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Emissions trading in international civil aviation

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Prepared by
Martin Cames (m.cames@oeko.de)
Odette Deuber (o.deuber@oeko.de)

With contributions by
Ulrike Rath

Translated into English by
Michael Gromm (gromm@web.de)

Öko-Institut e.V.
Institute for Applied Ecology
Berlin Office
Novalisstraße 10
D-10115 Berlin
Tel.: +49-30-280 486-80
Fax: +49-30-280 486-88

Freiburg Office
Binzengrün 34a
D-79114 Freiburg
Tel.: +49-761-452 95-0
Fax