intra-EU routes is far more limited, because the non-CO_2 effects are not taken into account.

Furthermore, as already discussed in detail in the previous chapter, two alternative scenarios have been run for Options 1 and 2: one in which the opportunity costs of grandfathered permits are not passed on in ticket prices, and the other with opportunity costs passed on in their entirety.

Given the variation in the policy-induced cost increases across the three Options, there is a clear variation in effects. This is shown in Table 27 (for the scenario with opportunity costs *not* passed on).

Table 27 Impacts on transport volume on the EU market[111] of the three selected Options **(opportunity costs not passed on),** based on AERO modelling results

Effect	Effects relative to BaU case 2012					
	Option 1		Option 2		Option 3	
	EU	Non-EU	EU	Non-EU	EU	Non-EU
Allowance price €10 per tonne						
Aircraft km	-0.2%	0.0%	-0.2%	0.0%	-0.6%	-0.1%
Revenue Tonne Km	-0.1%	0.0%	-0.1%	0.0%	-0.5%	-0.1%
Allowance price €30 per tonne						
Aircraft km	-0.4%	0.0%	-0.3%	0.0%	-1.8%	-0.2%
Revenue Tonne Km	-0.2%	0.0%	-0.4%	-0.1%	-1.4%	-0.2%

Impacts on transport volume if opportunity costs are passed on
Table 28 shows impacts on transport volume if opportunity costs are fully passed on in passengers' ticket prices. Again it should be stressed that in this case aircraft operators are faced with higher demand effects, but will raise at the same time so-called windfall profits (see also Section 5.3.4 and 6.6.1).

Table 28 Impacts on transport volume on the EU market of the three selected Options **(opportunity costs are fully passed on),** based on AERO modelling results

Effect	Effects relative to BaU case 2012					
	Option 1		Option 2		Option 3	
	EU	Non-EU	EU	Non-EU	EU	Non-EU
Allowance price €10 per tonne						
Aircraft km	-0.9%	0.0%	-0.8%	-0.1%	-0.6%	-0.1%
Revenue Tonne Km	-0.5%	0.0%	-0.7%	-0.1%	-0.5%	-0.1%
Allowance price €30 per tonne						
Aircraft km	-2.4%	0.0%	-2.3%	-0.3%	-1.8%	-0.2%
Revenue Tonne Km	-1.3%	0.0%	-2.1%	-0.4%	-1.4%	-0.2%

6.3 Change of competitive position of EU carriers vs. non-EU carriers

Besides examining general economic impacts, this study also looked specifically at potential economic distortions. Of particular concern in this respect would be effects on competition between EU and non-EU carriers.

– The main conclusion is that none of the policy options considered in this study will damage the competitive position of EU airlines relative to non-EU airlines significantly. This is because all the options assume that the scheme in question covers all the commercial aircraft operators flying a particular route, irrespective of nationality or type of operation. This implies that European and non-European airlines receive equal treatment under all the proposed policy options for including aviation in the EU ETS. This is not the

[111] The EU market is defined here as all intra EU routes and routes to and from the EU.

case for other sectors already covered by the EU ETS. Most of their competitors (e.g. the US steel industry) based outside the EU do not face similar cost increases. as they are obviously not covered by the EU emissions trading scheme.

- Consequently, both EU and non-EU carriers with the same emissions level would face the same cost increase on the same flight stage within the geographical scope concerned. However, as some airlines achieve a greater share of their turnover in the EU than others, it is important to know whether carriers will respond in the form of price increases or reduced profit margins. This study did not identify any convincing arguments for higher air fares not being passed on to customers (see Section 5.3.2). As a first-order effect, therefore, no distortion in competition among airline companies is expected. Moreover, model calculations show that the profit margins of EU and non-EU carriers would remain constant after introduction of the three policy options.
- Besides profit margins, the competitive position of carriers might also be affected by changes in the size of their home market. Obviously, one second-order effect of including aviation in the ETS might be a slow-down in the growth of the European air transport market owing to increased air fares compared to the business-as-usual scenario. A smaller home market for European compared with non-European carriers might reduce economies of scale and thereby weaken the competitive position of European airlines. This study shows that an allowance price range from € 10 to € 30 per tonne CO_2 would decrease air transport volume on the EU market by 0.1% to 0.2% under Option 1, by 0.1% to 0.4% under Option 2 and by 0.5% to 1.4% under Option 3, compared with a baseline growth of 17% between 2008 and 2012. Based on this impact on market size, it can be concluded that introduction of all three policy options would not affect economies of scale and thus the operating efficiency of EU carriers significantly compared with non-EU carriers.
- There is one possible distortion that does hold. Non-EU carriers will only be affected by inclusion of aviation in the EU ETS on a relatively small proportion of their flights, viz. flights to and from the EU. The response of non EU based carriers might be to deploy their newest and cleanest aircraft on routes falling under the scheme, diverting older aircraft to other routes. This may then give non-EU carriers a competitive advantage over EU carriers, because in order to keep abreast of their competitors the latter would need to buy new aircraft for all routes to and from the EU.

It should be noted that, although aviation is an international business, it is less vulnerable to economic distortions than other international sectors in the EU ETS. There are two reasons for this. First, the ‘product’ in the aviation industry, transportation, is by definition geographically bounded (to a major extent), with passengers and freight having relatively fixed origins and in many cases also relatively fixed destinations. An increase in the cost of European flights will not lead a Frenchman with business in Denmark, say, to buy a ticket from Los Angeles to Washington instead. In comparison, the steel sector, say, would appear to be more vulnerable, as the only relevant aspect here is the cost associated with producing the steel and transporting it to its place of use. Changes in taxation among countries may consequently easily lead buyers to opt for steel produced outside the EU. A second reason is that, although recognising the ongoing liberalisation process in the aviation sector, the air transport market is highly regulated by bilateral air service agreements that limit competition from airlines outside the EU.

6.4 Potential economic distortions between airports

Apart from changes in the competitive position of carriers, a second category of potential economic distortions concerns distortions between airports. We discuss two potential distortions. The first is related to the geographical location of the airport, the second is the so-called border effect, of which we distinguish two variants.

Geographical location
First of all, in schemes based on airspace (policy option 3) it is an airport's geographical location that will largely determine the degree to which flights departing from and arriving at that airport are subject to the scheme. This holds particularly for flights to and from third countries. See for an example Figure 13. In this form of scheme, depending on the spread of destinations from each airport, some airports (and, indirectly, the airlines having these airports as their home base) will be disadvantaged in that incoming and outgoing flights will, on average, have to cross larger tracts of EU airspace than flights to and from other airports[112]. Compare, for example, flights to and from Milan Malpensa with those to and from Lisbon in Figure 13.

This can be considered a potential economic distortion between airports, because it becomes more attractive for airlines to locate their home base at an airport near the rim of EU airspace. It may also be considered a distortion between airlines, because for intercontinental flights airlines with a home base at the rim of EU airspace are at an advantage. The distortionary effect between airports is likely to be small. Because of airlines' dependence on traffic rights and slots and, furthermore, on the catchment area of an airport[113], airlines do not readily change their home base. Furthermore, considering the expected flight price increases due to the scheme (see Section 5.4) and taking into account existing differences in airport charges at airports in Europe (see box), it is not realistic to expect airlines to change their home base.

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[112] Note the resemblance with the German kilometre charge for freight vehicles using the Autobahn. Some hauliers will enjoy a relative advantage because they are located close to the border and because they are in a position to take alternative routes, using other countries' motorway systems instead of the German Autobahn.

[113] Note that if from a new airport airlines could serve the same catchment area as from the old airport, airports would be located geographically close together and the advantage of having a smaller part of flights falling under the system would be virtually non-existent.

Box: airport charges differentials

In order to assess the degree to which cost increases might induce airlines to change their behaviour (by flying from a different airport, for example), it is important to have an idea of current airport charges differentials.

In 2003, aeronautical charges[114] at Amsterdam Schiphol for a Boeing 747-400 amounted to approximately € 9120 per LTO cycle, while those for a Boeing 737-300 were € 2350 [see SEO, 2003][115]. [SEO, 2003] also provides an overview of the relative aeronautical costs at six major European airports. The figures are for 2003, with a distinction being made between small aircraft (below 70 tons MTOW) and large aircraft[116] (over 70 tons MTOW). It is a hypothetical overview, in the sense that it represents the relative charges at airports with Schiphol taken as a benchmark.

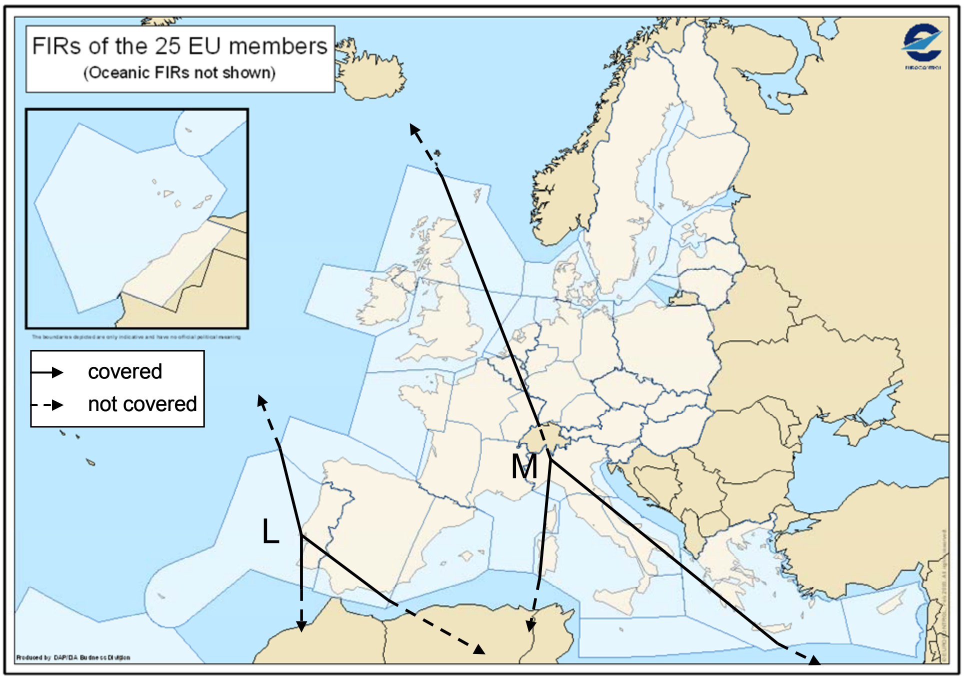
Table 29 Relative aeronautical charges at six EU airports (AMS=1)

	AMS	FRA	LHR	LGW	CDG	ORY
Small aircraft	1.00	0.98	1.79	1.53	1.00	0.8
Large aircraft	1.00	0.94	1.42	1.21	1.3	1.2

Source: SEO 2003, Table 3.5

As can be seen from Table 29, airport charges can differ substantially.

Figure 13 Airspace scenario: unfortunate geographical situation



114 Aeronautical charges at Amsterdam include airport landing and take-off charge, passenger service charge, airport security charge, government noise charge and ATC charge.

115 SEO 2003, Benchmark Government Influence on Aeronautical Charges, Amsterdam, November 2003, SEO Report no. 712.

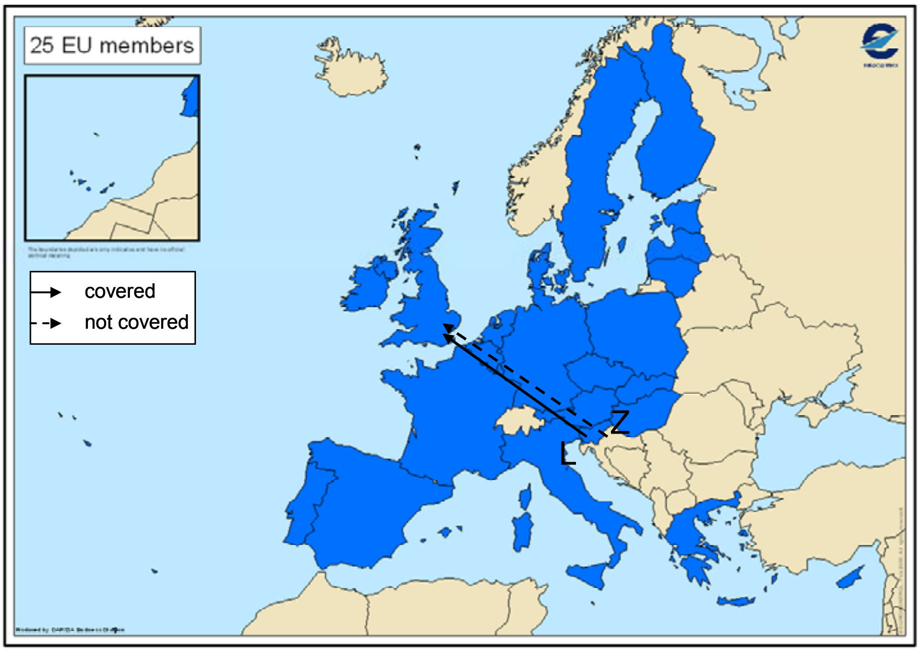
116 Estimates for relative average charges for small and large aircraft are based on the fleet mix at Schiphol.

Border effect
Apart from the potential distortion between airports related to their geographical location, there is the so-called *border effect*. This includes two potential distortions, both of which may also affect the environmental effectiveness of the system. These are:
- a change of airport for point-to-point passengers and freight.
- a change of hub for transfer passengers.

The first category refers to the possibility that air freight and passengers originally departing from an airport falling just inside the geographical scope of the system may, following its introduction, (be) transfer(red) by surface transport to airports just outside the EU[117]. This possibility is most likely to occur in route-based scenarios (Options 2 and 3). Figure 14 gives an example for a flight to London from the airports of Ljubljana in Slovenia and Zagreb in Croatia, which are some 100 km apart. Flights from Ljubljana would be covered under a route-based system, while flights from Zagreb would not.

As follows from Section 5.3 (impacts on ticket prices) for route-based systems, initial ticket price increases would lie between € 1 and € 3 for a return ticket for medium- and long-haul flights at an allowance price ranging from € 10 to € 30 per tonne/CO_2. Given this negligible impact on ticket price, on top of airlines' dependence on traffic rights and slots, and the effects moving to another airport just outside the EU might have on the cost (and/or time) for passengers to reach the airport, this type of 'border' effect can be expected to be virtually non-existent.

Figure 14 Route-based scenario: border effect on point-to-point flights



[117] Note the resemblance with car drivers located near the border who are induced to refuel in the country with the lowest fuel tax.

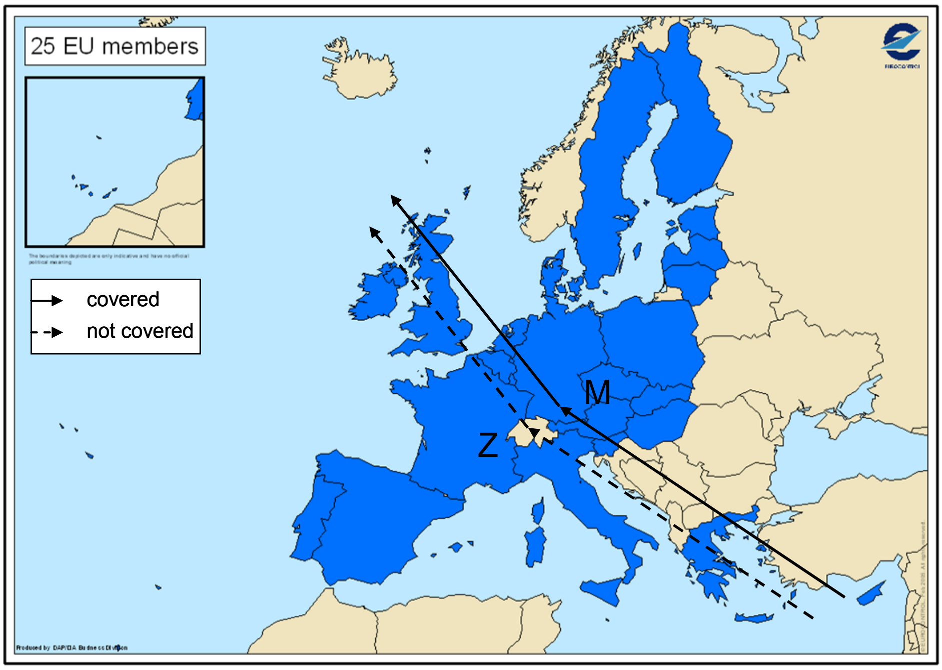
The second category of potential distortion refers to the possibility of airlines changing hub airport. Because it is a very closely related issue, we shall also discuss the possibility of a change of stop-over on long-haul flights. Theoretically, there is a potential for economic distortion between airports, as airports) just outside the geographic scope of the system might become popular stop-over and hub airports. In scenarios based on airspace this effect is likely to be relatively small, because to reach the hub airport aircraft will have to cross the system airspace anyway.

In the first place, a change of hub airport is by no means straightforward. As is the case with a change of home-base airport, traffic rights and slots must be acquired. In addition, not just any airport can serve as a hub. A central location is clearly preferable, since it minimises the distance travelled on each spoke. Also, the incentive to choose a hub outside the system might be partly counterbalanced by the economies of scale achieved at EU airports because of their much better developed home market. Furthermore, the hub potential of an airport depends on the concentration of economic activity in the catchment area of the airport concerned. Airports located just outside the EU do not yet appear to have the required potential to serve as a hub. For all these reasons, a change of hub airport is highly unlikely.

The second issue is the likelihood of changes being made in stop-over airports on long-haul flights as airports falling under the system become less attractive. Thus, flights from North America to the Far East, for example, might prefer to stop over at Reykjavik or Leningrad instead of Helsinki. Especially on long-haul flights the benefits of changing stop-over airport may be considerable, because then neither the flight stage arriving at the airport nor the stage departing from it will fall under scheme. See Figure 15 for another example. Under a route-based scenario, flights to and from Munich are (partly) covered, while those to and from Zurich are not.

However, there are several reasons why this kind of behaviour is unrealistic. First, the estimated cost increase in the three policy options is not significant enough to induce such behaviour. Second, even if far higher cost increases were likely, these operations involve landing rights that are country-specific. These rights cannot necessarily be exchanged for landing rights for stop-overs in other countries. Third, these flights are often part of extensive 'hub and spoke' systems, with many passengers boarding and terminating the flight at the stop-over airport. Flights are dually tied to the catchment area of the specific airport, both for arriving and departing passengers. Airlines will therefore be very reluctant to change their stop-over to an airport not subject to the scheme.

Figure 15 Route-based scenario: border effect by change of hub



6.5 Potential economic distortions between tourist areas

Besides economic distortions between airlines and airports, economic distortions between tourist areas are also conceivable. Thus, an increase in the price of air tickets may induce the following responses:

- Substitution to other modes of transport.
- A shift in consumer pattern away from travel and tourism.
- A change in choice of destination.

A substitution to other modes of transport and closer destinations would also occur under a global system. The same holds for a shift in consumer pattern. Even though these might in theory affect the airline industry and the income of some tourist areas while benefiting others, these effects cannot be regarded as economic distortions. In fact, they contribute to the ultimate aim of the scheme.

Assuming the general direction in which tourists wish to travel is given (sun, sea, snow, city trip), there are two potential responses from tourists that might cause economic distortions. In the case of option 1 (Intra-EU routes) tourists may avoid destinations 'covered' by the system by opting for nearby alternatives that are not covered: Turkey instead of Spain, for example. For example, flights from Stockholm to Crete are covered under intra-EU based option 1, whereas flights to nearby Bodrum in Turkey are not.

However, tourists may also opt for destinations further away. So instead of flying to Spain, they may go to the Caribbean. Such behaviour could potentially also influence the environmental integrity of the scheme, since a shift from short- and medium-haul to long-haul flights would lead to an increase in total emissions. If such shifts were indeed likely, economic distortions would be smaller in a route-based system, which could potentially cover half (or all) of the emissions of the long-haul flights, whereas intra-EU or airspace-based systems might cover much less. It should be noted, however, that given the expected impact of including aviation in the EU ETS on ticket prices, compared to current ticket price differentials between short-/medium- and long-haul flights the shift from the former to the latter is expected to be very modest in either case.

There is also the possibility of Europe becoming less attractive as a destination. [CE, 1997b] has studied this possibility and argues that this distortion is likely to be small, as many people come to Europe specifically to visit capital cities like London, Paris and Rome. These distortions may play a role in Options 2 and 3. However, for a flight from the US to Europe the initial price increase will be rather limited (see Section 5.3) compared to current ticket price differentials and total holiday expenditure. The effect on, say, US citizens planning to visit Europe is therefore likely to be negligible.

Note that under any scheme that includes all intra-EU flights there might be some economic distortions between tourist areas. There are several isolated islands under governance of EU Member States in the oceans, and including these in the scheme but not potentially competing islands close by could disadvantage the tourist industry on those particular islands. Exemptions for such cases should be considered if the actual impact on ticket prices proves substantial enough to justify such a move.

6.6 Revenues from grandfathering and auctioning

6.6.1 Windfall profits (Options 1 and 2)

Few things about the EU Emissions Trading Scheme cause as much surprise as the idea that some sectors might gain from it. However, this is a result that has been found consistently in numerous studies[118] (see also Section 5.3.4) and understanding it is important for understanding the potential impacts of the EU ETS on competitiveness.

The key is to understand that profit-maximising companies will generally tend to set prices in relation to marginal production costs – the cost of producing an extra unit is balanced against the value of the additional sales. The EU ETS increases this marginal cost, since companies would have to buy allowances (or forego selling allowances) to cover the associated extra emissions. As a result, companies will tend to raise their prices to reflect this additional revenue across all their sales. However, the companies do not face a corresponding increase in overall costs if allocation is based on grandfathering, i.e. if allowances are given

118 See for example [Nentjes, 1995; Woerdman, 2001; Mannaerts and Mulder, 2003; Oxera, 2004].

to aircraft operators free of charge. Consequently, although companies will face an added ‘cost of carbon’ at the margin of their operations (in considering whether to increase or reduce output), this will not apply across the main part of their cost base.

It is as if the price of energy inputs in the economy rises, but governments then compensate companies by paying them an amount close to their total cost increase. If companies still pass on most of the marginal increase in energy costs to their customers, they will then end up better off under the EU ETS, because they receive revenues that match the opportunity cost associated with all their emissions, while these theoretical costs are in fact almost all offset by the emission allowances received free from government.

In economic terms, the carbon cap creates ‘scarcity rents’. The impact on competitiveness will depend on who gets these rents, and the principle of giving the vast majority of the allowances to companies free of charge means that industry may capture a high share of these rents.

Windfall profits are estimated to be in the order of the estimates of auctioned revenues as estimated in Section 6.6.2.

Although economic theory suggests that companies would pass on the bulk of the marginal cost increase (and thus opportunity costs) in prices, in Section 5.3.4 it was already noted that there is as yet no empirical evidence for this. It is therefore uncertain whether increased operating profits would actually increase by the windfall profits. It is very likely, though, that in case of air carriers operating on competitive markets, at least a significant part of these profits will be realised by aircraft operators in the case of Options 1 and 2.

6.6.2 Revenues from auctioning (Option 3)

Total auction revenues under policy Option 3 can be simply calculated by multiplying the number of allowances auctioned (e.g. based on 2008 emissions) by the assumed price of allowances. With allowance prices of € 10 and € 30 per tonne CO_2, auction revenues are € 1.34 billion and € 4 billion, respectively. Besides covering the costs of administering the system, in general these auctioning revenues can be used for several purposes:
- To finance the EU budget and reduce the contributions of all Member States.
- To earmark for specific spending purposes, possibly environmentally motivated (e.g. R&D or to buy additional emission reduction units).
- To recycle back to the aviation sector.

Below, each of these options for use of the revenues is briefly discussed.

To finance the EU budget and reduce Member State contributions
The first option, to finance the EU budget while at the same time reducing Member State contributions, avoids any distributional complications and associated political problems as Member State contributions will be reduced equally, based on existing rules.

In the public finance literature the conventional view is that taxes collected from various activities should be paid into a general fund from which government expenditures are financed. If substantial revenues are raised through auctioning, the *theoretical first-best solution*, from the perspective of economic efficiency, is to recycle these revenues back to citizens through lump-sum payments or through reduction of lump-sum taxes; see [Musgrave and Musgrave, 1984]. The modern variant to this alternative is to recycle them by cutting back the government's budget deficit. A Japanese study [EIEP, 2000] showed that from the perspective of economic efficiency a policy of reducing public debt, which reduced interest rates and shifted money to the private sector, was the best alternative for spending the income raised from an assumed CO_2 tax.
[Pearce, 1991] has suggested that there may be a better *practical* solution to the expenditure of governmental revenues, known as the 'double dividend'. The revenues from environmental levies could be used to lower other taxes in the economy. In practice, many of these other taxes are distortionary (i.e. interfere with the efficient functioning of markets) and a reduction in their rates can therefore be seen as a means of improving efficiency, thus yielding a second 'dividend' from the adoption of environmental taxes over and above internalisation of external costs[119].

Earmark for specific purposes
A potential benefit of the second option: earmarking revenues for additional environmental measures by the EU, would be enhancement of *the environmental effectiveness* of the system, for example through purchase of additional emission reductions units (e.g. CERs). This may imply that the target of the emission trading system can be set lower for achieving a predefined environmental target compared with other policy options based on free allocation of allowances. This may increase the acceptability of auctioning.
Earmarking the revenues for additional environmental measures within the aviation sector would probably increase *the environmental effectiveness* of the system. However, depending on the spending purposes, gains in effectiveness might be offset to some extent by the fact that recycling the revenues to the aviation sector may reduce the price of air transport and thus increase demand.
In general terms, earmarking charge revenues for specific R&D within the aviation sector has a number of disadvantages. First, it allocates the revenues in advance, creating obstacles for re-evaluation, based on economic and environmental criteria, of a targeted expenditure programme financed from the recycled revenues. The result is inefficient spending of the revenues. In addition, earmarking revenues within the aviation sector may create inflexibility, as programmes may last longer than optimum because of obstructions to reform created by vested interests.
Another possible disadvantage of earmarking revenues within the aviation sector is that the revenues might support only a limited number of emission reduction measures (such as technologies, operational changes, etc.; see Section 5.2 for a

[119] The frequently made connection between the 'double dividend' and job creation ensues from the fact that one possible distortionary effect of taxation is to reduce employment.

full overview of these measures). This may in turn reduce economic efficiency, by limiting development of other, more efficient alternatives.
With regard to manufacturers, any R&D fund or investment programme should, from the efficiency point of view, be equally open to all manufacturers in the world as long as they meet the conditions for receiving support. An important argument for using revenues (in part) to provide extra incentives to manufacturers to develop improved, environmentally sound aircraft, might be the limited size of the EU market. This is because the EU market in which aircraft are subject to the system may not be large enough to justify a substantial manufacturers' response, given the major economic risks involved in developing improved engines and aircraft. Support could allow such economic barriers to be overcome.

Recycling back to the aviation sector
Another possibility is to recycle auctioning revenues back to the aviation sector on the basis of RTKs performed by an aircraft operator within the geographical scope of the system. An advantage of this option is that it alleviates the financial burden of the sector, while still retaining the advantages of auctioning (economic efficiency, fair treatment of new entrants, early action, low administration costs). In addition, the sector may be willing to accept higher targets.
An important disadvantage of this option is that the Polluter Pays Principle is not fully respected, as revenues are recycled to the aviation sector. This argument, however, also plays a role in the case of the baseline policy option (Option 1) and benchmarking (Option 2).

6.7 Marginal impact on EU-ETS and allowance price

The impact of including aviation in the EU ETS can be expected to operate via its impact on supply of and demand for emission allowances on the market.

For each of the three options, we calculated the expected demand for or supply of allowances on the part of aircraft operators and compared the results with demand and supply of allowances under the EU ETS in the Business as Usual scenario. If the contribution of aviation is at all substantial, we can expect price changes on the allowance market, which will in turn have an impact on the other EU ETS sectors.

To this end, we assumed that the total amount of CO_2 emissions covered by allowances falling under the EU ETS in the BaU scenario in 2012 is similar to the figure for the period 2005-2007: about 2,200 Mt. It is assumed no other new sectors will enter the EU ETS before 2012. It is assumed, furthermore, that the allocated amount in the National Allocation Plans of the Member States will not be significantly different in 2012 compared to the situation in 2005.

Table 30 compares the number of allowances to be bought by the aviation sector from other sectors with the amount of allowances allocated under the present EU ETS. The table shows that, in all Options, more allowances would be bought from other sectors at a relatively low allowance price. Obviously, at a higher allowance price of € 30 tonne/CO_2 more emission abatement measures become cost-effective within the aviation sector. Consequently, fewer allowances have to be bought from other sectors. Table 30 shows, furthermore, that in all three policy options aviation would buy about 1% of the allowances under the present EU ETS in the year 2012. It should be stressed that this percentage would be even lower if markets for JI and CDM credits were also taken into account.

Table 30 Absolute and relative amount of allowances bought by the aviation sector from the EU ETS in 2012

	Allowances (in million tonne)	% of present allowances in ETS
Allowances CO_2 emissions present Emission Trading System (2005-2007)		
Allocated CO_2 emissions	2,200 Mt	100.0%
Allowances bought by aviation from other sectors (2012)		
Allowance price € 10 per ton		
Option 1	20.0 Mt	0.9%
Option 2	24.8 Mt	1.1%
Option 3	20.7 Mt	0.9%
Allowance price € 30 per ton		
Option 1	19.3 Mt	0.9%
Option 2	22.7 Mt	1.0%
Option 3	17.1 Mt	0.8%

The extent to which inclusion of international aviation in the EU ETS would cause the allowance price to rise further over time than would have otherwise been the case is uncertain. A certain additional supply of AAUs from countries like Russia or a few big additional CDM projects could easily absorb the relatively small additional demand from aviation. In all three Options we therefore expect no significant rise in the allowance price if aviation were included in the EU ETS, provided there is sufficient supply of emission reduction units (AAUs[120], JI and CDM credits) from outside the scheme.

In the long run, if any option is introduced for more than one commitment period, continued growth of aviation might cause the allowance price to rise. The extent to which including international aviation in the EU ETS could, in the long term, cause the allowance price to rise faster than would have otherwise been the case depends on many factors influencing the demand and supply side of the international carbon markets, not least the marginal abatement cost curves of other sectors of the economy.

Although higher allowance prices will create greater supply-side incentives to industries in the EU ETS to reduce emissions, they could also have an impact on the competitiveness of certain installations operating under the EU ETS compared with those operating in non-EU countries without climate policies. Overall, existing participants in the current scheme would enjoy a net benefit of aviation being incorporated, as the sum of additional mitigation costs incurred

[120] AAUs here refers to government purchases which indirectly take the pressure off national allocation plans It is not possible for operators in the EU ETS to purchase AAUs directly. However, operators can purchase Kyoto project credits directly.

would be more than outweighed by the financial transfer received in return for allowances sold to the aviation sector. The socio-economic gain would thus benefit current ETS participants as a whole as well as the aviation sector, compared to a scenario whereby aviation had to make the same cuts within the sector.

7 Legal feasibility

7.1 Introduction

This analysis addresses the aspects of international law of relevance for including aviation emissions under the European Union Emission Trading Scheme (EU ETS) that started on January 1, 2005. It is carried out by the International Institute for Air and Space Law of Leiden and based also on a literature review[121]. It focuses on international provisions, including the UN Framework Convention on Climate Change, the Kyoto Protocol to that Convention, the Convention on International Civil Aviation (the ‘Chicago Convention’), bilateral Air Services Agreements, general principles of international law, and the legal framework of the European Union. Legal issues related to designing amendments to the EU ETS that might be necessary for a possible inclusion of aviation in that system will be treated in Annex A.

Against this background the following key question will be addressed:

Is the extension of the EU ETS to international aviation within, to and from the EU feasible under international and EU law and, if so, under what conditions?

Section A presents the international and EU legal framework for combating climate change:
1 The United Nations Framework Convention on Climate Change.
2 The Kyoto Protocol.
3 The binding nature of the above provisions.
4 EU law.

Section B looks at the implications of the EU emissions trading scheme for covered aircraft and thus defines more precisely the scope of the analysis.

Section C discusses the potential legal obstacles in this respect arising from:
1 The global framework, that is:
   a The Convention on International Civil Aviation (the ‘Chicago Convention’).
   b The ICAO standards and recommended practices.
   c The ICAO resolution on emissions trading (2004).
2 Bilateral Air Service Agreements.
3 EU law.

[121] E.g. ICF et al., 2004, IATA, 2002 and CE 2002.

7.2 Section A: The international and EU legal framework for combating climate change

7.2.1 United Nations Framework Convention on Climate Change (UNFCCC)

The United Nations Framework Convention on Climate Change (henceforth referred to as: the UNFCCC) forms the foundation of global efforts to tackle climate change. The ultimate objective of the UNFCCC, which 189 parties (including the US) have ratified, is to stabilise greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous human-caused inference with the climate system, within a time-frame that would be sufficient to allow ecosystems to adapt naturally, and to ensure food production is not threatened. In the view of European Heads of State, this requires the consideration of reductions of greenhouse gas emissions by 15-30% by 2020 for developed countries[122].

Article 3(3) of the UNFCCC provides that "*the Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects. Where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures, taking into account that policies and measures to deal with climate change should be cost-effective so as to ensure global benefits at the lowest possible cost.*"

Article 4 requires all States to formulate and implement national programmes containing measures to mitigate climate change. While not specifying what measures are to be applied, Article 4(1)(c) requires all Parties to promote and cooperate in the development and application of technologies, practices and processes that control or prevent human-induced greenhouse gas emissions, including in the transport sector. Article 4(2)(b) requires developed countries to "*adopt national policies and take corresponding measures on the mitigation of climate change*", to "*demonstrate that developed countries are taking the lead in modifying longer-term trends*", explicitly recognising that "*these Parties may implement such policies and measures jointly with other Parties*".

In 1995, the Parties to the UNFCCC recognised that the commitments by developed countries to return their emission levels to 1990 by the year 2000 were inadequate for achieving the UNFCCC's long-term objective, and so negotiations were begun on strengthening tates' commitments. This process led to the adoption of the Kyoto Protocol, which entered into force in February 2005 and currently has 150 Parties (not including the US and Australia) representing around 90% of the global population.

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[122] See http://www.eu2005.lu/en/actualites/conseil/2005/03/23conseileuropen/ceconcl.pdf.

7.2.2 Kyoto Protocol

The Kyoto Protocol of 1997, which upon ratification by Russia entered into force on 16 February 2005, requires that developed countries "*shall …implement and/or further elaborate policies and measures … such as (vii) measures to limit/or reduce emissions of greenhouse gases … in the transport sector*." (Article 2(1)(a)). Cooperation with other countries under the Kyoto Protocol is required by Article 2(1)(b) "*to enhance the combined effectiveness of their policies and measures adopted under this Article*". In addition, Article 2(2) states that developed countries "*shall pursue limitation or reduction of emissions … from aviation and marine bunker fuels, working through the International Civil Aviation Organisation and the International Maritime Organisation, respectively*".

7.2.3 The binding nature of the above provisions (UNFCCC and KP)

The Community and all EC Member States are Parties to the UNFCCC and to the Kyoto Protocol. Hence the above provisions are legally binding for the Community and its Member States, and for the remaining 163 and 124, respectively, parties.

7.2.4 EU law

The Treaty establishing the European Community, as amended[123] (henceforth "the EC Treaty"), provides the objectives of the European Community and the legal basis for it to take legislative action. Of relevance in this context are in particular Articles 2, 6, 174 and 175 and – as regards the existing emissions trading scheme covering industrial emissions - the Directives 2003/87/EC and 2003/87/EC of the European Parliament and of the Council:

Article 2 of the EC Treaty states that:
"*The Community shall have as its task, … by implementing common policies or activities referred to in Articles 3 and 4, to promote throughout the Community a harmonious, balanced and sustainable development of economic activities, … a high level of protection and improvement of the quality of the environment, the raising of the standard of living and quality of life, and economic and social cohesion and solidarity among Member States*". Article 3 goes on to say that "*For the purposes set out in Article 2, the activities of the Community shall include … (l) a policy in the sphere of the environment.*"

Article 6 of the EC Treaty states that:
"*Environmental protection requirements must be integrated into the definition and implementation of the Community policies and activities referred to in Article 3, in particular with a view to promoting sustainable development*."

[123] http://europa.eu.int/eur-lex/en/treaties/dat/EC_consol.pdf.

Article 174 of the EC Treaty states that:
"1. *Community policy on the environment shall contribute to pursuit of the following objectives:*

- Preserving, protecting and improving the quality of the environment.
- Protecting human health.
- Prudent and rational utilisation of natural resources.
- Promoting measures at international level to deal with regional or worldwide environmental problems.

2. Community policy on the environment shall aim at a high level of protection taking into account the diversity of situations in the various regions of the Community. It shall be based on the precautionary principle and on the principles that preventive action should be taken, that environmental damage should as a priority be rectified at source and that the polluter should pay …".
Article 175 of the EC Treaty lays down the manner in which the Community is to act in order to achieve its objectives relating to protection of the environment, and states that:
"*The Council, acting in accordance with the procedure referred to in Article 251 and after consulting the Economic and Social Committee and the Committee of the Regions, shall decide what action is to be taken by the Community in order to achieve the objectives referred to in Article 174*."

Directive 2003/87/EC establishing *a greenhouse gas emission allowances trading system* is the cornerstone of the European Community's action to tackle climate change. This Directive covers major activities that contribute to climate change (combustion installations and oil refineries, ferrous metal production, cement and lime production, glass production, ceramic production and plants for pulp and paper production). Many of the issues relating to the application of the emissions trading scheme to aviation are identical or similar to those relating to its application to other activities, in particular in terms of compatibility with EC law and non-discrimination. The EU emissions trading scheme applies without distinction to installations owned or operated by companies based in the EU or in third countries.

The EU emission trading Directive was amended by Directive 2004/101/EC to provide for the use of allowances originating from projects to address climate change taking place in third countries, from among the 124 countries that are also Parties to the Kyoto Protocol. This extends the scope of the EU emissions trading scheme beyond the linkages to third country emission trading schemes that are already foreseen by Article 25 of the EU emission trading Directive. A review has specifically been foreseen in Article 30(2) of the EU emission trading Directive to consider its amendment in order to include "other relevant sectors, *inter alia,* the transport sector".

The inclusion of aviation into the EU ETS could be achieved by amendment of the existing emissions trading Directive by means of co-decision procedure.

7.2.5 Conclusions

- The UNFCCC *requires* developed countries to take measures to mitigate climate change to demonstrate that developed countries are taking the lead in modifying longer-term trends, and explicitly recognises that they may implement such policies and measures jointly with other Parties. Although not specific, it provides a general mandate for addressing the climate change impact of aviation.
- The Kyoto Protocol reinforces the international mandate from the UNFCCC for the EU to take effective action on climate change, including aviation.
- EU law (the EC Treaty) provides the necessary legal basis for including aviation into the EU ETS, which could be achieved by amendment of the existing emissions trading directive by means of co-decision procedure.

7.3 Section B: Implications of the EU emissions trading scheme for covered aircraft and precise scope of the analysis

In order to identify any possible legal obstacles to the extension of an emissions trading scheme to aviation it is important to look at the implications for aircraft that would be covered by the scheme. The nature of regulation will determine whether it potentially oversteps the territorial boundaries as laid down in international law. Therefore it is necessary to identify the regulatory implications of an emissions trading scheme on covered aircraft.

In fact, emissions trading is an economic (or 'market-based') instrument and therefore would not regulate the operation of individual emitters. Though emissions trading implies in principle a total cap for emissions from all covered sectors, it would not impose a particular type of technology on any operator nor would it impose *individual* emission limits on any operator or affect existing traffic rights. Emissions trading leaves it entirely open for an emitter to decide when and how much to emit: he may freely buy and sell emissions allowances from others on the market or through the use of Kyoto flexible mechanisms (JI/CDM) even after the initial allocation of allowances has taken place. In effect, an emissions trading scheme puts a price on a particular emission or emissions. It transfers the external costs to the community arising from the emissions into the economic decision-making process of the emitter. Naturally the decisions would continue to be influenced by the interplay of many factors – the effect of emissions trading would be supplementary.

Conventional regulatory measures ('command and control') differ from emissions trading in that they have a direct impact on the operation of an emitter, e.g. by setting emission limit values, requirements of technology to be utilized etc. and therefore, if applied to aviation, would directly allow or disallow certain aircraft operations. Hence, the character of the EU emissions trading scheme and the extent of its impact upon the operation or navigation of an air carrier would be fundamentally different from traditional regulatory public interventions.

It is important to recognize that the EU emissions trading scheme would not impose any requirements on the operation or the navigation of air carriers. The

EU emissions trading scheme would not regulate the construction, design, manoeuvring or any other aspect of the operation or navigation of an air carrier. Nor would it set emission limits for individual air carriers. It would essentially require air carriers arriving and departing from Community airports to surrender an amount of allowances corresponding to their emissions of greenhouse gases[124]. This purely administrative aspect of the EU emissions trading scheme would therefore only be related to the departure and/or landing conditions for aircraft. The number of allowances to be surrendered by an operator for a flight departing from and/or landing in the EU would depend on the emissions caused by this flight and would be calculated on basis of objective parameters (emissions estimated according to published guidelines or methodologies). The amount of emissions of greenhouse gases caused by a flight would thus constitute only a calculation parameter to quantify the amount of allowances to be surrendered for this flight. Thus, the requirement to surrender allowances would purely constitute an obligation related to the admission to and/or departure from EU airports, as this already exist in a number of other contexts, notably the obligation to observe certain safety requirements. For instance, an aircraft which is found not to be in compliance with those requirements could be subject to penalties or ultimately refused permission to land in or depart from the territory of EU Member States. Similarly, an aircraft operator who fails to comply with EU requirements to surrender the necessary amount of emissions allowances to the competent authority, would be subject to financial penalties and, if necessary, other enforcement measures.

The EU emissions trading scheme would therefore not involve intervention in the operation or navigation of air carriers or their traffic rights, nor would it restrict the emissions caused by individual aircraft inside or outside the EU territory. The only direct implication of the scheme for any air operator would be an obligation to surrender allowances in respect of emissions from his aircraft using EU airports.

It follows already from general principles of international law that the 25 EU Member States, having formed the EU, are fully sovereign and therefore in principle free to regulate themselves or through the EU their own airspace and the obligations relating to arrival and/or departure of aircraft within their or EU territory. However, the design of such obligations would need to be in compliance with specific provisions in international and EU law, which the EU and its Member States may have concluded and would thus limit them in their freedom to regulate. These limits are examined in Section C.

It is not necessary to look into the specific aspects and possibilities of regulating the operation of air carriers in international flights (above the high seas or non-EU territory), since the EU emissions trading scheme, as outlined above, would not limit or otherwise regulate the operation of such flights. The EU emissions trading

[124] The present legal analysis assumes that emissions from aircraft that fly through EU airspace without stopping (“overflights”) are not addressed by the scheme and focuses only on emissions from aircraft operating to, from or between airports in the territory of EU Member States. Emissions from overflights are comparatively low, and including them in a scheme might be associated with a number of additional technical, political and legal complexities.

scheme would therefore have no extra-territorial implications and, in particular, it would not interfere with the sovereignty or territorial integrity of any other state, nor would it have any regulatory impact on the high seas.

Conclusions

- Emissions trading would not regulate the operation of aircraft or the amount of emissions, which an aircraft operator chooses freely to emit according to its commercial rationale, nor would it affect the existing traffic rights.
- Through the requirement to surrender allowances for emissions caused by flights departing from and/or landing in the EU, emissions trading would purely regulate the obligations relating to arrival and/or departure of aircraft within the EU territory.
- The 25 EU Member States, having formed the EU, are fully sovereign and therefore in principle free to regulate their own airspace and obligations related to arrival and/or departure within EU territory. Only the design of such obligations would need to be compatible with specific provisions in international and EU law (see Section C for a further analysis).
- The emissions caused by aircraft, within or outside the EU, would only serve as a calculation parameter for determining how many allowances the aircraft operator must surrender with the competent authorities within the EU.
- Consequently, coverage of international aviation by an EU emissions trading scheme would not interfere with the sovereignty or territorial integrity of other states or have any other regulatory impact on other territories outside the EU, for instance the high seas.

7.4 Section C: Potential legal obstacles related to the inclusion of aviation into the EU emissions trading scheme from:

7.4.1 The global framework

1) The Convention on international civil aviation ('The Chicago Convention')

All EC Member States are parties to the Chicago Convention (henceforth referred to as 'the Convention'). Hence, its provisions are binding international law for the 25 EU Member States (the Community itself is not a party to the Convention), and for the remaining 163 contracting states.

The Convention does not refer to trade in emission allowances, as this system did not exist when it was drafted in 1944.

The Chicago Convention can however be considered to be of relevance for the possible introduction of the EU ETS with respect to international aviation as its preamble provides that "international air transport services may be established on the basis of equality of opportunity and operated soundly and economically". As explained above, the EU ETS constitutes a market-based instrument introducing new economic incentives to reduce emissions and may therefore have implications in this respect.

The Convention does not apply to aviation within the territory of one state ("domestic aviation") as clear reference is made throughout the Convention only to *international* civil aviation. The Convention can therefore not impose any limits on the regulation of domestic aviation.

The Convention confirms in its Article 1 the principle of international law that each state has complete and exclusive sovereignty over its airspace, and that therefore, as reflected in its Article 6, no international scheduled air service may be operated over or into the territory of a Contracting State except with the permission of that state and in accordance with the terms of such permission.

Consequently, and as already stated in Section B, the 25 EU Member States, having formed the EU, are fully sovereign and therefore in principle free to regulate their own airspace and therefore also the obligations relating to arrival and/or departure of international aircraft within EU territory, as this would be the case for covering international aviation under an EU emissions trading scheme. The design of such obligations would need to be in compliance with the specific provisions of international law laid down in the Chicago Convention and in bilateral air services agreements (see below).

Article 11 of the Convention stipulates that, subject to other provisions of the Convention, the laws and regulations of contracting states relating to the admission to or departure from its territory of aircraft engaged in international air navigation, or to the operation and navigation of such aircraft while within national airspace, shall be applied to aircraft of all contracting States without distinction as to nationality.

Article 11 therefore requires laws and regulations relating to the admission to or departure from its territory of aircraft engaged in international air navigation to be non-discriminatory with respect to nationality. As the rules extending the ETS to cover aircraft can be viewed as falling under the scope of this provision by relating to the admission to or departure from its territory of aircraft engaged in international air navigation, the provision requires that the EU ETS would have to be applied to and complied with by all aircraft engaged in international air navigation without distinction as to nationality.

Article 12 of the Convention ("Rules of the Air") is not relevant as emissions trading, as outlined in Section B, would not affect the flight and manoeuvre of aircraft but only the terms for admission to and/or departure from EU territory, even in the case of sanctions for non-compliance with the requirement to surrender allowances.

The coverage of aviation under the EU ETS cannot be regarded as an airport charge or similar charge pursuant to Article 15 of the Convention. Under this provision, airlines pay airport charges "for the use of … airports and air navigation facilities by the aircraft" which they operate. Even if a public authority - of a Member State or the Community - were to grant emissions allowances against payment of money under an auction system, the envisaged allowances are not designed to compensate for the costs of the operation and management

of airports and air navigation facilities. But even if - unjustifiably - a broader interpretation was used, the provisions would not constitute an obstacle for incorporating international aviation in the EU ETS, it would just imply that foreign aircraft should be treated as national aircraft, as is already stipulated by Article 11.
Emissions trading allowances are fundamentally different from customs duties. Therefore, Article 24 of the Convention governing customs duties is not relevant for assessing the possible coverage of international aviation by an EU ETS.

Summary and conclusions:

- The operation and navigation of civil aircraft on *domestic* flights fall outside the scope of the Convention.
- The Chicago Convention does not address the issue of emission trading. But, according to its Preamble, the Chicago Convention relates also to establishing *international* air transport services on the basis of equality of opportunity and sound and economical operation. As emissions trading might in principle have implications in this respect, it is relevant to assess whether the Convention contains any requirements or obstacles with regard to the coverage of international flights by an EU emissions trading scheme.
- As outlined in section B, the EU emissions trading scheme can be considered to constitute laws and regulations relating to the admission to and/or departure of aircraft from its territory pursuant to Article 11 of the Convention. Therefore, the requirement in Article 11 of the Convention not to discriminate as to nationality of aircraft needs to be respected. Any EU emissions trading system must thus treat all aircraft engaged in international air navigation without distinction as to nationality.
- The coverage of international aviation under the EU emissions trading scheme does not find limits under Article 12 “Rules of the air”, Article 15 “Airport and similar charges” or Article 24 “Customs duty” of the Convention.

2) ICAO Standards and Recommended Practices (SARPs)

Annex 16, Volume II, of the Chicago Convention deals with *aircraft emissions*. It provides Standards and Recommended Practices (“SARPs”) for limiting smoke, HC, CO and NO_x emissions from aircraft engines. It lays down procedures for the independent assessment of engine designs prior to service for compliance with the appropriate limits.

Standards made and updated from time to time and recommended by ICAO may be binding upon EU Member States. The regulatory force of such standards depends on:

1 Whether or not a contracting state, that is, a Member State, has formally notified ICAO of a difference with the standards in question (in accordance with the procedure set out in Article 38 of the Convention).
2 Provisions of national law, including the constitution, of each Member State, regarding the implementation of such standards in the national jurisdiction.

Annex 16, Volume II, contains maximum levels for gaseous emissions which are allowed in the context of the certification process for new engine designs. Emissions trading, on the other hand, has implications for the aggregated aircraft emissions of certain greenhouse gases. Therefore, the Standards regarding maximum levels of certain gaseous emissions are not relevant for assessing the coverage of international aviation by the scheme as the scheme would not set standards for maximum levels of certain gaseous emissions by aircraft but, as explained in Section B, only create economic incentives for their reduction. So its scope would be completely different.

3) ICAO Resolution on emissions trading (2004)

While ICAO resolutions are statements of policy and not international law, they can illuminate what ICAO has in mind.

In October 2004 ICAO addressed the subject of emission trading in Resolution A35-5 including a "Consolidated statement of continuing ICAO policies and practices related to environmental protection".

Appendix I to this resolution pertaining to market-based measures regarding aircraft emissions contains the following:

> "….*ICAO endorses an open emission system for international aviation*."
>
> "… *the General Assembly of ICAO* Requests *the Council, in its further work on this subject, to focus on two approaches. Under one approach, ICAO would support the development of a voluntary trading system that interested Contracting States and international organizations might propose. Under the other approach, ICAO would provide guidance for use by Contracting States, as appropriate, to incorporate emissions from international aviation into Contracting States' emissions trading schemes consistent with the UNFCCC process. Under both approaches, the Council should ensure the guidelines for an open emissions trading system address the structural and legal basis for aviation's participation in an open emissions trading system, including key elements such as reporting, monitoring and compliance*."

The second approach implies that Parties to the UNFCCC or regional organizations (e.g. European Union) have to take the initiative for implementing open emission trading systems. The fact that ICAO policy explicitly establishes the ambition of providing guidance for use by Contracting States, as appropriate, to incorporate emissions from international aviation into Contracting States' emissions trading schemes, is another indication that the existing international legal framework for aviation does not constitute a barrier to this effect.

Summary and Conclusions

- ICAO rules relating to its Standards do not cover emission trading and do not create legal obstacles for the introduction of an ETS.
- The ICAO Resolution of October 2004 on the subject supports the inclusion of emissions from international aviation into Contracting States' emissions trading schemes consistent with the UNFCCC process.

7.4.2 Bilateral Air Service Agreements

EC Member States have concluded around 1,600 bilateral air services agreement world-wide, regulating the operation of the agreed international scheduled air services. Again, as ETS is a new instrument, bilateral agreements do not address it. However, such agreements contain some provisions, which can be considered to be relevant for its introduction. These provisions have not been subject to court or arbitration decisions.
The provisions mentioned below are relevant for assessing the legality of an ETS involving emissions from *international* aviation. Again, like the Chicago Convention, they are not relevant in case of coverage of purely domestic aviation.

The application of domestic laws to the navigation and operation of aircraft
Bilateral agreements confirm the provision of the Chicago Convention (Article 11) that operators of aircraft must comply with domestic regulations regarding the admission to or departure from its territory of aircraft engaged in international air navigation, or to the operation and navigation of such aircraft while within their territory[125]. Therefore, the above analysis of Article 11 of the Chicago Convention need not be repeated here.

As to *enforcement* of this provision, a state party to a bilateral air services agreement may revoke, suspend or limit the operating authorisations or technical permissions of an airline designated by the other state where that airline fails to comply with the local or domestic laws of that state (wishing to revoke or suspend the authorisation or permit)[126]. Hence, if the Community were to make its ETS applicable to non-Community air carriers, and if a non-Community air carrier did not comply with the scheme, a Member State could ultimately be entitled (as to which see the following remarks) to refuse the non-compliant airline access into its airspace (by revocation etc.)[127].

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[125] See for instance Article 5 of the US-Germany *Open Skies* agreement of 1955, as variously amended, lately in 2000:
'(1) The laws and regulations of one contracting party relating to the admission to or departure from its territory of aircraft engaged in international air navigation, or to the operation and navigation of such aircraft while within its territory, shall be applied to the aircraft utilized by the airline or airlines designated by the other contracting party, and shall be complied with by such aircraft upon entering or departing from and while within the territory of the first contracting party.
(2) The laws and regulations of one contracting party relating to the admission to or departure from its territory of passengers, crew, or cargo of aircraft, such as regulations relating to entry, clearance, immigration, passports, customs, and quarantine shall be complied with by or on behalf of such passengers, crew or cargo of the other contracting party upon entrance into or departure from, and while within the territory of the first contracting party.'

[126] See, for instance, Article 4(1)(b) and 5(1) of the bilateral air services agreement between the US and France (1997).

[127] It should be noted that in the EU ETS the sanction for failure to surrender a sufficient number of allowances is a financial penalty rather than any revocation of rights to operate.

The imposition of customs duties and charges

Traditional bilateral agreements contain clauses restricting the imposition of charges and taxes even more than the Chicago Convention. There is a tendency to remove such restrictions with respect to fuel taken on board, a tendency which is strongly promoted by the European Community. As this clause does not affect the introduction of an ETS, further discussion is not needed.

Unilateral limitation of traffic volume

Bilateral air agreements, and, in any case the Open Skies agreements concluded between the US and EC Member States, include a clause which prohibits the unilateral limitation of the volume of traffic, frequency or regularity of service or the aircraft types operated by the airlines of the other party, except as may be required by, inter alia, environmental reasons, ‘under uniform conditions consistent with Article 15 of the Chicago Convention’[128].

As outlined in Section B, the operation of an ETS would not unilaterally limit the volume of traffic, frequency or regularity of service or the aircraft types operated by the airlines of the other party. It provides only incentives to reduce emissions over time by putting a price on carbon, e.g. by operating airplanes in a more fuel-efficient way or putting more emphasis on fuel-saving engines in the future.

Fair and equal opportunity to compete

Bilateral air agreements may contain a clause dictating that each party must allow the designated airlines of both parties ‘a fair and equal opportunity to compete in the international air services’ covered by the agreement. All Open Skies agreements concluded by the US with EC Member States have such a clause. More traditional bilateral air services agreements refer to ‘a fair and equal opportunity to operate the agreed services’.

However, this is not relevant if the inclusion of aviation in the EU ETS took place in a non-discriminatory manner with respect to nationality, as already required by the Chicago Convention. As explained above, the scheme creates equal economic incentives for all airlines to reduce their emissions. For this reason, the fair and equal opportunity for airlines to compete would not be affected.

Third states might argue that trade of emission allowances affect the competitive position of their airlines, as such (third country) air carriers are on the “buyer’s” side rather than on the “seller’s“ side. Reference is made to the Heathrow arbitration case of 1992, which is one of the very few (four in total over 60 years)

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[128] See Article 8 of the agreement mentioned in the previous footnote:

‘(1) Each contracting party shall allow a fair and equal opportunity for the designated airlines of both parties to compete in the international air transportation covered by the Agreement.

(2) Each contracting party shall allow each designated airline to determine the frequency and capacity of the international air transportation it offers, based upon commercial considerations in the marketplace. Consistent with this right, neither contracting party shall unilaterally limit the volume of traffic, frequency or regularity of service, or the aircraft type or types operated by the designated airlines of the other contracting party, except as may be required for customs, technical, operational, or environmental reasons under uniform conditions consistent with Article 15 of the Convention.’

arbitration cases resulting from disagreements on the interpretation and application of bilateral provisions[129].

But such reasoning could in no way constitute an argument against the coverage of aviation by an emissions trading scheme. There is no indication that third country carriers would systematically be rather on the buyers' side than on the sellers' side. This is a question of concrete design of the scheme, in particular the allocation methods, which would need to be non-discriminatory with respect to nationality. This potential argument is therefore not relevant with respect to analysing the fundamental compliance of including aviation under the EU ETS with international law.

Summary and conclusions:

- Bilateral air services agreements do not address the issue of ETS.
- Bilateral air services agreements reflect the entitlement of the states that are parties to the agreement regarding the application of national regulations to civil aircraft operating to, from or within their national airspace, which is coupled with an enforcement provision to the effect that non-compliance with such national regulations may result in the revocation of the permission to fly in the national airspace of the revoking state.
- Clauses in bilateral agreements on the "fair and equal opportunity to compete" concern the concrete design of an emissions trading system, in particular with respect to the allocation methods, which needs to be non-discriminatory, but do not constitute a fundamental obstacle against the coverage of aviation by the EU ETS.

7.4.3 EU Law

Non-discrimination

EU law prohibits discrimination in many respects and takes the non-discrimination principle into account, with due respect for international aviation policy considerations such as the reciprocity principle. This is demonstrated, for instance, by the following:

- Regulation 785/2004 on *insurance requirements for air carriers and aircraft operators*, applying to "all aircraft operators flying within, into, out of, or over the Territory of a Member state to which the Treaty applies."[130] (which issue – insurance - does not fall under the scope of bilateral air services agreements, but which regulation makes reference to the Montreal Convention, 1999, on air carrier liability, to which the EC Member States and the Community are a party).

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[129] Most disagreements are resolved through negotiations, through which parties (states) attempt to restore the balance of interests achieved under the bilateral air services agreements, so as to protect or enhance the position of their own carriers.

[130] See Article 2(1).

- Council regulation 323/1999 on a *Code of Conduct for Computer Reservation Systems*, applying "irrespective of the status or nationality of the system vendor"[131] which is made subject to the principle of reciprocity[132].
- Directive 2002/30 on the establishment of rules and procedures with regard to *the introduction of noise related operating restrictions at Community airports*, under which Member States must take measures which are "non-discriminatory on grounds of nationality to identity of air carrier or aircraft manufacturer.",[133] under which regulation reciprocity could not be taken into account because of ICAO's multilateral involvement with noise restrictions.
- Council Regulation 95/93 on *common rules for the allocation of slots* at Community airports (as amended), mandating the slot coordinator to act in a "neutral, non-discriminatory and transparent way"[134] but, at the same time, requiring reciprocity by promoting the objective that third countries offer Community air carriers similar treatment[135].
- Proposal for a Council Directive on *airport charges* of 20 June 1997 (as amended), confirming compliance with the "principles of non-discrimination, cost-relatedness and transparency as regards airport charges."[136], which matter is also governed by multilateral rules (see Article 15 of the Chicago Convention) and ICAO based principles).

General principles of Community law

Next to the above mentioned conditions, Community law related principles must be taken into account. They include but are not limited to:

- The *prohibition of distortion of competition*, as allocation systems will - probably - be allocated on a Member State by Member State basis,[137] and related with this:
- The rules on *state aid*, as allocation systems may vary from one Member State to another.
- The strict observance of the *non-discrimination* principle, as explained above.
- The *proportionality* principle, under which the ETS must be proportional with the aim to be achieved, that is, protection of the environment.
- The principle of *free movement of* (*air*) *services* which may not be hampered by the implementation of an ETS.

7.5 Summary of main conclusions

1 The EU has a mandate under the UNFCCC and the Kyoto Protocol to implement effective climate policies, including on aviation. The EU also disposes of the necessary legal basis under the EC Treaty to cover aviation under an EU emissions trading scheme.

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131 See Articles 1(1) and 5(1), 5(2) and 5(3).
132 As to which see Article 7(1), referring to "equivalent treatment" which must be granted by a third country.
133 See Article 3(3).
134 See Article 4(3).
135 See Article 12.
136 See Article 1(1).
137 See Articles 81 and 82 of the EC Treaty, as explained in a great number of ECJ cases.

2 As an expression of the sovereignty of its Member States, the EU is entitled to introduce an emissions trading system with respect to aviation.

3 Emissions trading does not relate to the operation of aircraft. It would establish obligations relating to arrival and/or departure of aircraft within the EU territory. The regulation of these conditions needs to be in compliance with international public law and EU law.

4 The quantity of aircraft emissions, within or outside the EU, only serves as a calculation parameter for determining how many allowances the aircraft operator must surrender with the competent authorities within the EU.

5 Consequently, coverage of international aviation by an EU emissions trading scheme would not interfere with the sovereignty of other states or have any other regulatory impact on other territories outside the EU, including the high seas.

6 The provisions of the Chicago Convention, notably its Article 11, and similar provisions in bilateral agreements and EU law, require a non-discriminatory application of the scheme with respect to international flights. The possible extension of the EU ETS to international aviation within, to and from the EU is therefore feasible provided that it is applied without distinction as to nationality.

References

Arthur Andersen, 2001: Emissions trading for aviation – Workstream 3, key findings and conclusions. Report prepared for International Air Transport Association, Arthur Andersen Consulting

Babikan R., Lukachko S.P. and Waitz I.A., 2002: The historical fuel efficiency characteristics of regional aircraft from technological, operational, and cost perspectives. *Journal of Air Transport Management* **8**, 389 – 400

Baughcum, S.L., T.G. Tritz, S.C. Henderson, D.C. Pickett, 1996: Scheduled Civil Aircraft Emissions Inventories for 1992: Data base Development and Analysis. NASA Contractor report 4700, NASA Langley Research Center, US

Boeing 2003: + Freighter Reference Guide 2003. D906Q0819.R1.
http://www.tiaca.org/content/Boeing_2003_1.pdf

British Airways 2003/2004: Social and Environmental Report,
http://jaarverslag.info/home/klm/$File/KLM_AnnualReport_2003_2004_EN.pdf,
http://www.britishairways.com/cms/masterEN/content/company information/community_and_environmental/social_and_environmental report_2004.pdf

Brunner D., Staehelin J., Rogers H.L., Köhler M.O., Pyle J.A., Hauglustaine D., Jourdain L., Berntsen T.K., Gauss M., Isaksen I.S.A., Meijer E., van Velthoven P., Pitari G., Mancini E., Grewe V., and Sausen R. 2003: An evaluation of the performance of chemistry transport models by comparison with research aircraft observations. Part 1: Concepts and overall model performance. *Atmospheric Chemistry and Physics* 3, 1609–1631

Brunner D., Staehelin J., Rogers H.L., Köhler M.O., Pyle J.A., Hauglustaine D., Jourdain L., Berntsen T.K., Gauss M., Isaksen I.S.A., Meijer E., van Velthoven P., Pitari G., Mancini E., Grewe V., and Sausen R. 2005: An evaluation of the performance of chemistry transport models. Part 2: Detailed comparison with two selected campaigns. *Atmospheric Chemistry and Physics* 5, 107–129

Cames M. and Deuber O., 2004: Emissions trading in international civil aviation. Öko-Institut eV, Institute for Applied Ecology, Berlin, ISBN 3-934490-0

CE Delft, 2002, Economic incentives to mitigate greenhouse gas emissions from air transport in Europe, Feasibility study for the European Commission. http://www.ce.nl/pdf/02_4733_10_rep.pdf

Cess, R.D., G.L. Potter, J.P. Blanchet, G.J. Boer, G.-A.D. Del, M. Deque, V. Dymnikov, V. Galin, W.L. Gates, S.J. Ghan, J.T. Kiehl, A.A. Lacis, T.-H. Le, Z.X. Li, X.Z. Liang, B.J. McAvaney, V.P. Meleshko, J.F.B. Mitchell, J.J. Morcrette, D.A. Randall, L. Rikus, E. Roeckner, J.F. Royer, U. Schlese, D.A. Sheinin, A. Slingo, A.P. Sokolov, K.E. Taylor, W.M. Washington, R.T. Wetherald, I. Yagai and M.H. Zhange, 1990: Intercomparison and interpretation of climate feedback processes in 19 atmospheric general circulation models. *Journal of Geophysical Research*, **95**, 16601–16615

Cess, R.D., M.H. Zhang, W.J. Ingram, G.L. Potter, V. Alekseev, H.W. Barker, E. Cohen-Solal, R.A. Colman, D.A. Dazlich, A.D. Del Genio, M.R. Dix, V. Dymnikov, M. Esch, L.D. Fowler, J.R. Fraser, V. Galin, W.L. Gates, J.J. Hack, J.T. Kiehl, H. Le Treut, K.K.W. Lo, B.J. McAvaney, V.P. Meleshko, J.-J. Morcrette, D.A. Randall, E. Roeckner, J.-F. Royer, M.E. Schlesinger, P.V. Sporyshev, B. Timbal, E.M. Volodin, K.E. Taylor, W. Wang, and R.T. Wetherald, 1996: Cloud feedback in atmospheric general circulation models: An update. *Journal of Geophysical Research*, **101**(D8), 12,791–12,794

Carbon Trust, The, 2004: *The European Emissions Trading Scheme: Implications for Industrial Competitiveness*, available at
www.thecarbontrust.co.uk

Deidewig, F., Döpelheuer, A., Lecht, M., 1996: *Methods to Assess Aircraft Engine Emissions in Flight*, ICAS-96-4.1.2

Derwent R.G. and Friedl R., 1999: Impacts of aircraft emissions on atmospheric ozone. Chapter 2 of '*Aviation and the Global Atmosphere*' J. E. Penner, D.H. Lister, D.J. Griggs, D.J. Dokken and M. McFarland (eds). Special Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge

EASA (European Aviation Safety Agency) 2004: Safer Skies for European Citizens, http://www.easa.eu.int/home/easa_saferskies.html

European Environment Agency, Annual European Community greenhouse gas inventory 1990-2003 and inventory report 2005; Submission to the UNFCCC Secretariat, revised final version, 27 May 2005, Version 1.3

Eyers C.J., Addleton, D., Atkinson K., Broomhead M.J., Christou R., Elliff T., Falk R., Gee I., Lee D.S., Marizy C., Michot S., Middel J., Newton P., Norman P., Plohr M., Raper D. and Stanciou N. 2004: AERO2K global aviation emissions inventories for 2002 and 2025. QinetiQ/04/01113, Farnborough. Available from http://www.cate.mmu.ac.uk/reports_aero2k.asp

FESG, 1998: Report 4. Report of the Forecasting and Economic Analysis Sub-Group (FESG): Long-range scenarios. International Civil Aviation Organization Committee on Aviation Environmental Protection Steering Group Meeting, Canberra, Australia, January 1998

Fichter C., Marquart S., Sausen R. and Lee D.S., 2005: The impact of cruise altitude on contrails and related radiative forcing. *Meteorologische Zeitschrift* (accepted, under revision)

Fuglestvedt J.S., Berntsen T.K., Isaksen I.S.A., Mao H., Liang X.Z. and Wang W.C., 1999: Climatic forcing of nitrogen oxides through changes in tropospheric ozone and methane. Global 3D model studies. *Atmospheric Environment* **33**, 961–977

Fuglestvedt J.S., Berntsen T.K., Godal O., Sausen R., Shine K.P. and Skodvin T., 2003: Metrics of climate change: Assessing radiative forcing and emission indices. *Climatic Change* **58**, 267–331

Gierens K., Sausen R. and Schumann U., 1999: A diagnostic study of the global distribution of contrails part II: future air traffic scenarios. *Theoretical and Applied Climatology* **63**, 1–9

Godal O. 2003: The IPCC's assessment of multidisciplinary issues: the case of greenhouse gas indices. *Climatic Change* **58**, 243–249

Grewe V., Dameris M., Fichter C., Lee D. S., 2002: Impact of aircraft NO_x emissions. Part 2: Effects of lowering the flight altitude. *Meteorologische Zeitschrift* **11**, 197–205

Hammond A. L., Rodenburg E. and Moomaw W., 1990: Commentary in *Nature* **347**, 705–706

Hasselmann K., Sausen R., Maier-Reimer E, and Voss R., 1993: On the cold start problem in transient simulations with coupled atmosphere-ocean models. *Climate Dynamics* **9**, 53–61

Hasselmann K., Hasselmann S., Giering R., Ocana V. and von Storch H., 1997: Sensitivity study of optimal CO_2 emission paths using a Simplified Structuiral Integrated Assessment Model (SIAM). *Climatic Change* **37**, 345–386

Hansen, J., and Nazarenko L., 2004: Soot climate forcing via snow and ice albedos. *Proceedings of the National Academy of Sciences* **101**, 423–428, doi:10.1073/pnas.2237157100

Hansen J., Sato M. and Ruedy R, 1997: Radiative forcing and climate response. *Journal of Geophysical Research* **102**, 6831–6864

Hansen, J., M. Sato, R. Ruedy, L. Nazarenko, A. Lacis, G.A. Schmidt, G. Russell, and 38 other co-authors 2005: Efficacy of Climate Forcings. Submitted to *Journal of Geophysical Research*

IEA, 2004c, *CO_2 emissions from fuel combustion 1971-2002, 2004 Edition*. International Energy Agency (IEA), Paris

IATA (International Air Transport Association) 2001: Emissions Trading for aviation. Workstream 3: Key findings and conclusions. Anderson Consulting

ICCAIA, 1997: 2050 fuel efficiency and NO_x technology scenarios. ICAO/CAEP-4/Working Group 3 (emissions) fourth meeting, 12-14th November 1997, Bern, Switzerland

ICF et al., 2004, Designing a greenhouse gas emissions trading system for international aviation – final report. ICF Consulting in association with H. Somerville, Jones Day, CE-Delft. ICF Consulting, London

IPCC, 1997: An introduction to simple climate models used in the IPCC Second Assessment Report. IPCC Technical Paper II, J.T. Houghton, L. Gylvan Meira Filho, D.J. Griggs and K. Maskell (eds), Intergovernmental Panel on Climate Change, Switzerland

IPCC, 1999: Aviation and the global atmosphere - A special report of IPCC working groups I and III. Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK

IPCC, 2001: Climate Change 2001, the Scientific Basis. Summary for policymakers and technical Summary of the Working Group I Report. Cambridge University Press, UK

IPPR (Institute for Public Policy Research) 2000: Plane Trading. Policies for reducting the climate chage effects of international aviation

Joshi M., Shine K., Ponater M., Stuber N., Sausen R. and Li L., 2003: A comparison of climate response to different radiative forcings in three general circulation models: towards an improved metric of climate change. *Climate Dynamics* **20**, 843–854

Kärcher B., 1998: Physico-chemistry of aircraft-generated liquid aerosols, soot, and ice particles. 1. Model description. *Journal of Geophysical Research* **103**, 17111–17128

Kärcher B., Busen R., Petzold A., Schröder F. P., Schumann U. and Jensen E. J., 1998: Physico-chemistry of aircraft-generated liquid aerosols, soot and ice particles. 2 Comparison with observations and sensitivity studies. *Journal of Geophysical Research* **103**, 17129–17147

Keay-Bright S., 2005: Proceedings of the UK Energy Research Centre (UKERC) ‘Workable metrics for the EU emissions trading scheme seminar’. http://www.eci.ox.ac.uk/lowercf/ukerc/event2.html

KLM Royal Dutch Airlines 2003/2004: Annual Report

Lee D.S., 2003: Annex 1 to QinetiQ report QINETIQ/FST/CR030440

Lee D.S., Clare P.E., Haywood J., Kärcher B., Lunnon R. W., Pilling I., Slingo A. and Tilston J.R., 2000: Identifying the uncertainties in radiative forcing of climate from aviation contrails and aviation-induced cirrus. DERA/AS/PTD/CR000103, DERA Pyestock

Lee., D.S. and Sausen, R., 2000: New Directions: Assessing the real impact of CO_2 emissions trading by the aviation industry. *Atmos. Environ. 34*, 5337-5338.
Lim L.L., Lee D.S., Sausen R. and Ponater M., 2005: Quantifying the effects of aviation on radiative forcing and temperature with a climate response model. Manuscript in preparation for *Climatic Change*

Lister D.H., Ayeh E., BaUdoin C., Burbank J., Deidewig F., Falk R.S., Kapernaum M., Kleffman J., Kluge V., Kurtenback R., Lecht M., Metcalfe M.,
Lufthansa 2003/2004: Balance. Das Wichtigste zu Umweltschutz und Nachhaltigkeit bei Lufthansa. Daten und Fakten

Sami A., Wahl C., Wiesen P. and Zarzalis N., 1995: Sub Project 1, Engine Exhaust Emissions. In '*AERONOX The Impact of NO_x Emissions from Aircraft Upon the Atmospherei at Flight Altiudes 8 – 15 km*' U. Schuman (ed), EC-DLR Publication

Lister D.H. and Norman P.D., 2003: EC-NEPAIR: Work Package 1, aircraft engine emissions certification – a review of the development of ICAO Annex 16, Volume II. QinetiQ/FST/CR030440, QinetiQ, UK

Mannaerts, H. and M. Mulder, 2003, Emissions trading and the electricity market; Consequences of emissions trading on prices of electricity and competitiveness of basic industries. CPB Netherlands Bureau for Economic Analysis, The Hague

Mannstein H., Spichtinger P. and Gierens K., 2005, How to avoid contrail cirrus. Manuscript submitted

Marquart S. and Mayer B., 2002: Towards a reliable GCM estimation of contrail radiative forcing. *Geophysical Research Letters* **29,** 1179, doi: 10.1029/2001GL014075

Meerkötter R., Schumann U., Doelling D.R., Minnis P., Nakajima T. and Tsuchimia Y., 1999: Radiative forcing by contrails. *Annales Geophysicae* **17**, 1080–1094

Meira Filho L.G. and Miguez J. D. G., 2000 note on the time-dependent relationship between emissions of greenhouse gases and climate change. Brazilian Ministry of Science and Technology. (http://www.mct.gov.br/clima/ingles/negoc/proposta.htm)

Minnis P., Schumann U., Doelling D. R., Gierens K. and Fahey D.W., 1999: Global distribution of contrail radiative forcing. *Geophyical. Research Letters* **26,** 1853–1856

Minnis P., Ayers J.K., Palikonda R. and Phan D., 2004: Contrails, cirrus trends, and climate. *Journal of Climate* **17**, 1671–1685

Myhre G. and Stordal F., 2001: On the tradeoff of the solar and thermal infrared radiative impact of contrails, *Geophysical Research Letters* **28**, 3119–3122

Nentjes, A., P. Koutstaal, G. Klaassen, 1995, Tradable Carbon Permits: Feasibility Experiences, Bottlenecks, Dutch National Research Programme on Global Air Pollution and Climate Change (NRP), Report NO. 410 100 114, Groningen / Bilthoven

Norman P.D., Lister D.H., Lecht M., Madden P., Park K., Penanhoat O., Plasiance C. and Renger K., 2003: Development of the technical basis for a New Emissions Parameter covering the whole AIRcraft operation NEPAIR. Final Technical Report NEPAIR/WP4/WPR/01, QinetiQ, UK

NRC, 2005: Radiative forcing of climate change. Expanding the concept and addressing uncertainties. National Research Council of the National Academies, The National Academies Press, Washington, D.C.

Olivier and Peters, 2004, *International marine and aviation bunkers 1970-2002: definitions, trends, ranking of countries, corrections and comparison with other emissions.* RIVM report 728001 030

Oxera, 2003, Assessment of the financial impact on airlines of integration into the EU Greenhouse Gas Emissions Trading Scheme, Oxford, UK

Oxera, 2004, CO_2 emissions trading: how will it affect UK industry? Report prepared for The Carbon Trust Oxford, UK

PointCarbon 17 March 2005: British Airways wants aviation in EU ETS
http://www.pointcarbon.com/article.php?articleID=7269

Ponater M., Marquart S. and Sausen R. 2002: Contrails in a comprehensive global climate model: parameterization and radiative forcing results. *Journal of Geophysical Research* **107**, 10.1029/./2001JD000429

Pulles J.W. et al., 2002, Aviation emissions and Evaluation of Reduction options / AERO, Ministry of Transport, Public Works and Watermanagement, Directorate-General of Civil Aviation, The Hague, The Netherlands

Requate, T./Graichen, P. 2003: Der steinige Weg von der Theorie in die Praxis des Emissionshandels: Die EU-Richtlinie zum CO_2-Emissionshandel und ihre nationale Umsetzung. CAU Economic Working Papers No 2003-08,
http://opus.zbw-kiel.de/volltexte/2003/852/pdf/EWP-2003-08.pdf

Roeckner E., K. Arpe, L. Bengtsson, M. Christoph, M. Claussen, L. Dümenil, M. Esch, M. Giorgetta, U. Schlese, and U. Schulzweida, 1996: The atmospheric general circulation model ECHAM4: Model description and simulation of present-day climate. Max Planck Institut für Meteorologie, Report No. 218, Hamburg, Germany, 90 pp

Sausen R. and Schumann U., 2000: Estimates of the climate response to aircraft CO_2 and NO_x emissions scenarios. *Climatic Change* **44**, 27–58

Sausen, R., Fichter, C. and Amantides, G. (eds), 2004: European Conference on Aviation, Atmosphere and Climate (AAC), proceedings of an international conference, Friedrichshafen, Germany, 30th June to 3rd July, 2003. Air Pollution Research Report no. 83. Eur 21051 (see http://www.pa.op.dlr.de/aac/proceedings.html)

Sausen, R., Gierens, K., Ponater, M. and Schumann, U., 1998: A diagnostic study of the global distribution of contrails part I: Present day climate. *Theoretical and Applied Climatology* **61**, 127–141

Sausen, R., Isaksen, I., Grewe, V., Köhler, M., Lee, D.S., Myhre, G., Schumann, U., Stordal, F., and Zerefos, C., 2005: Aviation radiative forcing in 2000: an update on IPCC (1999). *Meteorologische Zeitschrift* (accepted, under revision)

Schumann, U., 1996: On conditions for contrail formation from aircraft exhausts. *Meteorologische Zeitschrift N.F.* **5**, 4–23

Schumann U., 2000: Influence of propulsion efficiency on contrail formation. *Aerospace Science and Technology* **4**, 391–401

Schumann U., Busen R. and Plohr M., 2000: Experimental test of the influence of propulsion efficiency on contrail formation. *Journal of Aircraft* **37**, 1083 – 1087

Sentance and Pulles 2001: Discussion paper on: The initial allocation of permits at the beginning of each year 'Bench marked Allocation'. CAEP 5-WG5 WP5-5/3

Shine K.P., Fuglestvedt J., Hailemariam K. and Stuber N., 2004: Alternatives to the global warming potential for comparing climate impacts of emissions of greenhouse gases. *Climatic Change* (in press)

Smith S.J. and Wigley T.M.L., 2000a: Global warming potentials: 1. Climatic implications of emissions reductions. Climatic Change 44, 445-457

Smith S.J. and Wigley T.M.L., 2000b: Global warming potentials: 2. Accuracy. Climatic Change 44, 459-469

Stevenson, D.S., R.M. Doherty, M.G. Sanderson, W.J. Collins, C.E. Johnson, and R.G. Derwent, 2004: *Radiative forcing from aircraft NO_x emissions: Mechanisms and seasonal dependence, J. Geophys. Res.*, *109*, D17307, doi:10.1029/2004JD004759

Stordal F., Myhre G., Arlander D.W., Svendby T., Stordal E.J.G., Rossow W.B. and Lee, D.S., 2005: Is there a trend in cirrus cloud cover due to aircraft traffic? *Atmospheric Chemistry and Physics.* (accepted, under revison)

Stuber N., Sausen R. and Ponater M., 2001a: Stratosphere adjusted radiative forcing calculations in a comprehensive climate model. *Theoretical and Applied Climatology* **68**, 125–135

Stuber N., Ponater M. and Sausen R., 2001b: Is the climate sensitivity to ozone perturbations enhanced by stratospheric water vapour feedback? *Geophysical Research Letters* **28**, 2887–2890

TRUCOST, 2004: Emissions trading and European aviation. TRUCOST sector report, Trucost plc, London

Wigley T.M.L. and Reeves C. (1991) *Global Warming Potentials*. A report to the Department of Environment, London

Wigley T.M.L., Richels R. and Edmonds J.A., 1996: Economic and environmental choices in the stabilization of atmospheric CO_2 concentrations. *Nature* **379**, 240–243

Zerefos, C.S., Eleftheratos, K., Balis, D.S., Zanis, P., Tselioudis, G., and Meleti, C., 2003: Evidence of impact of aviation on cirrus cloud formation. *Atmospheric Chemistry and Physics* **3**, 1633–1644

Glossary

AAU	Assigned Amount Units
AEA	Association of European Airlines
AEM	Advanced emission model, employed by EUROCONTROL
AERO	Aviation Emissions and analysis of Reduction Options: model developed by Dutch CAA
AGWP	absolute global warming potential
Allocation	Method for initial distribution of allowances among entities
Allowance	A tradable emission permit that can be used for compliance control
ANCAT	Expert Group on Abatement of Noise Caused by Air Transportation
ANCAT3	Emission model based on the EMEP/CORINAIR methodology
Annex B countries	Countries listed in annex B of the Kyoto Protocol, these countries have legally binding emission reduction obligations
Anthropogenic	caused or produced by humans
ATC/ATM	Air Traffic Control/Air Traffic Movement
Auctioning	Allocation method in which allowances are sold in an auction
BADA	Base of Aircraft Data, database developed and maintained by EUROCONTROL
Baseline	Total amount of allowances auctioned or grandfathered to aviation sector
BaU	Business as Usual, reference scenario
Benchmarked allocation	Allocation method in which allowances are allocated free of charge based on benchmarks, such as emissions per unit of output
Burden Sharing Agreement	Agreement between EU Member States redistributing the overall 8 percent reduction target for the EU under the Kyoto Protocol among EU Member States
CAEP	Committee on Aviation Environmental Protection: environmental committee of ICAO
CDM	Clean Development Mechanism
CER	Certified emission reduction unit
CFMU	Central Flow Management Unit of EUROCONTROL
CH_4	Methane
Cirrus	A type of cloud composed of ice crystals and shaped like hair like filaments. May partly be aviation induced

CNS/ATM	Communication, Navigation, Surveillance/Air Traffic Management
CO_2	carbon dioxide, the principal greenhouse gas
Contrails	The condensation trail left behind jet aircraft. Contrails form when hot humid air from jet exhaust mixes with environmental air of low vapor pressure temperature
COP	Conference of the Parties
Cruise phase	Phase of the flight above, generally, 3,000 feet. Also called the en route phase
DETR	Department of the Environment, Transport and the Regions
DLR	German Aerospace Center
Domestic flights	Flights departing from and arriving in the same country
€, EUR	Euro
€ct	Euro cent
€M	Million Euro
ECAC	European Civil Aviation Conference
Economic distortion	In this study defined as distortions in competition between European and non-European airline companies caused by the limited geographical scale of the policy options
EEA	European Economic Area
efficiency	In economic theory and in this report, the pursuit of optimum pricing based on marginal costs; cf. 'distribution' and 'fairness'
EFTA	International organization of Iceland, Norway, Switzerland, and Liechtenstein
$EINO_x$	NO_x emission index, NO_x emissions per unit fuel
Emission Index	The mass of material or number of particles emitted per burnt mass of fuel (for NO_X in g of equivalent NO_2 per kg of fuel; for hydrocarbons in g of CH_4 per kg of fuel)
Energy efficiency	Ratio of energy output of a conversion process or of a system to its energy input; also known as first-law efficiency
En-route phase	See cruise phase
Environmental cost	Financial value assigned to negative environmental effects, based either on the costs of losses or on the costs of prevention
ERLIG	Emissions Related Landing Charges Investigation Group
Eurocontrol	European Organization for the Safety of Air Navigation
ERU	Emission reduction unit
EU airspace	In this study defined on the basis of the FIR of the EU Member States
EU ETS	EU Emissions Trading Scheme

FAA	United States Federal Aviation Authority
FESG	Forecasting and Economic Support Group of CAEP/ICAO
FIR	Flight information region
Flanking instruments	Policy instruments steering on non-CO_2 effects of aviation, aimed at reducing these effects and prevention of potential negative trade-offs of a 'CO_2 only regime'
Full climate change impact	Apart from CO_2 emissions alone, aviation causes other emissions and effects such as NO_x emissions and contrails that have an impact on climate change
Fungibility	The inter-changeability of the emission reduction credits among the mechanisms
Gateway	Instrument to overcome trading problem due to lack of AAUs for international aviation. The aviation sector obtaines allocated allowances and can, as a maximum, sell as many allowances as it have already bought during the trading period from non-aviation sectors
GDP	Gross Domestic Product
Geographical scope	Refers to the geographical coverage of aviation emissions under the trading scheme, i.e. specification of the countries, routes and type of flights/aircraft to be included
GNP	Gross National Product
Grandfathering	Allocation method in which allowances are allocated for free based on historical emissions
Greenhouse gas	A gas that absorbs radiation at specific (infrared) wavelengths of the spectrum emitted by the Earth's surface and by clouds. At altitudes cooler than surface temperature, these gases emit infrared radiation. The net effect is a local trapping of part of the absorbed energy and a tendency to warm the planet's surface. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the principal greenhouse gases in the Earth's atmosphere
GTI	Global Temperature Index
GTP	Global Temperature Potential, indicates global mean temperature change as a result of emissions of a greenhouse gas
GWP	Global Warming Potential
H_2O	Water (vapour)
HC	Hydrocarbons; in this report, all hydrocarbons
IATA	International Air Transport Association
ICA	Intercontinental: aviation term
ICAO	International Civil Aviation Organization
IFR	Instrumental Flight Rules

Intra-EU	Flights departing from and arriving at an EU airport
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
kerosene	Hydrocarbon fuel for jet aircraft
km	Kilometre(s)
KP	Kyoto Protocol
Kyoto Protocol	An international treaty on global warming, amending the UNFCCC. Countries which ratify this protocol commit to reduce their emissions of greenhouse gases or engage in emissions trading if they maintain or increase emissions of these gases
LTO	Landing/Take-Off cycle
LTO-cycle	Landing/Take-Off cycle, a reference cycle for the calculation and reporting of emissions, composed of four power settings and related operating times for subsonic aircraft engines. Take-Off: 100% power / 0.7 minutes; Climb: 85% / 2.2; Approach: 30% / 4.0; Taxi / Ground Idle: 7% / 26.0
MTOW	Maximum Take-off Weight
NGO	Non government organization
nm	Nautical mile
NO_X	generic term for oxides of nitrogen (NO, NO_2, NO_3), which contribute to acid rain, eutrophication and tropospheric ozone formation and indirectly to global warming and ozone layer changes
O_3	Ozone
OPR	Overall pressure ratio
PAGODA	Datawarehouse evolution project by EUROCONTROL
Passenger-km	Passenger-kilometre, unit of passenger transport provision: one person moved one kilometre
Pax	Aviation term for 'passengers'
Payload	Weight of passengers, cargo and baggage (These may be revenue and/or non-revenue)
pkm	Passenger kilometre
Polluter pays principle	The principle that the causer of pollution should pay for removing it or provide compensation to those that have been affected by it
Pressure ratio	The ratio of the mean total pressure exiting the compressor to the mean total pressure of the inlet when the engine is developing take-off thrust rating in ISA (International Standard Atmosphere) sea level static conditions
PRISME	Pan-European Repository of Information Supporting the Management of EATM, data warehouse managed by EUROCONTROL
Pulse	A one-off emission, in contrast to a sustained emission

Radiative forcing	A change in average net radiation (in Wm^{-2}) at the top of the troposphere resulting from a change in either solar or infrared radiation due to change in atmospheric greenhouse gas concentrations; peturbance of the balance between incoming solar radiation and outgoing infrared radiation
RF	Radiative Forcing
RFI	Radiative Forcing Index
RMU	Emission removal unit
RTK	Revenue Tonne Kilometres, usually calculated as 0.1*(passenger kilometres) + (cargo tonne kilometres)
SBSTA	Subsidiary Body for Scientific and Technical Advice of the UNFCCC
SFC	Specific fuel consumption
Spec. fuel consumption	The fuel flow rate (mass per time) per thrust (force) developed by an engine
Surrendering	Handing in of allowances for emissions
Sustained	A continuous emission, in contrast to a one off pulse emission
tonne-km (tkm)	Tonne-kilometre, unit of freight transport provision: one tonne moved over one kilometre
TRADEOFF	Project into aircraft emissions and the contribution of different climate components to changes in radiative forcing, funded by the 5th framework programme of the European Commission, see www.iac.ethx.ch/tradeoff/
Trading entity	Entities obliged to surrender allowances for emissions generated
UNFCCC	United Nations Framework Convention on Climate Change
UPR	Ultra peripheral regions
VFR	Visual Flight Rules
WTO	World Trade Organization
W/m^2	Measure for energy flux
λ (lambda)	Climate sensitivity parameter indicating the relation between changes in global mean radiative forcing and global mean perturbed surface temperature

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Giving wings to Emission Trading

Inclusion of aviation under the European emission trading system (ETS): Design and impacts

Annexes

Report for the European Commission, DG Environment
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A Amendments

A.1 Necessary amendments to existing legal provisions of the EU ETS

The following section analyses, for all three policy options described in Section 4.3 (subsequently referred to as Options 1, 2 and 3), in what respects the legal provisions of the existing EU emissions trading scheme would have to be amended. More specifically, this analysis focuses on required amendments to the European Emissions Trading Directive[138], the Registry Regulation (Commission Regulation (EC) No. 2216/2004)[139] and the Monitoring and Reporting Guidelines (Commission Decision 2004/156/EC)[140]. The Linking Directive (Directive 2004/101/EC)[141] was not assessed in detail, as it can be assumed that the need for amendments is minor. To achieve consistency, some definitions and terms will require amendment throughout the legal documents. In the following section, the most important needs for amendments in the recitals of the EU ETS Directive are summarised and then specified in detail in regard to the individual articles of the Directive.

A.2 Emissions Trading Directive

In the recitals of the Emissions Trading Directive, new paragraphs should be added explaining the aim of including aviation in the emissions trading scheme. Particularly the obligation to limit or reduce emissions from aviation pursuant to Article 2.3 of the Kyoto Protocol should be explicitly mentioned.

The other key amendments to the recitals comprise the following:

– Responsibility for establishing the allowance allocation method is currently assigned to Member States, which must be amended for all three Options considered. While in Options 1 and 2 an EU body is charged only with an establishing allocation method, in Option 3 it is charged additionally with all tasks relating to the administration of emissions. This deviating administrative structure leads to a need for several amendments (paragraphs 6, 7, 8, 11, 12 and 14 of the recitals).
– If non-CO_2 climate impacts of aviation are included in the scheme (Option 1), all articles and paragraphs referring to 'greenhouse gas emissions' must be

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138 Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emissions allowance trading within the Community and amending Council Directive 96/61/EC.

139 Commission Regulation of 21 December 2004 for a standardised and secured system of registries pursuant to Directive 2003/87/EC of the European Parliament and of the Council and Decision 280/2004/EC of the European Parliament and of the Council.

140 Commission Decision of 29/01/2004 establishing guidelines fort the monitoring and reporting of greenhouse gas emissions pursuant to Directive 2003/87/EC of the European Parliament and of the Council. C(2004) 130 final.

141 Directive 2004/101/EC of the European Parliament and of the Council of 27 October 2004 amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, in respect of the Kyoto protocol's project mechanisms.

amended. This amendment is necessary as NO_X, contrails and cirrus clouds are not greenhouse gases but are either greenhouse gases precursors (NO_x reacting to methane and ozone) or clouds with greenhouse impacts (paragraphs 6 and 15 of the recitals).

- The allocation methods in Option 1 (no allocation) and Option 3 (auctioning) are markedly different from the allocation method defined in the EU ETS Directive. These deviations lead to a need for amendments in several articles throughout the Directive (e.g. paragraph 8 of recitals).
- None of the Options allows emission allowances earmarked by AAU to be allocated to aircraft operators in the five-year period beginning in 2008. Furthermore, trading of allowances between the aviation sector and the sectors covered by the EU ETS Directive is restricted, to the extent that net purchases of allowances by the aviation sector must always be at least equal to net sales of allowances from the aviation to the EU ETS sectors. As there are two parallel systems of allowances (allowances earmarked by AAU and those not earmarked thus), transfers of allowances within a gateway will involve corresponding adjustments of AAU under the Kyoto Protocol (compare also paragraph 10 of the recitals).
- In the proposed Options for including aviation in the EU ETS, the entities obliged to surrender allowances move more centre stage than in the EU ETS itself. All the Options can be characterised as operator-based approaches, while the current EU ETS scheme is installation-based. Because of this structural difference, several articles will require substantial amendment. In general, where 'installations' are addressed in the EU ETS Directive, this will have to be amended to either 'aircraft operators' or 'aircrafts operated by aircraft operators in the geographical scope of the scheme'. Which of these formulations is appropriate will be explained in the analysis below.
- Regardless of which policy option is selected, certain technical and legal aviation-specific details will have to be amended, e.g. the description of measures to be addressed by the Directive (paragraph 20 of the recitals) and the possibility of taxation as a national policy to temporarily limit emissions from installations (paragraph 24 of the recitals).

In the following sections, the required amendments to the individual articles of the Emissions Trading Directive are identified and explained.

Article 1
Subject matter is greenhouse gas emissions. If Option 1 is selected, Article 1 must be amended to '… promote reduction of greenhouse gas emissions ***and climate impacts*** in a cost-effective ….'. The same need for amendment applies to all articles referring to greenhouse gases (e.g. Article 26, Annex II).

Article 2
The scope of the trading scheme will apply to emissions from activities listed in Annex I and greenhouse gases listed in Annex II. Annex I will need to be amended for all Options considered, Annex II only for Option 1, which is designed to capture the full climate impact of aviation. Annex II could be changed

– compare also details regarding Article 1 – from ‘greenhouse gases listed in Annex II’ to ‘greenhouse gases and climate impacts listed in Annex II’.

In Annex I the categories of activities which are covered by the Directive are defined in detail. The activities are categorised by a description of the activity itself and in some cases by the threshold values referring to production capacities or outputs of the installations. For all three Options the flight activities covered by the scheme – which types of flights and in which geographical scope – must be defined in this Annex. Similar to the threshold values referring to installations in the existing scheme, de-minimis rules regarding e.g. the size or weight of the aircraft must be amended here as well.

As some of the design elements in the proposed three Options for including aviation activities in the EU ETS are new, e.g. responsibility for allocation of allowances, allocation method deviating from the existing trading scheme, it seems to make sense to categorise the activities in Annex I as follows:

- Annex I a) activities which are already listed in Annex I, and
- Annex I b) activities which are amended in Annex I: aviation activities.

With this categorisation, it is easier to refer to the activities if differentiation in other design elements is required.

Article 3
Several definitions will need to be amended or extended:

(b) In Article 3 (b) ‘emissions’ are defined as the release of greenhouse gases into the atmosphere from sources in an installation. For Option 1 this article should be amended by a broader definition of emissions (see Article 3 (c)). Furthermore – regardless of which Option is chosen – the definition of ‘installation’ requires clarification (see Article 3 (e)).

(c) The Directive refers only to greenhouse gases and –for Option 1, at least – needs to be amended with a broader definition of emissions, as the non-CO_2 climate impacts of aviation are not greenhouse gases but greenhouse impacts. It is here that this broader definition including non-CO_2 climate impacts should be added. The Directive makes frequent use of the term ‘greenhouse gas’; if Option 3 is selected, this will have to be replaced by the new definition (see Article 1).

(e) The concept of ‘installation’ is not relevant for the aviation sector. In the new situation, then, this paragraph will refer only to the stationary sources under the current EU ETS. It should perhaps be stated explicitly that this term does not refer to the aviation sector.

(f) This paragraph needs to be extended to include the exact definition of an aircraft operator. It is suggested to add a definition to the effect that ‘operator’ means any person who has continual effective disposal over an aircraft used or operated in the geographical scope of the trading scheme.

(j) Depending on the coverage of climate impacts in the trading scheme for aviation, supplementary definitions of CO_2 equivalents might be necessary. If, for example, the unit ‘global temperature potential’ (GTP) proves to be more appropriate to describe aviation climate impacts, it is in this paragraph that this concept should be defined. Furthermore, if Option 1 is adopted the multiplier for non-CO_2 climate impacts should be introduced either in this paragraph or in Annex II, to which this paragraph refers. If it is intended to adjust the multiplier for total climate impact in future years according to new scientific findings on aviation impacts in this regard, it is advantageous to define the exact value of the multiplier in a legal document that can be amended with comparatively little administrative burden, possibly in the Monitoring and Reporting Guidelines.

If one or several administrative tasks are to be carried out at the EU level (Option 3), it would be adequate to include a new paragraph defining the competent authority for stationary sources and for the aviation sector separately.

Article 6
Pursuant to this article, a greenhouse gas emissions permit may cover one or more installations on the same site operated by the same operator. For aviation, this article needs to be extended to provide a broader definition of permit coverage. Against the background that the proposed aviation scheme is operator- rather than installation-based, the permit should be granted to operators flying aircrafts in the geographical scope of the emissions trading scheme.

Article 9
In all three Options considered, allocation of allowances will be carried out at the EU level. Therefore, Article 9 in which the allocation of allowances is assigned to the Member States needs to be amended with a paragraph specifying the allocation procedure and assigning responsibility for the allocation decision for the aviation sector. Correspondingly, the differentiation of who is responsible for allocating allowances needs to be amended in all relevant articles (e.g. Articles 11, 13).

Article 10
In this article the method of allocation is defined. For the five-year period beginning 1 January 2008, Member States shall allocate at least 90% of the allowances free of charge. The allocation methods defined in Option 1 (no allocation) and Option 3 (auctioning) are not in line with the EU ETS Directive, standing in clear violation of Article 10. Thus, if one these options is selected, this article will require amendment to the effect that the allocation method is different for activities in installations (Annex I a) and aviation activities (Annex I b).

Article 11
This article defines procedures regarding allocation and issuance of allowances. Similarly to Article 9, responsibility for allocation of emission allowances needs to be amended. Contrary to establishing allocation methods, if Option 1 or 2 is adopted Member States might be assigned responsibility for the allowance issuance procedure. However, if the competent authority is defined separately for

stationary sources and the aviation sector, as suggested (see Article 3), no changes will be necessary in paragraph 4 of this article.

In the case of allowances allocated free of charge to aircraft operators (Option 2), a new paragraph should be added to this article requiring and securing equal treatment of domestic and third-country operators.

Article 12
This article (transfer, surrender and cancellation of allowances) only allows for transfers of allowances between persons in countries that are covered by the trading scheme. Each aircraft operator starting and landing in the European Union needs to provide evidence of entry permission, which in turn requires a legal representative in the European Union. Accordingly, it is guaranteed that third-country operators will have a legal representative in the European Union, who will then be obliged to surrender and may transfer allowances. In this regard, therefore, no specific amendments are necessary.

Articles 14, 15, 16, 18, 19 and 21
If the centralised administration structure of Option 3 is adopted, responsibilities for several administrative tasks will have to be amended:
- Monitoring and reporting of emissions (Article 14).
- Verification (Article 15).
- Penalties (Article 16).
- Competent authorities (Article 18).
- Registries (Article 19).

While in the current Directive the Member States bear responsibility for these administrative tasks, if Option 3 is adopted they will be fulfilled by an EU body. The extent to which Member States are still responsible for delivering ‘technical support’ to the EU body will have to be discussed and specified in these articles. Accordingly, reporting by Member States (Article 21) will have to be amended to the effect that the EU body in charge of the administrative tasks shall be responsible for the reporting obligation of Article 21 for aviation activities.

Article 19
The third paragraph of this article refers to the Registry Regulation, which defines a standardised and secured system of registries that ensures *inter alia* that there are no transfers incompatible with obligations resulting from the Kyoto Protocol. In this regard, amendments are necessary to ensure that transfers of allowances earmarked by AAU from the ETS sector and allowances not earmarked by AAU from the aviation sector are compatible with the obligations resulting from the Kyoto Protocol. However, these amendments will have to be specified in the Registry Regulation rather than in the Directive itself (see section 3.4).

A.3 Monitoring and reporting guidelines

Article 14 of the EU ETS Directive requires the Commission to elaborate guidelines for monitoring and reporting of greenhouse gas emissions under the ETS. This article also requires Member States to ensure that emissions are monitored in accordance with these guidelines, which are legally binding.

The Monitoring and Reporting Guidelines comprise one Annex with general guidelines (Annex I), one which refers to all activities listed in Annex I of the EU ETS Directive (Annex II) and nine activity-specific guidelines (Annex III-XI). While Annex I will have to be amended, the guidelines on activity-specific activities can remain unchanged. However, a new Annex XII would have to be included, specifying the monitoring procedures for the aviation industry.

The general guidelines will have to be amended on several points. In general, all definitions amended and newly incorporated in the EU ETS owing to the inclusion of aviation will need to be adopted. While the principles of monitoring and reporting can remain unchanged, the scope of the monitoring will have to be adjusted to the new activities.

Fairly substantial amendments to the guidelines on determining greenhouse gas emissions will be necessary. The monitoring methodology includes the decision between measurement and calculation as well as the selection of specific tiers for determining activity data, emission factors and oxidation or conversion factors.

Annex IV to the EU ETS Directive permits determination of emissions using either a calculated-based or measurement-based methodology. The monitoring methods proposed are thus generally in line with the existing directive. Whichever policy option is adopted, though, due provisions will have to be included to ensure that the appropriate monitoring methods can be applied (determination of emissions on the basis of actual trip fuel reported by aircraft operator under Options 1 and 2 and *ex ante* and surveillance emission data from EUROCONTROL under Option 3). A general description of the calculation and measurement methods is provided in section 4.2 of Annex I of the Monitoring and Reporting Guidelines. The emission sources regulated are divided into three categories. Depending on the emission output of the installation, different tiers of approaches are to be applied. The highest tier reflects the highest level of accuracy. Correspondingly, the monitoring methodologies and accuracy tiers will have to be adjusted in line with the requirements of monitoring the aviation's sectors climate impacts.

A.4 Registry regulation

Under the EU ETS Directive and particularly Article 19 (3) thereof, a standardised secured system of registries was established by Commission Regulation (EC) No. 2216/2004. This regulation specifies a system of registries in the form of standardised electronic databases containing common data elements to track the issue, holding, transfer and cancellation of allowances. It also defines how public access and confidentiality are to be guaranteed and how it is to be ensured that there are no transfers incompatible with obligations under the Kyoto Protocol.

Several design features of the emissions trading scheme for aviation will mean a need for amendments to the Registry Regulations.

Subject matter and definitions
The terms needed for the regulation of the registries are defined in the first chapter of the Registry Regulations. A definition of 'aviation allowances' as a new type of allowance is needed, as these were not initially earmarked by a Kyoto Unit. It seems necessary, furthermore, to introduce a new type of unit in order that differentiation with respect to other aspects can be formulated more straightforwardly.

Registries and transaction logs
According to the Registry Regulations, each registry shall be capable of executing correctly all the processes concerning allowances and Kyoto Units specified in certain Annexes. Obviously, this will have to be extended to emission allowances from the aviation sector.

Contents of the registries
In this chapter of the Registry Regulations issues on reporting and confidentiality, certain accounts, tables, codes and identifiers are described. Several amendments to this chapter will be necessary, the most important of which are the following. The holding accounts are key elements of the Registry Regulation and several different categories are defined: one for Parties, one for operators and one for persons. As it is intended that aircraft operators should also have an account, it will be necessary either to amend the existing articles concerning operator holding accounts (Article 15-18, Annex III) or add a new type of account relating to aircraft operators. These changes are required because the definition of operators in the current EU ETS Directive relates to installations (Article 3(f)) and, correspondingly, installations are mentioned in Article 15 of the Registry Regulation, while this installation-based approach is inappropriate for the aviation sector. Depending on the role of Member States regarding issue of emission allowances, the articles defining the Party account should also be checked.

To ensure correct interpretation of the information exchanged, the Registry Regulation defines several types of codes and identifiers (e.g. identification codes for units, accounts, permits, account holders, installations, etc.). In general, the amendments required here are of a technical nature. To give some examples: According to the deviating structure in an operator-based scheme, certain identifiers such as the installation identification codes might have to be omitted or defined for the case that no installation exists. In addition, the fact that the aviation allowances are not earmarked by AAU in the period from 2008 to 2012 will have to be mirrored in a separate identification code.

Transactions
The Registry Regulation comprises regulations on the allocation and issuance of allowances, on transfers and eligibility, on verified emissions, and on surrendering of allowances as well as their cancellation, retirement and replacement. Amendments are required concerning the different units and the trading restrictions between the aviation and EU ETS sector. For example, according to the regulation on allocation and issuance of allowances, the total quantity of allowances set out in the national allocation plan are issued into the Party holding account by converting an equal quantity of AAUs into allowances. Differentiation is obviously needed here, as allowances issued in the aviation sector are not earmarked by AAU.

B Appendix I [Sausen *et al*., 2005]

Table 31 Estimates of radiative forcing for 1992, 2015 and 2050 [IPCC, 1999] and for 2000 [Sausen *et al.*, 2005]

Scenario	Fuel burn (Mt yr^{-1})	NO_x emission (Mt yr^{-1})	CO_2 conc (ppmv)	CO_2	O_3	CH_4	H_2O	Contrails	Sulphate aerosols	BC aerosols	Total	RFI
NASA 1992[a]	**160.3**	**1.92**	**1.0**	**+0.018**	**+0.023**	**-0.014**	**+0.0015**	**+0.020**	**-0.003**	**+0.003**	**+0.048**	**2.7**
Low				+0.013	+0.011	-0.005	+0.000	+0.005	-0.001	+0.001		
High				+0.023	+0.046	-0.042	+0.005	+0.060	-0.009	+0.009		
NASA 2015	**324.0**	**4.34**	**2.5**	**+0.038**	**+0.040**	**-0.027**	**+0.003**	**+0.060**	**-0.006**	**+0.006**	**+0.114**	**3.0**
Fa1-2050	**471.0**	**7.15**	**6.0**	**+0.074**	**+0.060**	**-0.045**	**+0.004**	**+0.100**	**-0.009**	**+0.009**	**+0.193**	**2.6**
Low				+0.052	+0.030	-0.015	+0.000	+0.030	-0.003	+0.003		
High				+0.096	+0.120	-0.120	+0.015	+0.400	-0.027	+0.027		
Fa2-2050	487.6	5.55	6.1	+0.075	+0.047	-0.035	+0.005	+0.100	-0.009	+0.009	+0.192	
Fc1-2050	**268.2**	**4.01**	**4.9**	**+0.060**	**+0.034**	**-0.025**	**+0.003**	**+0.057**	**-0.005**	**+0.005**	**+0.129**	**2.2**
Fc2-2050	277.2	3.14	5.0	+0.061	+0.026	-0.020	+0.003	+0.057	-0.005	+0.005	+0.127	
Fe1-2050	**744.3**	**11.38**	**7.4**	**+0.091**	**+0.096**	**-0.072**	**+0.007**	**+0.158**	**-0.014**	**+0.014**	**+0.280**	**3.1**
Fe2-2050	772.1	8.82	7.6	+0.093	+0.074	-0.055	+0.007	+0.158	-0.015	+0.015	+0.277	
TRADEOFF 2000				**+0.0253**	**+0.0219**	**-0.0104**	**+0.0020**	**+0.010**	**-0.0035**	**+0.0035**	**+0.0478**	**1.9**
TRADEOFF 2000 (scaled to IPCC)				+0.0250	+0.0289	-0.0185	+0.0020	+0.0339	-0.0040	+0.0040	+0.0713	2.9

[a] Scenarios in bold were studied with atmospheric models and defined 3D emission inventories; others were scaled to these scenarios. The NASA 1992 and 2015 scenarios were scaled by 1.15 and 1.05, respectively, to account for inefficiencies in flight routing.

C Details of the linear climate response model

C.1 Model description

The modelling approach adopted was to calculate the emissions and subsequent concentrations of a climate gas, then to calculate its radiative forcing, and finally to calculate the temperature response of the forcing using a simplified climate response function. This approach was proposed by [Hasselmann *et al.*, 1993] and has subsequently been widely used, for example by [Hasselmann *et al.*, 1997], [Füssel and van Minnen, 2001] and [Sausen and Schumann, 2000]. The formulation of the model is a development of that of [Sausen and Schumann, 2000]; for clarity the approach is described in detail below.

The climate response function approach can be represented by a convolution integral, use of which assumes that small perturbations to a system (here, climate) can be represented in a linearly additive manner. Thus, the response of a climate variable Φ at time (*t*) to a forcing *F*(*t*) is:

$$\Phi(t) = \int_{t_0}^{t} G_\Phi(t-t')F(t')dt' \quad [1]$$

where $G_\Phi(t)$ is the impulse or Green function, e.g. [Livesley, 1989], which describes the response of the system to a change in forcing at t=0. The forcing *F*(*t'*) and $\Phi(t)$ are perturbations relative to an equilibrium (climate) state.

The changes in global mean surface temperature ΔT and sea level Δh can be calculated by approximating results from a coupled ocean-atmosphere simulation of IPCC scenario IS92a [Cubasch *et al.*, 1992], as derived by [Hasselmann *et al.*, 1993; 1997]:

$$\Delta T(t) = \int_{t_0}^{t} G_T(t-t')RF^*(t')dt' \quad [2]$$

$$\Delta h(t) = \int_{t_0}^{t} G_h(t-t')RF^*(t')dt' \quad [3]$$

where

$$G_T(t) = \alpha_T e^{-t/\tau_T} \quad [4]$$

$$G_h(t) = \alpha_T e^{-t/\tau h} \quad [5]$$

using the parameters given in Table 32.

Table 32 Coefficients of the impulse response functions G_T and G_h for changes in global mean surface temperature ΔT and sea level change Δh, respectively [Sausen and Schumann, 2000]

i	*T*	*h*
α_i	(2.246/36.8) K/yr	(50/99) cm/yr
τ_i	36.8 yr	99.0 yr

The above equation [2] has been modified in order to represent specific values of λ, the climate sensitivity parameter. Previously, the climate sensitivity (equilibrium temperature response to a doubling of CO_2 concentration) was inherently present in G_T; it is now necessary to rearrange the equations in order to separate this out, so that λ can be made more specific to the parent model and can be modified to take account of specific species. In equation [2], G_T *(t)* for CO_2 can be represented as:

$$G_T(t) = \alpha_T e^{-t/\tau_T} = \frac{\Delta T_{2\times CO_2}}{\tau_T} \times e^{-t/\tau_T} \quad [6]$$

where α_T is (2.246/36.8) K/yr, i.e. the temperature response to a doubling of CO_2 in the ECHAM model which accounts for the thermal inertia of the upper ocean levels.

The normalised radiative forcing for CO_2 was previously expressed as:

$$RF^*_{CO_2}(t) = \frac{\ln(C(t)/C_0)}{\ln 2} \quad [7]$$

The *actual* RF_{CO2} for a doubling of CO_2 concentration is 1, thus:

$$RF_{CO_2}(t) = \frac{RF^*_{CO_2}(t)}{RF^*_{CO_2}(1992)} \times RF_{CO_2}(1992) \quad [8]$$

where in [Sausen and Schumann, 2000)], RF_{CO2} (1992) = 1.56 W m^{-2}. However, we now use the IPCC Third Assessment Report value of 1.46 W m^{-2} for 2000 (IPCC, 2001) so that:

$$RF^*_{CO_2}(t) = \frac{RF^*_{CO_2}(2000)}{RF_{CO_2}(2000)} \times RF_{CO_2}(t) \quad [9]$$

$$\Delta T_{2\times CO_2} = \lambda \times RF(2 \times \mathrm{CO_2}) \quad [10]$$

where:

$$RF_{CO_2}(2 \times \mathrm{CO_2}) = \frac{RF_{CO_2}(2000)}{RF^*_{CO_2}(2000)} \quad [11]$$

The revised linear response equation becomes:

$$\Delta T(t) = \beta \int_{t_0}^{t} \hat{G}_T(t-t')RF(t')dt' \quad [12]$$

with the revised Green's function becoming:

$$\hat{G}_T(t) = \frac{1}{\tau} e^{-t/\tau_T} \quad [13]$$

where τ is the coefficient of the impulse response function and β is:

$$\beta = \Delta T(2 \times \mathrm{CO_2}) \times \frac{RF^*_{CO_2}(2000)}{RF_{CO_2}(2000)} = \lambda \quad [14]$$

i.e. [14] is equal to λ, the climate sensitivity (K[W m^{-2}]) remembering that RF* is the normalised forcing and thus dimensionless.

We now use the generalised formula:

$$\Delta T(t) = r * \lambda \int_{t_0}^{t} \hat{G}_T(t-t')RF(t')dt' \quad [15]$$

The value of λ is generally consistent within GCMs for the long-lived climate gases but has been found to vary for some specific effects. Thus, we incorporate λ and a species or effect-specific modifier, *r** which is defined as:

$$r^* = \frac{\lambda_{species}}{\lambda_{CO_2}} \qquad [16]$$

The values for λ and *r**, and their derivation are given in Table 33.

Table 33 Values for λ (CO_2), λ (specific), and r* for and potential ranges

Species	GCM parent model	Reference	λ (CO_2)	λ (specific)	*r** (range)
CO_2	ECHAM3	Sausen & Schumann, 2000	0.497	0.497	1
Aviation O_3	ECHAM3	Sausen & Schumann, 2000	0.497		2.897
CO_2	ECHAM4/T30.L19		0.81		1
Aviation O_3	ECHAM4/T30.L19		0.81		1.2 (1 – 2)
O_3(trop.) background	ECHAM4/T30.L19		0.81	0.81	1
CH_4	ECHAM4/T30.L19	Berntsen et al., 2005	0.81		1.1 (1 – 1.2)
Contrails	ECHAM4/T30.L39	Marquart et al., 2003	0.73	0.43	0.59 (1 – 0.59)
Sulphate	ECHAM4/T30.L19		0.81		1
BC/soot	ECHAM4/T30.L19		0.81		1

Having outlined the overall approach of calculating the climate response to a forcing agent, individual forcing gases and effects are now considered.

Modelling CO_2 climate response

As the radiative forcing of CO_2 is dependent on its own concentration, to calculate the impacts of CO_2 from aviation it is necessary to know the background. [Sausen and Schumann, 2000] used concentration data (ppm) dating back to 1800 based on IPCC scenario IS92a, from ECHAM GCM simulations. In addition, other background data are available from other scenarios using the MAGICC model, which is another simplified climate model extensively used in IPCC projections.

The contribution of aviation CO_2 is calculated explicitly, being assumed to be the difference of total 'background' emissions the calculated aviation contribution to concentrations as follows. The response of CO_2 concentrations, *C*(*t*), to a CO_2 emissions rate, *E*(*t*), is modelled as per [Hasselmann *et al.*, 1997], which approximates to the results of the carbon cycle model of Meier-Reimer and Hasselmann (1987), so that:

$$\Delta C(t) = \int_{t_0}^{t} G_C(t-t')E(t')dt' \qquad [17]$$

and:

$$G_C(t) = \sum_{j=0}^{5} \alpha_j e^{-t/\tau_j} \qquad [18]$$

where τ_j is the e-folding time of mode *j* and the equilibrium response of mode *j* to a unit forcing is $\alpha_j\tau_j$, using the mode parameters given in Table 34.

Table 34 Coefficients of the impulse function G_C for CO_2 concentration (Sausen and Schumann, 2000)

J	1	2	3	4	5
α_j [ppbv/Tg(C)]	0.067	0.1135	0.152	0.097	0.041
τ_j [yr]	∞	313.8	79.8	18.8	1.7

Emissions of aviation CO_2 are available for particular years only (e.g. 1992, 2015, 2050 – various scenarios), and in order to calculate the full contribution to concentrations, radiative forcing and temperature response, historical emissions and extrapolation to 2100 were taken from [Sausen and Schumann, 2000]. These are summarised in Table 34.

In order to calculate the resultant sea level rise and change in global mean temperatures, a 'normalised' radiative forcing is calculated. According to [IPCC, 1992], the radiative forcing of CO_2 can be estimated from the logarithm of the concentration, which approximates the effect of saturation in radiative forcing with increased CO_2 concentrations. [Sausen and Schumann, 2000], following [Hasselmann *et al*., 1993] calculated a normalised radiative forcing (*RF**) to RF=1 for a doubling in CO_2 concentration is using the formula:

$$RF^*(t) = \frac{\ln(C_{(t)}/C_{(0)})}{\ln 2} \quad [19]$$

where C_0 is the observed pre-industrial CO_2 concentration for 1800. Here, we use the more recent expression from [Ramaswamy *et al*., 2001] which uses an updated α coefficient of 5.35 from [Myhre *et al*., 1998]:

$$RF(t) = \alpha\left[\ln(C_{(t)}/C_{(0)})\right] \quad [20]$$

Actual radiative forcing can then be calculated at any particular time, in this case 1992, by means of:

$$RF(t) = \frac{RF^*(t)}{RF^*(1992)} \times 1.56 \quad [21]$$

where 1.56 W m^{-2} is the calculated radiative forcing from 1800 to 1992 due to CO_2 [IPCC, 1995].

Modelling methane concentrations and radiative forcing

Historical methane concentrations for the period 1765 to 2000 were obtained from the MAGICC model (version 4.1) and correspond to those published in Table II.2.2 of the IPCC Third Assessment Report [IPCC, 2001]. After 2000, CH_4 concentrations were determined using a standard global-mean, mass-balance equation [Wigley *et al*., 2002]:

$$\frac{dC}{dt} = \frac{E}{\beta} - C\left(\frac{1}{\tau_{OH}} + \frac{1}{\tau_{strat}} + \frac{1}{\tau_{soil}}\right) \quad [22]$$

where: C = global mean tropospheric CH_4 concentration (ppbv)
E = CH_4 emissions from natural and anthropogenic sources (Tg/yr)
β = factor for converting mass emissions to concentrations (Tg/ppbv)
and τ_{OH} = tropospheric sink (yr)
τ_{strat} = stratospheric sink (yr)
τ_{soil} = soil sink (yr)

The solution to the differential equation in [22] (assuming that E/β and $\left(1/\tau_{OH} + 1/\tau_{strat} + 1/\tau_{soil}\right)$ are constant during the time step) [Fuglestvedt and Berntsen, 1999] is:

$$C_t = \frac{E}{\beta Q} + \left(C_{t-1} - \frac{E}{\beta Q}\right)e^{-Q\Delta t} \qquad [23]$$

where: C_t = CH_4 concentration at time t (ppbv)
C_{t-1} = CH_4 concentration at time $t-1$ (ppbv)
β = 2.78 Tg/ppbv
Q = $\left(\frac{1}{\tau_{OH}} + \frac{1}{\tau_{strat}} + \frac{1}{\tau_{soil}}\right)$ = $\left(\frac{1}{9.6} + \frac{1}{120} + \frac{1}{160}\right)$
Δt = 1 year for CH_4

However, equation 22 does not account for the effect of CH_4 concentrations on CH_4 lifetime, whereby tropospheric lifetime, τ_{OH}, varies with CH_4 abundance and reactive gas emissions, parameterised by [Wigley *et al.*, 2002] as:

$$\delta \ln(\tau_{OH})_t = -0.32\delta \ln(C)_{t-1} + 0.0042\delta(e - NO_X)_t - 0.000105\delta(e - CO)_t - 0.000315\delta(e - VOC)_t \qquad [24]$$

where: $(\tau_{OH})_t$ = tropospheric sink at time t (yr)
$(e\text{-}NO_X)_t$ = anthropogenic NO_X emissions at time t (Tg(N)/yr)
$(e\text{-}CO)_t$ = anthropogenic CO emissions at time t (Tg/yr)
$(e\text{-}VOC)_t$ = anthropogenic VOC emissions at time t (Tg/yr)

All changes in lifetime, concentration and emissions are relative to the year 2000. It was also assumed that the natural emissions of CH_4, NO_X, CO and VOC remain constant such that the SRES scenarios describe all changes in emissions [Wigley *et al.*, 2002]. SRES data are taken from MAGICC v4.1.

A simplified approach was taken to calculate the effect of aircraft NO_x emissions on the CH_4 destruction rate by using data from IPCC (1999). A linearised destruction rate of 1.82% in 1992, 3.64% in 2015 and 5.46% in 2050, as in scenario Fa1, was used to reduce total CH_4 concentrations [IPCC, 1999, Section 6.3.4, p. 203].

Having calculated the background CH_4 concentrations and the aviation fraction of CH_4 destruction, the radiative forcing due to CH_4 was calculated from the expression given by [IPCC, 2001]:

$$RF_{CH_4} = \alpha\left(\sqrt{C_{(t)}} - \sqrt{C_0}\right) - \left(f(C_t, N_0) - f(C_0, N_0)\right) \qquad [25]$$

where: α = 0.036

C_t = CH_4 concentration at time *t* (ppbv)

C_0 = pre-industrial CH_4 concentration (700 ppbv)

N_0 = pre-industrial N_2O concentration (280 ppbv)

f(C,N) = correction for overlap with N_2O

and:

$$f(C,N) = 0.47\ln\left(1 + 2.01\times10^{-5}(C\cdot N)^{0.75} + 5.31\times10^{-15}C(C\cdot N)^{1.52}\right) \quad [26]$$

Thus, similarly to CO_2, the CH_4 radiative forcing was calculated from:

$$RF_{CH_4aviation} = RF_{CH_4total} - (RF_{CH_4total} - RF_{CH_4aviation}) \quad [27]$$

Modelling ozone radiative forcing and the contribution of aviation

Background tropospheric O_3 radiative forcing was calculated using the simplified methodology given by the [IPCC, 2001], which uses O_3 column data (Dobson Units). It was assumed that the pre-industrial O_3 column was 25 DU and a time series of radiative forcing was constructed from interpolation of 5-yearly data given by [IPCC, 2001], reproduced in Table 35.

Table 35 Ozone radiative forcing (5-year averages) from 1961 to 1995 [IPCC, 2001]

Time period	RF (W/m^2)
1961-1965	0.17
1966-1970	0.20
1971-1975	0.22
1976-1980	0.25
1981-1985	0.28
1986-1990	0.31
1991-1995	0.34

Following [IPCC, 2001], it was assumed that in 2000 the O_3 column was 34 DU and the resultant radiative forcing 0.38 W m^{-2} and that the mean forcing per DU was 0.042 Wm^{-2}/DU.

The effective O_3 column (post-1999) was determined using [IPCC, 2001]:

$$\delta(effective\ O_3)_t = +6.7\delta\ln(CH_4)_{t-1} + 0.17\delta(e-NO_X)_t + 0.0014\delta(e-CO)_t + 0.0042\delta(e-VOC)_t \quad [28]$$

where: $(effective\ O_3)_t$ = effective O_3 at time t (DU)

$(e\text{-}NO_X)_t$ = anthropogenic NO_X emissions at time t (Tg(N)/yr)

$(e\text{-}CO)_t$ = anthropogenic CO emissions at time t (Tg/yr)

$(e\text{-}VOC)_t$ = anthropogenic VOC emissions at time t (Tg/yr)

All changes in concentration and emissions are relative to the year 2000. It was also assumed that natural emissions of CH_4, NO_X, CO and VOC remain constant. The SRES scenarios therefore describe all changes in emissions [IPCC, 2001]. Total O_3 is therefore:

$$(Total\ O_3)_t = (O_3)_{2000} + \delta(effective\ O_3)_t \quad [29]$$

where: $(Total\ O_3)_t$ = total O_3 at time t (DU)

$(O_3)_{2000}$ = O_3 at year 2000, i.e. 34 DU [IPCC, 2001]

The mean forcing per DU is 0.042 W m^{-2}/DU. Therefore:

$$\left(RF_{O_3}\right)_t = 0.042 \times \delta(effective\,O_3) + \left(RF_{O_3}\right)_{2000} \quad [30]$$

where: $(RF_{O3})_t$ = RF O_3 at time t (W m^{-2})

$(RF_{O3})_{2000}$ = RF O_3 at year 2000, i.e. 0.38 (W m^{-2})

The resultant radiative forcing of tropospheric O_3 can then be used to calculate the climate response from [8].

The aviation O_3 RF was determined similarly to [Sausen and Schumann, 2000], assuming a linear relationship between aviation NO_x emissions and O_3 concentration change (e.g. [Grewe *et al*., 1999; Rogers *et al*., 2001]). Although this holds on a global scale, the relationship differs on regional scales [Rogers *et al*., 2001]. It was assumed, furthermore, that O_3 concentration and radiative forcing scale linearly according to:

$$Aviation\ RF_{O_3}(t) = Aviation\ RF_{O_3}(1992) \times \frac{EI_{NO_X}(t)}{EI_{NO_X}(1992)} \times \frac{E_a(t)}{E_a(1992)} \quad [31]$$

where: aviation $RFO_3(t)$ = aviation RF O_3 at time t (W m^{-2})

aviation RF_{O_3} (1992) = RF O_3 at year 1992 (W m^{-2})

EI_{NOx} = emission index of nitrogen oxides per mass of fuel burnt

E_a = aircraft fuel emissions rate per year

The above was scaled to a particular externally-calculated radiative forcing for aviation O_3, e.g. 0.023 W m^{-2} (1992), or a more recent result such as 0.022 W m^{-2} (2000) [Sausen *et al*., 2005]. Since the generalised temperature response equation [8] now includes λ and *r** explicitly, a correction ratio for [24] as employed by [Sausen and Schumann, 2000] that accounts for O_3 sensitivity to altitude, normalised by a climate response temperature, is no longer necessary.

Modelling radiative forcing from contrails

Similarly to aviation-induced O_3, a simplified linear approach was taken, normalised to an externally-calculated radiative forcing response in a particular year. The methodology of [Sausen *et al*., 1998] assumed that contrail coverage scales with fuel usage: and the same has been assumed here, but with introduction of an additional factor, *F*, to account for larger, persistent contrails.

Thus, contrail radiative forcing can be determined from:

$$RF_{contrail} = F \times \frac{E_a(t)}{E_a(1992)} \times RF_{contrail}(1992) \quad [32]$$

where: $RF_{contrail}(t)$ = contrail radiative forcing at time t (W/m^2)

F = additional factor to account for larger, persistent contrails (available as a table, scaled to the results in Tables 6.1 and 6.2, pp. 194-195, of [IPCC, 1999])

E_a = aircraft fuel emissions rate

$RF_{contrail}(1992)$ = contrail radiative forcing at time 1992

Values of $RF_{contrail}$ are available, e.g. 0.02 W m^{-2} (1992), [IPCC, 1999]; 0.0035 W m^{-2} (1992) [Marquart *et al*., 2003a]; 0.010 W m^{-2} (2000), [Sausen *et al*., 2005].

Modelling RF from sulphate and soot particles
Total background concentrations of both sulphate and soot (or black carbon, BC) were modelled, along with the contribution of aviation. The total background particle concentration was scaled to emissions for tghe year 2000 [IPCC, 2001]:

$$C(t) = \frac{E(t)}{E(2000)} \times C(2000) \quad [33]$$

where: *C(t)* = concentration at time *t* (Tg)
E(t) = emissions at time *t* (Tg/yr)
E(2000) = emissions at 2000 (69.0 TgS/yr for SO_2 and 12.4 Tg/yr for BC)
C(2000) = concentration at 2000 (0.52 Tg SO_4 and 0.26 Tg for BC)

Total radiative forcing due to particles was scaled to concentrations for the year 2000 [IPCC, 2001]:

$$RF(t) = \frac{C(t)}{C(2000)} \times RF(2000) \quad [34]$$

where: *RF(t)* = RF at time *t* (W/m^2)
RF(2000) = RF at 2000 (-0.40 W/m^2 for SO_4 and 0.4 W/m^2 for BC)

In the next step, the contribution of aviation was calculated according to the aviation fuel burned, using existing CO_2 emissions data (with a carbon mass fraction of 0.86) [Sausen and Schumann, 2000]. Aviation SO_4 particle emissions were derived from the sulphur content of fuel:

$$E_{SO_4}(t) = \text{Total Fuel} \times EI_{Sulphur} \times \beta \times 0.001 \quad [35]$$

where: $E_{SO4}(t)$ = SO_4 aviation emissions at time *t* (TgS)
$EI_{Sulphur}$ = emission index, 0.4 g/kg fuel [IPCC, 1999]
β = effective conversion factor from fuel sulphur to optically active sulphate, 50% [IPCC, 1999]

Aviation soot emissions were derived from:

$$E_{Soot}(t) = \text{Total Fuel} \times EI_{Soot} \times 0.001 \quad [36]$$

where: $E_{Soot}(t)$ = soot aviation emissions at time *t* (Tg)
EI_{Soot} = emission index, 0.04 g/kg fuel [IPCC, 1999]

The radiative forcing due to aviation sulphate and BC was then scaled to aviation emissions for the year 1992 [IPCC, 2001]:

$$RF_{SO_4,BC}(t) = \frac{E_{SO_4,BC}(t)}{E_{SO_4,BC}(1992)} \times RF_{SO_4,BC}(1992) \quad [37]$$

where: $RF_{SO_4,BC}(t)$ = aviation RF at time *t* (W/m^2)
$E_{SO_4,BC}$ *(1992)* = aviation emissions at 1992 [IPCC, 1999]
(0.03 Tg S/yr for SO_4 and 0.006 Tg/yr for soot)
$RF_{SO_4,BC}(1992)$ = aviation RF at time 1992 [IPCC, 1999]

The radiative forcing for SO_4 and BC can be taken from e.g. [IPCC, 1999], i.e. -0.003 W m^{-2} for SO_4 and 0.003 W m^{-2} for BC.

C.2 References

Cubasch U., Hasslemann K., Höck H., Meier-Reimer E., Mikolajewicz U., Santer B. D. and Sausen R., 1992, Time-dependent greenhouse warming computations with a coupled ocean-atmosphere model. *Climate Dynamics* **8**, 55–69.

FESG, 1998, Report 4. Report of the Forecasting and Economic Analysis Sub-Group (FESG): Long-range scenarios. International Civil Aviation Organization Committee on Aviation Environmental Protection Steering Group Meeting, Canberra, Australia, January 1998.

Forster P.M.D. and Shine K.P., 1997, Radiative forcing and temperature trends from stratospheric ozone changes. *Journal of Geophysical Research* **102**, 10841–10855.

Füssel H.-M. and van Minnen J.G., 2001, Climate impact response functions for terrestrial ecosystems. *Integrated Assessment* **2**, 183–197.

Fuglestvedt J.S., Berntsen T.K., Godal O., Sausen R., Shine K.P. and Skodvin T., 2003, Metrics of climate change: assessing radiative forcing and emission indices. *Climatic Change* 58, 267–331.

Grewe V., Dameris M., Hein R., Koehler I and Sausen R., 1999, Impact of future subsonic aircraft NO_x emissions on the atmospheric composition. *Geophysical Research Letters* **26**, 47–50.

Grooß J.-U., Brühl C. and Peter T., 1998, Impact of aircraft NO_x emissions on tropospheric and stratospheric ozone. Part I: Chemistry and 2-D model results. *Atmospheric Environment* **32**, 3173–3184.

Hansen J.E., Sato M. and Ruedy R., 1997, Radiative forcing and climate response. *Journal of Geophysical Research* **102**, 6831–6684.

Hasselmann K., Sausen R., Maier-Reimer E and Voss R (1993) On the cold start problem in transient simulations with coupled atmosphere-ocean models. *Climate Dynamics* **9**, 53–61.

Hasselmann K., Hasselmann S., Giering R., Ocana V. and von Storch H., 1997, Sensitivity study of optimal CO_2 emission paths using a Simplified Structuiral Integrated Assessment Model (SIAM). *Climatic Change* **37**, 345–386.

Livesey R.K., 1989, *Mathematical Methods for Engineers*. Ellis Horwood Limited, Chichester, UK.

Meier-Reimer E. and Hasselmann K., 1987, Transport and storage of CO_2 in the ocean – an inorganic ocean-circulation carbon cycle model. *Climate Dynamics* **2**, 63–90.

Prather M. and Sausen R., 1999, Chapter 6 — Potential climate change from aviation. In '*Aviation and the Global Atmosphere'*. A Special Report of IPCC Working Groups I and III in collaboration with the Scientific Assessment panel to the Montreal Protocol on Substances that Deplete the Ozone Layer, J.E. Penner, D.H. Lister, D.J. Griggs, D.J. Dokken and M. McFarland (eds). Intergovernmental Panel on Climate Change, Cambridge University Press, UK.

Rogers H.L., Lee D.S., Raper D.W., de Forster P.M., Wilson C.W. and Newton P.J., 2002, The impacts of aviation on the atmosphere. *The Aeronautical Journal* (in press).

Sausen R. and Schumann U., 2000, Estimates of the climate response to aircraft CO_2 and NO_x emissions scenarios. *Climatic Change* **44**, 27–58.

ICCAIA, 1997, 2050 fuel efficiency and NO_x technology scenarios. ICAO/CAEP-4/Working Group 3 (emissions) fourth meeting, 12-14th November 1997, Bern, Switzerland.

ICCAIA, 2000, Summary of aircraft and engine short-to-medium term technology status fo CAEP/5. ICAO/CAEP/WG3 (emissions – technical) meeting, 15-16th June 2000, Cleveland, Ohio.

IPCC, 1992, Climate Change 1992 – the Supplementary Report to the IPCC Scientific Assessment. J.T. Houghton, B.A. Callander and S. K. Varney (eds), Cambridge University Press, UK.

IPCC, 1995, Climate Change 1995, the Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change. J.T. Houghton, L.G. Meira Filho, Callander, E. Haites, N. Harris, A. Kattenberg and K. Maskell. (eds), Cambridge University Press, UK.

IPCC, 1997, An introduction to simple climate models used in the IPCC Second Assessment Report. IPCC Technical Paper II, J.T. Houghton, L. Gylvan Meira Filho, D.J. Griggs and K. Maskell (eds), Intergovernmental Panel on Climate Change, Switzerland.

IPCC, 1999, *Aviation and the Global Atmosphere*. A Special Report of IPCC Working Groups I and III in collaboration with the Scientific Assessment panel to the Montreal Protocol on Substances that Deplete the Ozone Layer, J.E. Penner, D.H. Lister, D.J. Griggs, D.J. Dokken and M. McFarland (eds). Intergovernmental Panel on Climate Change, Cambridge University Press, UK.

IPCC, 2000, *Emission Scenarios*. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change. Cambridge University Press, UK.

IPCC (2001) Climate Change 2001, the Scientific Basis. Cambridge University Press, UK.

Johnson C.E., 1993, Modelling the growth of methane. AEA/CS/18358017/001/1, AEA Technology, Harwell.

McGuffie K. and Hendersen-Sellers A., 1997, *A Climate Modelling Primer*. John Wiley & Sons, Chichester, UK.

Ponater M., Sausen R., Feneberg B. and Roeckner E., 1999, Climate effect of ozone changes caused by present and future air traffic. *Climate Dynamics* **15**, 631–642.

Shine K.P. and Forster P.M. de F., 1999, The effect of human activity on radiative forcing of climate change: a review of recent developments. *Global and Planetary Change* **20**, 205–225.

Wigley T.M.L., 2000, Updated version of, and results from, the simple climate model MAGICC. Background paper prepared for the IPCC Third Assessment Report, National Center for Atmospheric Research, Boulder, Colorado.

D Global temperature index for aviation – a new metric

Derivation of a Global Temperature Index for sustained emissions (GTI_s) is an extension of the concept of GTP_s of [Shine *et al*., 2005] and was outlined in Section 2.3 and 2.4 of the main report. Using the model of [Lim *et al*., 2005], RFs were calculated over time for background CO_2, aviation CO_2, background CH_4, aviation CH_4 (reduction), aviation O_3, aviation soot and sulphate particles and contrails. Using these RFs, it is then possible to calculate the temperature response via the simple impulse response function model of [Hasselman *et al*., 1993; 1997], assuming that other forcings produce a similar climate response to that of CO_2 [Sausen and Schumann, 2000]. This is set out in more detail in Annex C.

In calculating a GTI_s, the same basic approach as [Shine *et al*., 2005] was taken, with a sustained emission being considered. As an illustration, the case of constant aviation emissions after 2000 has been considered against a background of IS92a CO_2 emissions/concentrations (other scenarios are available to the model) up until 2100.

From this constant 2000 case (C2000), the aviation emissions were arbitrarily incremented at 2000 (but as a constant) by 10%, 20% and 30%. The purpose of this was to determine whether a robust and understandable relationship between CO_2 emission and temperature response of CO_2 and non-CO_2 effects could be observed over a time frame of 100 years. The choice of 100 years was also arbitrary, much as was the case for the choice of 100 years for GWPs.

A number of simulations were run, as follows:
1 C2000 (and increments), tuned to TRADEOFF [Sausen *et al*., 2005] RFs in 2000, with **fixed** climate sensitivity (hereafter C2000-T-fixed).
2 C2000 (and increments), tuned to TRADEOFF [Sausen *et al*., 2005] RFs in 2000, with **variable** climate sensitivity (hereafter C2000-T-variable).

'Fixed' and 'variable' climate sensitivity refer to the use of climate sensitivity parameters (see Section 2.3) and efficacies particular to GCMs and effects (see Annex C for details). The value of λ (for CO_2) is taken from the parent GCM, ECHAM4 [Roeckner *et al*., 2004] and values of λ_i are taken from evaluations of particular effects (see Annex C for details), allowing calculation of *r**, or efficacy, where:

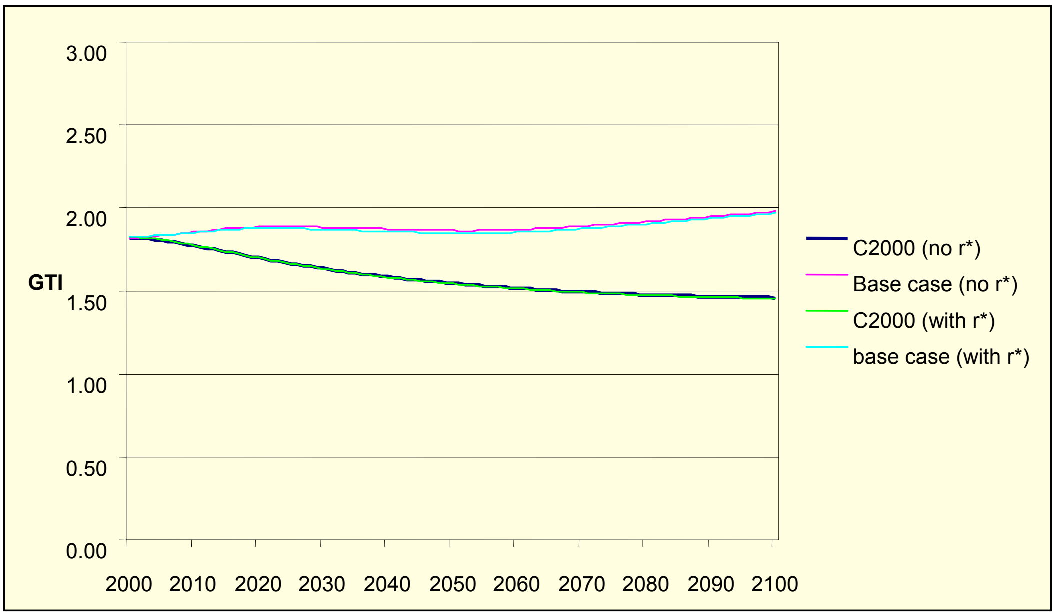
$$r^* = \frac{\lambda_i}{\lambda_{CO_2}} \quad [2]$$

Values of *r** are rather uncertain, which is why C2000-T-fixed was also calculated, providing a rather more conservative but less uncertain evaluation.

The temperature effects are not given as relationships between an individual species'/effect's temperature and CO_2 emissions, but rather as ratios. As outlined in Section 2.3 and 2.4 values of λ are model-dependent and rather variable: taking the ratios of the temperature responses of different species/effects makes the result less model-dependent and removes some of the uncertainties.

A GTI_s analogous to RFI, i.e. the sum of the temperatures/CO_2-only temperature perturbation, has been calculated for C2000-T-fixed and C2000-T-variable and is shown in Figure 16. Also shown are GTI for the base cases (i.e. a 'normal' aviation Fa1 scenario).

Figure 16 GTI_s for C2000-T-fixed (dark blue line) and C2000-T-variable (green line): also shown are GTI_{scen} for Fa1, fixed climate sensitivity (i.e. 'Base case, no r*', pink line) and variable climate sensitivity ('base case with r*' light blue line) calculated using model of [Lim *et al.*, 2005]. Note that the oscillation in GTI_{scen} is an artefact of the interpolation of CO_2 emissions



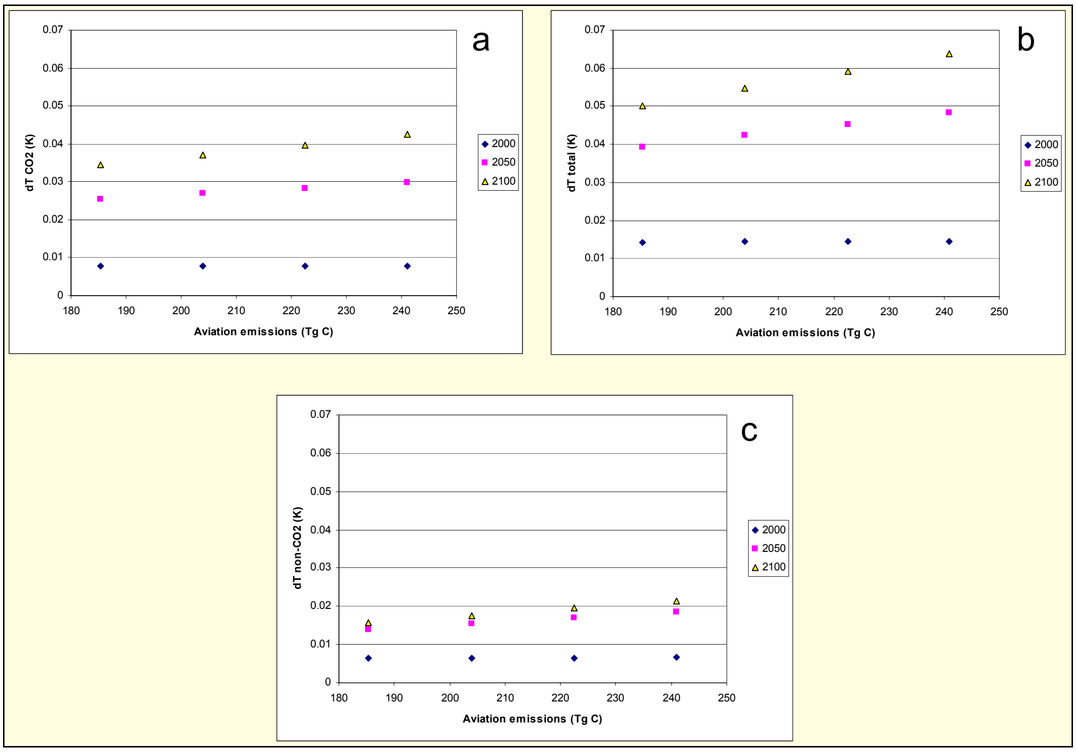
From Figure 16 it can be seen that there is little difference between C2000-T-fixed and C2000-T-variable, as the efficacies (*r**) tend to cancel. The calculations are, of course, very sensitive to the values of these efficacies and these are rather uncertain. However, C2000-T-fixed provides a conservative estimate, as noted above. The values tend to stabilise over time to a value of approximately 1.5. Thus, over the 100 year time frame for **constant** emissions, non-CO_2 effects are approximately 30% of the total temperature effect, with CO_2 accounting for 70%. These proportions will clearly be different if a real emission scenario is considered.

The next step is to determine whether a relationship can be derived between the temperature effects of aviation CO_2 emissions and CO_2 and non-CO_2 effect temperature increases. To this end, the aviation CO_2 emissions of the C2000-T-fixed and C2000-T-variable scenarios were incremented at 2000 by 10%, 20% and 30%. This can only be investigated on the basis of absolute temperature

changes, rather than ratios. It has already been shown that the ratio of non-CO_2 to CO_2 changes is rather stable by 2100.
Figures 17 and 18 for C2000-T-fixed and C2000-T-variable plotted against incremented aviation CO_2 emissions show little difference between them, as expected from the similarity of GTIs over time, shown in Figure 6. What can be clearly seen, however, is an increase in changes in global mean surface temperatures ('dT') and global CO_2 emission rates for both CO_2 and non-CO_2 effects. Results have been plotted for 2000, 2050 and 2100. As might be expected, a better response is seen by 2100, while in 2000, in contrast, hardly any response is seen for an increase in emissions, as is also to be expected. Considering absolute temperatures introduces uncertainty, as the parent GCM (ECHAM4) may have a different temperature response to other GCMs. However, the stability of the *ratio* of CO_2/non-CO_2 effects is important; moreover, it is the slope of the line, rather than the intercept, that is of interest.

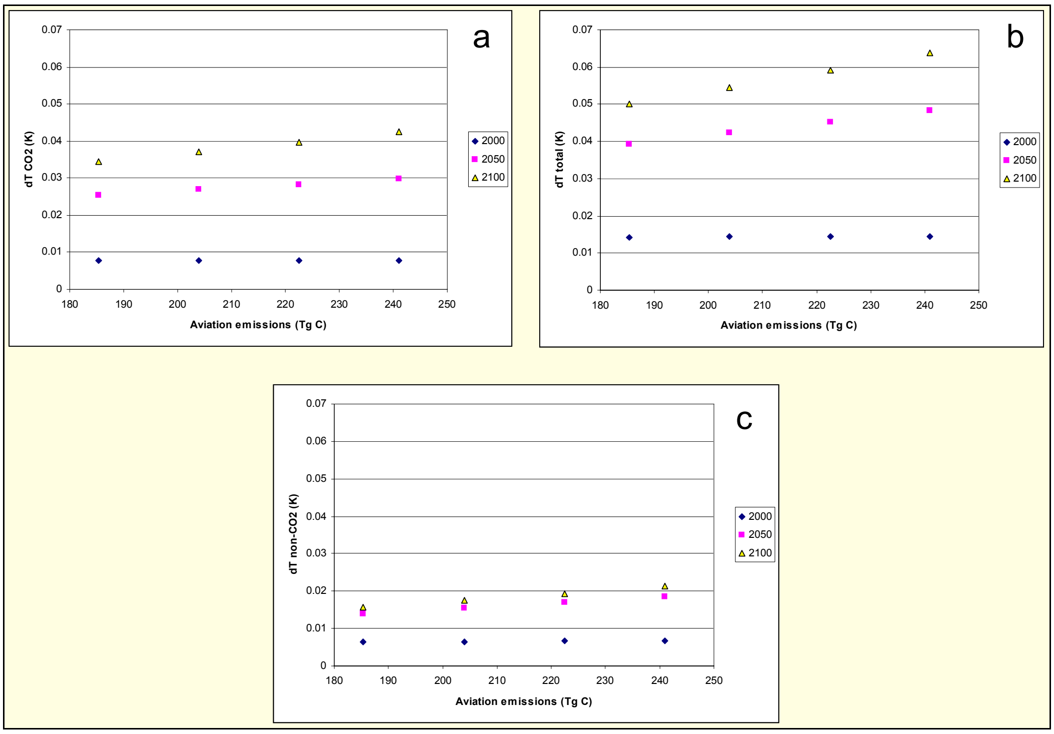
This initial finding indicates that it may be possible in the future to derive a function that relates CO_2 emissions to such temperature changes.

Figure 17 Relationships between aviation emissions (Tg C) for C2000-T-fixed and change in mean global surface temperature for CO_2 (a), total aviation emissions/effects (b) and non-CO_2 effects (c) calculated with model of [Lim *et al*., 2005]



Source: Lim et al., 2005

Figure 18 Relationships between aviation emissions (Tg C) for C2000-T-variable and change in mean global surface temperature for CO_2 (a), total aviation emissions/effects (b) and non-CO_2 effects (c) calculated with model of [Lim *et al*., 2005]



Source: Lim et al., 2005

The GTI_s concept is more akin to the GWP concept and has some of the advantages of the GWP in that it is: forward-looking (i.e. takes account of temperature potential at some future time horizon, which the RFI does not), it relates effects to emissions, and it is further down the cause-effect chain than RF. The GTI_s lacks the disadvantages of a GWP in that it overcomes the difficulty/impossibility of GWPs for O_3/contrails-cirrus. The GTI_s (and GTP_s) concept differs from that of GWP in that a *sustained* emission is considered, rather than a pulse. [Shine *et al*., 2005] found that the results of a GTP-pulse did not compare well with an energy balance model, except for long-lived gases. However, it should also be considered that others have argued against using a pulse for GWPs, claiming that a sustained emission change is a more suitable concept [Wigley and Reeves, 1991].

The calculations presented here represent the change in global mean surface temperature resulting from a stepwise change in emissions sustained over a 100 year time frame. This differs from the formulation of the GWP, which involves a pulse emission, the ratio of the resultant RFs over a 100 year (or other) time frame are compared. Note that an equivalency of GWPs and GTP/GTI is not being claimed – they are being compared for similarities and differences in their formulation. Few workers have considered the differences between 'pulse' and 'sustained' emissions. In [Fuglestvedt *et al*., 2003] review of climate metrics, they note that the ratio between steady-state warming from stepwise increases and the reference gas (CO_2) is not equal to the ratio of integrals of forcings from pulses. [Fuglestvedt *et al.*, 2003] cite the earlier work of [Wigley and Reeves, 1991], who argue that a sustained stepwise GWP is more satisfactory than a pulse-based GWP as it removes some of the ambiguity of comparing short- and longer-lived species (note that 'short' refers to CH_4, with a lifetime of approximately 10 years) and that they vary less with lifetime.

[Smith and Wigley, 2000a,b] also discuss emissions changes (reductions) in terms of pulse and sustained emissions, but only in the context of the GWP. The issue here is whether there is an equivalence problem between the GTI (sustained) and the GWP (pulse). Given the preliminary nature of the GTP and its application to a GTI, it is not yet possible to conclude much other than has already been done by [Shine *et al.*, 2005], viz. that a GTP (sustained) performs better than a GTP (pulse) when compared to an energy balance model. The clear conclusion is that more work needs to be done on comparing metrics and their formulation.

The GTI concept as applied here overcomes the difficulty of RFs/RFI, since it is forward-looking over some time frame and therefore accounts for the potential of historical or present-day emissions, and it is also possible to relate a range of effects to CO_2 emissions, for which purpose the RFI cannot be reliably used.

In conclusion, a number of points emerge from the preceding description of derivation of a GTI_s for aviation, building on the approach of [Shine *et al.*, 2005]:
- That it may be possible to derive a multiplier for aviation non-CO_2 effects that is broadly consistent with the GWP concept.
- The approach relies on sustained rather than on pulse emissions, which differs from the GWP approach. This requires further study. From the initial results of [Shine *et al.*, 2005], the GTP **is** compatible with GWP, having very similar values to GWPs for long-lived gases, but more work will be needed to establish whether this approach can be extended, as suggested here for short-lived aviation impacts.
- The results are inherently more uncertain as one moves down the cause/effect chain and there are many uncertainties associated with some of the critical parameters: thus, more underlying science (e.g. values of λ) is required to make the metric more robust.
- The concept is new and it will therefore take some time for the technique to be refined, critically reviewed and gain wider acceptance from science and stakeholder communities; it is suggested that further scientific work will take between 2 and 5 years.

E Cost impact calculations

E.1 Allowances purchased per average tonne emitted

The number of allowances that operators need to purchase under Options 1 and 2 depends on the baseline and the year of reference. In this study we have assumed the baseline is set at the 2008 emissions level. Under Option 1 the industry will have to purchase allowances for emissions above this level, while under Options 2 and 3 this level defines the total amount of emissions grandfathered and auctioned, respectively.

Operators will therefore not have to purchase allowances for all CO_2 emissions. Given the baseline 2008 emission level and the assumption of 4% annual growth, 2012 emissions will be 1.04^4 = 1.17 times larger than 2008 emissions. More in general, emissions in any year will be (1+annual growth rate)^(number of years) times the baseline emission level.

Under Options 1 and 2, then, on average operators will only have to buy allowances for 0.17 / 1.17 = 14.5% of their 2012 emissions. Because under Option 3 allowances are auctioned, operators will face financial costs for all their 2012 emissions.

For converting kg fuel to kg CO_2 a multiplication factor of 3.16 was applied.

As explained in Section 5.3.5 of the main report, the following calculations of potential cost increases to airlines relate to the following three exemplary flights:
- Short-haul flight: Amsterdam – Paris Charles de Gaulle, 480 km (259 nm).
- Medium-haul flight: Munchen – Palma de Mallorca, 1,402 km (757 nm).
- Long-haul flight: London Gatwick – Newark, 6,404 km (3,458 nm).

E.2 No opportunity costs passed on

Short- and medium-haul flights

Short- and medium-haul flights are fully covered by the geographical scope adopted in all three Options. Cost impacts at flight level can be estimated as follows.

Option 1: On the short-haul flight considered, CO_2 emissions are assumed to be 8,024 tonnes for a single flight (see Table 21 of main report) and twice this figure on a round trip. Only for emissions growth above the 2008 baseline, about 14.5% of emissions, will there be financial costs, i.e. for about 2.3 tonnes. Because of the multiplier employed in Option 1, operators will be required to surrender two allowances for every tonne of CO_2 emitted. For this flight, then, 2 * 2.3 is 4.7[142]

[142] We have rounded numbers to one decimal figure.

allowances will have to be purchased from other sectors. Multiplying this by the allowance price yields the cost impact at flight level.
Option 2: The methodology is similar to Option 1, except that the multiplier does not now apply.

Long-haul flights
In the case of short- and medium-haul flights, assumed to be fully covered under all options, calculations can be based on trip emissions. The same does not hold for long-haul flights, however, which are not covered under Option 1 and covered to 50% under Option 2 (the stage from Gatwick to Newark only, with the return stage not covered). Under Option 3, only that part of the departing and arriving flight is covered that is within EU airspace. For this specific flight we assumed that the LTO phase at Gatwick is covered, and 1000 kilometres of the en route stages of both the departing flight and the arriving flight. Separate information on LTO fuel use is therefore required. According to the Corinair database, the LTO fuel consumption of a Boeing 777 is 2,563 kilograms.

The cost increase for the long-haul flight can now be calculated as follows.

Option 1: No cost increase, because the flight is not covered.

Option 2: Only the departing flight is covered. Total fuel consumption on a single flight is 49,694 kg and CO_2 emissions therefore total 157,033 kg. On average, operators will have to purchase allowances for 14.5% of their emissions growth above the 2008 baseline. The cost impact at flight level is then calculated as 14.5% of CO_2 emissions (in tonnes) multiplied by the allowance price per tonne. For an allowance price of € 10 / tonne, for example, we obtain 0.145 * 157 * 10 = € 228.

Option 3: Under this option, the fuel consumption of 1 LTO is included and 1,000 km of the cruise emission on both the departing and arriving flight. Total fuel use in EU airspace is therefore an estimated 2,563 + 2 * 1,000 / 6,404 * (49,694 – 2,563) = 17,282 kg. In general, the formula is: LTO fuel use + 2 * portion of flight in EU airspace * cruise fuel use.
This is equivalent to 54.6 tonnes of CO_2. Multiplying this by the allowance price (assumed to be equal to the auctioning price), we obtain the cost impact at flight level.

E.3 Opportunity costs passed on

If opportunity costs are assumed to be passed on, the calculation methodology becomes slightly different in the first two options. Under Options 1 and 2, it is not only the purchase cost of the allowances for the 14.5% of CO_2 emissions that are passed on, but also the opportunity costs associated with the remaining 85.5%. Under these two options, then, the cost impact is therefore a factor 100/14.5 higher than under the assumption that opportunity costs are not passed on.

As there are no opportunity costs under Option 3, calculation of cost impact is the same as for the case of opportunity costs being not passed on.

Short- and medium-haul flights
Option 1: The cost impact is equal to the total amount of CO_2 emissions for a round trip multiplied by the allowance price and taking account of the multiplier. Thus, for the medium-haul flight and an allowance price of € 30, for example, we calculate 15.8 tonnes * 2 (round trip) * 2 (multiplier) * 30 = € 1,895.

Option 2: Similar to Option 1, except for the multiplier.

Option 3: See Section E.2.

Long-haul flights
Option 1: No cost increase, because the flight is not covered.

Option 2: In contrast to the situation in which no opportunity costs are passed on, it is now not only the cost of 14.5% of emissions that are passed on, but also the opportunity costs for allowances for the other emissions. Total CO_2 emissions times the allowance price yields the cost impact at flight level.

Option 3: See Section E.2.

E.4 From flight-level cost impact to ticket price increase

The cost increases at flight level can be converted to average ticket price increases in two steps, based on assumptions regarding load factor and number of seats per aircraft. The assumptions used here are to be found in Table 21 of the main report.

In the first step, the load factors are multiplied by the number of available seats to yield the average number of seats sold for the flight in question. Step 2 consists of dividing the total flight-level cost impact by this figure for the average number of seats sold, yielding the average ticket price increase needed to cover the cost increase at flight level.

For example, we assume the A320 has on average of 150 seats, of which 70% are occupied. On the short-haul flight there are then, on average, 105 occupied seats. By dividing the flight-level cost increase (e.g. € 47) by 105, we obtain an average ticket price increase of about € 1.4 (Option 1, assuming no opportunity cost are passed on, and an allowance price of € 10).

F AERO model

This annex provides a brief description of the AERO Model and the scenario results for the three policy options considered. The model description is based on a report published by the Dutch Civil Aviation Administration, the owner of the AERO model, and for a detailed description of the model the reader is referred to that report [Pulles *et al*., 2002]. The authors wish to extend their special thanks to the Dutch CAA for making the AERO model available for this study.

F.1 Background and objectives

In 1994 the Dutch Civil Aviation Authority started a major policy analysis called the AERO project (Aviation emissions and Evaluation of Reduction Options). The objectives of this project were to assess the problems related to air pollution from aircraft engine emissions and to analyse possible measures to reduce the atmospheric impacts of air transport, taking in account the environmental benefits and economic impacts of such measures. In order to achieve these objectives, an extensive global information and modelling system was developed, which is referred to as the AERO modelling system (AERO-MS).

The AERO-MS comprises a sequence of steps, from description and generation of air transport demand through to assessment of the environmental and economic impacts of aircraft engine emissions, thereby achieving comprehensive integration of relevant economic, commercial, technological and environmental factors. In essence, the AERO-MS is a policy-testing tool to evaluate the environmental and economic consequences of responses to emission-related measures within the context of relevant future developments in the air transport sector.
Potentially, a great many possible measures and different future developments are relevant. Consequently, the AERO-MS had to be capable of analysing a wide range of measures (including economic, regulatory, technical and operational measures) within a variety of autonomous (economic and technological) developments. The AERO-MS was therefore designed to meet the following analysis requirements:
- To provide an adequate description of the economic and environmental aspects of the air transport system (in particular the extent and effects of aircraft engine emissions).
- To adequately reflect economic and technological developments in air transport.
- To assess the effects of a range of possible measures to reduce the environmental impact of air transport, taking into account the responses of the major actors (airlines, consumers, manufacturers) to such measures.

The design philosophy and architecture underlying the AERO-MS allow the user a large degree of flexibility in analysing the effects of specific developments and measures in a 'what-if' fashion. This was implemented by creating a great many user options to change key assumptions, schematisation aspects, (scenario) developments and possible measures (policy options).

The AERO project and the AERO-MS were developed principally to analyse the impacts of aircraft engine emissions on a global scale and therefore provide a complete description of worldwide aviation activity. In addition, within the analysis capabilities of the modelling system, specific options were provided to allow for a more detailed analysis of the aviation sector in the European context (the EU countries at the close of the 20th century). Within the European context, a number of specific options are provided for analysing the Netherlands' aviation (in particular, aviation activity at Amsterdam-Schiphol Airport). These different spatial levels of analysis all reflect the areas of interest to the Dutch Civil Aviation Authority, which – as noted already – commissioned the AERO project.

F.2 Applications of the AERO modelling system

From the very start of the AERO project, activity has been strongly focused on developing the AERO-MS as a comprehensive tool for analysing the complex environmental and economic effects of policy measures in different scenarios. This was ultimately achieved in five project phases, though the system has been actively applied since the second phase.

From the second phase of the project onwards, versions of the AERO-MS have been available for analysis. In subsequent phases, the modelling system was further expanded, updated and improved. Based on earlier versions of the AERO-MS a number of rather substantial analyses were carried out. In addition to the intermediate analyses directly carried out for the Dutch Civil Aviation Authority, these include:

- A global analysis of emission charges and taxes for the Focal Point on Charges (carried out for CAEP/4) [FPC, 1998].
- An analysis of the impact of fuel taxation in the European context, carried out for the European Commission [Resource Analysis, 1999].
- A study commissioned by the Dutch Civil Aviation Authority to facilitate the debate on the national allocation of CO_2 between the Subsidiary Body for Scientific and Technological Advice (SBSTA) of the UN Framework Convention on Climate Change (UNFCCC) and ICAO's Committee on Environmental Protection (CAEP) [Resource Analysis / CE, 2000].
- An analysis of market-based options for reducting CO_2 emissions from aviation for the Forecast and Economic Support Group of ICAO (CAEP/5) [Pulles et al., 2000].

As described in the present documentation, the currently available version of the AERO-MS provides a powerful and flexible tool to support the analysis of economic and environmental (atmospheric) impacts on the aviation sector arising from a wide variety of possible developments and measures.

F.3 Design of the overall AERO documentation

The complete documentation of the AERO project comprises the following elements:

A Main report:
- Part I: Description of the AERO modelling system.
- Part II: Analysis preparation, execution and results.

B Reports on individual models:
- General reports:
  - Aircraft Technology Model (ATEC).
  - Air Transport Demand and Traffic Model (ADEM).
  - Aviation Operating Cost Model (ACOS).
  - Economic impact models: Direct Economic Impact Model (DECI) and Macro-Economic Impact Model for the Netherlands (MECI).
  - Flights and Emissions Model (FLEM).
  - Atmospheric impact models: Other Atmospheric Immissions Model (OATI), Chemical Tracer Model KNMI (CTMK), Environmental Impact Model (ENVI).
- System documentation:
  - Aircraft Technology Model (ATEC).
  - Air Transport Demand and Traffic Model (ADEM).
  - Aviation Operating Cost Model (ACOS).
  - Economic impact models: Direct Economic Impact Model (DECI) and Macro-Economic Impact Model for the Netherlands (MECI).
  - Flights and Emissions Model (FLEM).
  - Atmospheric impact models: Other Atmospheric Immissions Model (OATI), Chemical Tracer Model KNMI (CTMK), Environmental Impact Model (ENVI).

C AERO Modelling system:
- Technical report.
- User manual.
- Scenario and policy variables.

D CD-ROM of AERO project:
The CD-ROM of the AERO project consists of two parts. The first contains an electronic version of selected AERO documentation, viz. a description of the AERO-MS and the main results of the AERO analysis. The second part is a demonstration version of the AERO-MS, providing insight into its functions and uses.

F.4 Oil price and price elasticities used in the model

Oil price
In the model run for this project an oil price of US$ 50 per barrel was assumed.

Price elasticities of demand
In the model run for this project the following price elasticities of demand were used for analysing the demand effects of the three policy options considered.

Table 36 Price elasticities of demand in the AERO model

Route group	Passenger demand		Cargo Demand
	First/Business	Economy	
EU - North America	-0.3	-0.8	-0.7
EU - Central America	-0.2	-0.8	-0.7
EU - South America (N)	-0.2	-0.7	-0.7
EU - South America (S)	-0.2	-0.7	-0.7
EU - EU	-0.2	-0.7	-0.7
EU - Non-Aligned Europe	-0.2	-0.7	-0.7
EU - Middle East	-0.3	-1.1	-0.7
EU - Eastern Africa	-0.2	-0.7	-0.7
EU - Western Africa	-0.2	-0.7	-0.7
EU - Southern Africa	-0.2	-0.7	-0.7
EU - Far East (N)	-0.2	-1.0	-0.7
EU - Far East (S)	-0.2	-1.0	-0.7
EU - Southwest Pacific	-0.2	-1.0	-0.7
EU - Former Eastern Bloc	-0.2	-0.9	-0.7

G Geographical scope scenarios: detailed results

Emission calculations for both CO_2 and NO_x have been made by EUROCONTROL for the years 2002, 2003 and 2004. In doing so, use was made of the PRISME database, which contains data on all flights using the airspace for which EUROCONTOL provides the central (air traffic) flow management service. The emission calculations are based, furthermore, on the ECAC-recommended ANCAT3 method[143]. ANCAT3 makes use of generic aircraft types. EUROCONTROL has improved the computational method by introducing coefficients to specifically capture the fuel flow and emission characteristics of non-generic aircraft. This improved computational method has been used for the emission calculations of the present study.

Tables 37 and 38, below, specify the number of flights and flight km from the PRISME database underlying the results of the emission calculations, with the results broken down according to route group and geographical scope scenario. Tables 39 and 40 present the emission calculation results for CO_2 and NO_x, respectively. The CO_2 calculations follow directly from calculated fuel use (one kg of kerosene burned creates 3.14 kg of CO_2). The NO_x calculations are based on the aircraft-specific NO_x emission characteristics included in the ANCAT3 computational methodology.

In line with the recommended cut-off points described in Section 3.3.3, the results presented in Tables 37 to 40 relate only to:
- Flights with Instrument Flight Rules (IFR flights).
- Flights flown at least in part under civil ATC flight rules and procedures.
- Flights operated by aircraft with MTOW >= 8,618 kg.

With respect to the other possible cut-off points it is noted that:
- Flights with a military flight purpose but flying at least in part under civil ATC flight rules and procedures are included in the results.
- Flights operated by all airports and operators (independent of the annual number of operations executed) are included in the results.

In relation to the route groups presented in Tables 37 to 40 several remarks are in order.
- Domestic routes are subdivided into 4 groups: A1. Domestic routes within EU States; A2. Domestic routes within Ultra Peripheral Regions (UPR); A3. Domestic routes within Overseas Countries and Territories (OSCT); and A4. Domestic routes outside the EU but within the European Free Trade Association (EFTA). All these domestic routes are presented, as they are all potentially included in an EU ETS. For Domestic OSCT, however, there are no computational results, because these flights are not covered by EUROCONTROL. For domestic UPR the results presented relate only to

[143] More information on ANCAT3 can be found at: http://reports.eea.eu.int/EMEPCORINAIR.

routes within the Canaries, Azores, Madeira as these regions fall within the area covered by EUROCONTROL. The results thus not relate to routes within Guadeloupe, Martinique, La Reunion and French Guyana because these regions fall outside the area covered by EUROCONTROL. It is noted, further, that the scenarios relate only to domestic routes within the EU and not to the other domestic routes presented (see also Section 2.2).

- Definitions of the UPR, OSCT, EFTA and Annex B countries are included in Annex H to this report.
- Intra-European routes are also subdivided into 4 groups: B1. Routes between EU Member States; B2. Routes between EU Member States and UPR; B3. Routes between EU Member States and OSCT; B4. Routes between EU Member States and EFTA countries. Note that scenario 1 (Intra EU routes) relates only to route group B1 (see also Section 3.3).
- The computational results have been broken down not only by route group but also by operator nationality, thereby distinguishing between operators of EU and other (i.e. non-EU) nationality[144]. There is also a column for flights for which operator nationality is unknown[145].
- For the year 2002 EUROCONTROL was not able to quantify emissions for the route groups through EU airspace (route groups G, H and I), because of the granularity of the data in PRISME and because the process used for 2003 and 2004 was not appropriate for 2002.
- For the data generated, the nationality of the aircraft operating agency has been determined using the information contained in field 7 "aircraft identification" and field 18 "other information" of the flight plan. Field 7 contains:
    - The ICAO designator for the aircraft operating agency (see ICAO Doc. 8585) followed by the flight identification; or

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[144] This nationality assessment is based on the aircraft operating agency mentioned in the flight plan, making use of ICAO Doc. 8585: ‘Designators for Aircraft Operating Agencies, Aeronautical Authorities and Services’.

[145] It may be the case that there is no record in the PRISME-loaded Doc. 8585 corresponding to the ICAO designator associated by the IFPS system. In such cases, UNKNOWN has been used as nationality. These instances are due either (i) to the fact that Doc. 8585 is published by ICAO on a quarterly basis and some airlines may have started/ceased operations between two issues, or (ii) to the fact that the association has provided a designator no longer valid according to the relevant document but still used in the flight plans submitted. Finally, it should be noted that Doc. 8585 has been loaded into PRISME on a regular basis only since 2003. This explains the significant difference in the number of UNKNOWN events between 2002 and 2003, 2004 (a ratio of 1 to 10).

- The registration marking of the aircraft; or
- The call sign determined by the military authorities if this will be used to identify the aircraft during flight.

Field 18 may (it is not mandatory) contain information on the aircraft operating agency if this is not clearly provided in field 7.

Table 37 Number of flights in emission trading system per route group and geographical scope scenario (in 1,000 flights per year)

Route Group / Scenario	Year											
	2002				2003				2004			
	Operator nationality				Operator nationality				Operator nationality			
	EU	non-EU	Unknown	Total	EU	non-EU	Unknown	Total	EU	non-EU	Unknown	Total
Route Group												
A. Domestic routes												
A1. Domestic EU States**	2,129	72	84	2,286	2,176	22	79	2,278	2,186	20	98	2,303
A2. Domestic Ultra Peripheral Regions (UPR)	61	0	1	62	65	0	8	74	67	0	12	80
A3. Domestic Overseas Countries and Territories (OSCT)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
A4. Domestic EEA countries	54	161	15	230	44	209	3	256	42	215	5	262
B. Intra European routes												
B1. EU - EU (between Member States)	2,516	55	110	2,681	2,639	70	84	2,793	2,812	62	83	2,956
B2. EU - UPR / UPR - EU	170	4	3	177	175	1	5	181	178	1	5	184
B3. EU - OSCT / OSCT - EU	4	0	1	5	5	0	1	6	5	0	0	5
B4. EU - EEA / EEA - EU	226	84	138	448	243	178	19	439	270	164	21	454
Other International routes												
C. EU - Annex B	45	52	7	104	52	56	7	115	60	62	9	132
D. Annex B - EU	45	52	7	104	52	56	7	115	60	63	9	132
E. EU - Non-Annex B	229	240	31	500	237	258	32	527	270	278	34	582
F. Non-Annex B - EU	227	239	32	498	236	258	32	526	270	277	34	581
Routes through EU airspace												
G. EU - Non-EU (EU airspace only)	n.a.	n.a.	n.a.	n.a.	500	402	51	953	556	422	57	1,035
H. Non-EU - EU (EU airspace only)	n.a.	n.a.	n.a.	n.a.	498	403	51	952	556	422	56	1,034
I. Non-EU - Non-EU (EU airspace only)	n.a.	n.a.	n.a.	n.a.	75	145	24	244	79	156	31	266
Scenario												
1. Intra-EU (A1+B1)	4,645	127	194	4,966	4,815	92	163	5,071	4,997	81	180	5,259
2a. Intra EU+50% on routes to/from EU (A1+B1+B2+B3+B4+C+D+E+F)	5,591	798	413	6,802	5,814	900	266	6,980	6,110	926	293	7,329
2b. Departing from EU (A1+B1+50%(B2+B3+B4)+C+E)*	5,119	463	303	5,885	5,315	496	215	6,026	5,554	504	237	6,295
3. Emissions in EU airspace (A1+B1+G+H+I)	n.a.	n.a.	n.a.	n.a.	5,888	1,043	290	7,220	6,189	1,081	324	7,594
4. Departing from EU + EU airspace (A1+B1+50%(B2+B3+B4)+C+E+H+I)*	n.a.	n.a.	n.a.	n.a.	5,888	1,045	290	7,222	6,189	1,082	324	7,595
5. Route Based sytem (A1+B1+B4+C+D)	4,961	315	346	5,622	5,162	383	196	5,740	5,388	370	219	5,977

* For B2, B3 and B4 no distinction is made between routes from the EU and to the EU. Therefore for scenarios 2b and 4, 50% of the routes are selected as an estimation for the routes departing from the EU.

** Most domestic EU flights operated by non-EU carriers are related to freight operations, and some to military flights. In addition there are air taxi services and aircraft relocation flights.

Source: EUROCONTROL.

Table 38 Number of flight-Nm covered by emission trading system per route group / scenario (in million flight-km per year)

Route Group / Scenario	Year											
	2002				2003				2004			
	Operator nationality				Operator nationality				Operator nationality			
	EU	non-EU	Unknown	Total	EU	non-EU	Unknown	Total	EU	non-EU	Unknown	Total
Route Group												
A. Domestic routes												
A1. Domestic EU States	561	22	21	604	580	7	23	609	581	4	25	610
A2. Domestic Ultra Peripheral Regions (UPR)	8	0	0	8	8	0	1	9	9	0	2	10
A3. Domestic Overseas Countries and Territories (OSCT)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
A4. Domestic EEA countries	12	28	2	43	10	37	1	48	9	39	1	49
B. Intra European routes												
B1. EU - EU (between Member States)	1,451	32	59	1,542	1,562	39	54	1,655	1,665	33	51	1,750
B2. EU - UPR / UPR - EU	278	7	3	288	279	2	9	290	281	2	9	292
B3. EU - OSCT / OSCT - EU	15	0	2	18	18	0	3	21	17	0	2	18
B4. EU - EEA / EEA - EU	107	44	57	208	119	83	10	211	132	81	10	223
Other International routes												
C. EU - Annex B	84	93	10	187	93	98	11	203	107	104	14	225
D. Annex B - EU	83	92	10	185	93	98	11	202	106	106	14	226
E. EU - Non-Annex B	605	592	62	1,259	631	649	73	1,354	704	692	79	1,475
F. Non-Annex B - EU	598	585	64	1,247	628	647	74	1,349	702	689	80	1,471
Routes through EU airspace												
G. EU - Non-EU (EU airspace only)	n.a.	n.a.	n.a.	n.a.	470	333	46	850	514	349	49	912
H. Non-EU - EU (EU airspace only)	n.a.	n.a.	n.a.	n.a.	445	320	43	808	495	345	47	886
I. Non-EU - Non-EU (EU airspace only)	n.a.	n.a.	n.a.	n.a.	17	29	6	51	18	31	0	49
Scenario												
1. Intra-EU (A1+B1)	2,012	55	80	2,147	2,142	46	77	2,265	2,247	38	76	2,360
2a. Intra EU+50% on routes to/from EU (A1+B1+50%(B2+B3+B4+C+D+E+F))	2,897	761	184	3,843	3,073	835	171	4,080	3,271	875	179	4,325
2b. Departing from EU (A1+B1+50%(B2+B3+B4)+C+E)*	2,901	766	183	3,850	3,075	836	171	4,082	3,272	875	179	4,326
3. Emissions in EU airspace (A1+B1+G+H+I)	n.a.	n.a.	n.a.	n.a.	3,075	728	172	3,975	3,272	763	171	4,207
4. Departing from EU + EU airspace (A1+B1+50%(B2+B3+B4)+C+E+H+I)*	n.a.	n.a.	n.a.	n.a.	3,537	1,185	220	4,942	3,784	1,251	225	5,261
5. Route Based sytem (A1+B1+B4+C+D)	2,286	284	157	2,727	2,448	326	108	2,881	2,592	329	113	3,034

* For B2, B3 and B4 no distinction is made between routes from the EU and to the EU. Therefore for scenarios 2b and 4, 50% of the routes are selected as an estimation for the routes departing from the EU.

Source: EUROCONTROL.

Table 39 CO_2 emissions covered by emission trading system per route group and scenario (in million kg per year)

Route Group / Scenario	Year											
	2002				2003				2004			
	Operator nationality				Operator nationality				Operator nationality			
	EU	non-EU	Unknown	Total	EU	non-EU	Unknown	Total	EU	non-EU	Unknown	Total
Route Group												
A. Domestic routes												
A1. Domestic EU States	12,862	612	283	13,758	13,260	256	351	13,866	13,286	172	397	13,856
A2. Domestic Ultra Peripheral Regions (UPR)	106	0	2	109	110	1	16	127	124	1	15	140
A3. Domestic Overseas Countries and Territories (OSCT)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
A4. Domestic EEA countries	357	483	51	891	299	640	12	951	252	660	16	928
B. Intra European routes												
B1. EU - EU (between Member States)	31,866	1,132	961	33,959	34,108	1,329	845	36,282	36,184	1,074	761	38,019
B2. EU - UPR / UPR - EU	8,149	186	76	8,411	7,917	67	206	8,190	7,914	50	268	8,232
B3. EU - OSCT / OSCT - EU	734	3	81	818	861	3	97	961	824	4	41	869
B4. EU - EEA / EEA - EU	2,426	919	1,153	4,497	2,567	1,818	119	4,504	2,733	1,755	104	4,592
Other International routes												
C. EU - Annex B	3,447	3,525	131	7,102	3,668	3,642	163	7,473	4,051	3,695	194	7,940
D. Annex B - EU	3,380	3,473	148	7,002	3,694	3,611	160	7,466	4,056	3,800	187	8,042
E. EU - Non-Annex B	26,840	26,069	1,850	54,759	28,001	28,909	2,174	59,084	30,934	30,468	2,340	63,742
F. Non-Annex B - EU	26,390	25,661	1,855	53,906	27,752	28,785	2,147	58,685	30,768	30,307	2,333	63,408
Routes through EU airspace												
G. EU - Non-EU (EU airspace only)	n.a.	n.a.	n.a.	n.a.	15,792	12,411	1,092	29,295	17,063	12,660	1,155	30,878
H. Non-EU - EU (EU airspace only)	n.a.	n.a.	n.a.	n.a.	14,972	11,866	1,008	27,845	16,524	12,588	1,091	30,203
I. Non-EU - Non-EU (EU airspace only)	n.a.	n.a.	n.a.	n.a.	318	869	114	1,302	337	935	110	1,382
Scenario												
1. Intra-EU (A1+B1)	44,728	1,745	1,244	47,717	47,368	1,584	1,196	50,148	49,471	1,246	1,158	51,875
2a. Intra EU+50% on routes to/from EU (A1+B1+50%(B2+B3+B4+C+D+E+F))	80,411	31,662	3,891	115,964	84,598	35,002	3,729	123,329	90,110	36,285	3,892	130,287
2b. Departing from EU (A1+B1+50%(B2+B3+B4)+C+E)*	80,669	31,892	3,880	116,441	84,710	35,079	3,744	123,533	90,191	36,313	3,899	130,403
3. Emissions in EU airspace (A1+B1+G+H+I)	n.a.	n.a.	n.a.	n.a.	78,449	26,731	3,410	108,590	83,394	27,429	3,514	114,337
4. Departing from EU + EU airspace (A1+B1+50%(B2+B3+B4)+C+E+H+I)*	n.a.	n.a.	n.a.	n.a.	100,000	47,814	4,866	152,680	107,051	49,836	5,100	161,988
5. Route Based sytem (A1+B1+B4+C+D)	53,981	9,661	2,676	66,318	57,297	10,656	1,638	69,590	60,310	10,496	1,643	72,449

* For B2, B3 and B4 no distinction is made between routes from the EU and to the EU. Therefore for scenarios 2b and 4, 50% of the routes are selected as an estimation for the routes departing from the EU.

Source: EUROCONTROL.

Table 40 NO_x emissions covered by emission trading system per route group and scenario (in million kg per year)

Route Group / Scenario	Year											
	2002				2003				2004			
	Operator nationality				Operator nationality				Operator nationality			
	EU	non-EU	Unknown	Total	EU	non-EU	Unknown	Total	EU	non-EU	Unknown	Total
Route Group												
A. Domestic routes												
A1. Domestic EU States	52.94	2.69	1.11	56.75	54.61	1.26	1.43	57.29	54.96	0.85	1.66	57.47
A2. Domestic Ultra Peripheral Regions (UPR)	0.41	0.00	0.01	0.42	0.42	0.01	0.06	0.49	0.47	0.00	0.05	0.53
A3. Domestic Overseas Countries and Territories (OSCT)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
A4. Domestic EEA countries	1.31	1.58	0.22	3.12	1.15	2.14	0.04	3.33	0.85	2.19	0.05	3.09
B. Intra European routes												
B1. EU - EU (between Member States)	122.92	5.53	3.83	132.29	131.21	6.43	3.25	140.89	139.05	5.12	2.92	147.09
B2. EU - UPR / UPR - EU	35.01	0.83	0.29	36.13	33.07	0.28	0.89	34.24	32.97	0.20	1.09	34.26
B3. EU - OSCT / OSCT - EU	3.56	0.01	0.34	3.91	4.13	0.02	0.40	4.55	3.95	0.02	0.17	4.14
B4. EU - EEA / EEA - EU	9.53	3.70	4.88	18.11	9.88	7.64	0.45	17.96	10.28	7.27	0.37	17.92
Other International routes												
C. EU - Annex B	16.07	15.56	0.49	32.13	16.97	16.09	0.61	33.67	18.94	16.30	0.74	35.98
D. Annex B - EU	15.70	15.28	0.56	31.54	17.10	15.93	0.59	33.62	18.93	16.83	0.70	36.46
E. EU - Non-Annex B	125.53	121.74	8.15	255.42	130.44	135.65	9.60	275.69	143.71	142.07	10.27	296.05
F. Non-Annex B - EU	123.21	119.76	8.13	251.09	129.19	135.06	9.41	273.66	142.85	141.26	10.17	294.28
Routes through EU airspace												
G. EU - Non-EU (EU airspace only)	n.a.	n.a.	n.a.	n.a.	69.53	56.45	4.61	130.60	74.89	56.99	4.88	136.75
H. Non-EU - EU (EU airspace only)	n.a.	n.a.	n.a.	n.a.	65.80	53.88	4.23	123.90	72.45	56.76	4.60	133.80
I. Non-EU - Non-EU (EU airspace only)	n.a.	n.a.	n.a.	n.a.	1.20	3.72	0.46	5.38	1.26	3.98	0.43	5.66
Scenario												
1. Intra-EU (A1+B1)	175.86	8.23	4.94	189.03	185.82	7.68	4.68	198.18	194.01	5.97	4.58	204.56
2a. Intra EU+50% on routes to/from EU (A1+B1+50%(B2+B3+B4+C+D+E+F))	340.16	146.67	16.37	503.20	356.21	163.02	15.65	534.88	379.82	167.95	16.34	564.11
2b. Departing from EU (A1+B1+50%(B2+B3+B4)+C+E)*	341.51	147.80	16.35	505.66	356.77	163.40	15.75	535.92	380.26	168.09	16.41	564.76
3. Emissions in EU airspace (A1+B1+G+H+I)	n.a.	n.a.	n.a.	n.a.	322.35	121.73	13.97	458.06	342.61	123.69	14.48	480.78
4. Departing from EU + EU airspace (A1+B1+50%(B2+B3+B4)+C+E+H+I)*	n.a.	n.a.	n.a.	n.a.	423.77	220.99	20.44	665.20	453.97	228.83	21.43	704.22
5. Route Based sytem (A1+B1+B4+C+D)	217.16	42.78	10.88	270.81	229.77	47.35	6.32	283.43	242.16	46.38	6.39	294.93

* For B2, B3 and B4 no distinction is made between routes from the EU and to the EU. Therefore for scenarios 2b and 4, 50% of the routes are selected as an estimation for the routes departing from the EU.

Source: EUROCONTROL.

Table 37 to 40 show aviation activities and absolute associated emissions over the 3-year period considered. During this period the number of flights covered under the various scenarios grew by between 3% and 3.5% per year. Based on the figures for the most recent year (2004), the absolute number of flights covered under the scenarios lies between 5 and 8 million.

H Overview of countries under scope scenarios

I. Ultra Peripheral Regions (UPR)

I-1. Azores
I-2. Canaries
I-3. French Guiana
I-4. Guadeloupe
I-5. Madeira
I-6. Martinique
I-7. Reunion

II. Overseas Countries and Territories (OSCT)

II-1. Anguilla
II-2. Aruba
II-3. Bermuda
II-4. British Indian Ocean Territory
II-5. Cayman Islands
II-6. French Polynesia
II-7. Greenland
II-8. Mayotte
II-9. Montserrat
II-10. Netherlands Antilles
II-11. New Caledonia
II-12. Saint Helena
II-13. Saint Pierre and Miquelon
II-14. Turks and Caicos Islands
II-15. Virgin Islands, British
II-16. Wallis and Futuna

III. Countries outside the European Union (EU) but in the European Free Trade Association (EFTA)

III-1. Iceland
III-2. Liechtenstein
III-3. Norway
III-4. Switzerland

IV. Annex B countries that have ratified the Kyoto Protocol*

IV-1. Bulgaria
IV-2. Canada
IV-3. Japan
IV-4. New Zealand
IV-5. Romania
IV-6. Russian Federation
IV-7. Ukraine

* These are the non-EFTA Annex B countries that have ratified the Kyoto Protocol.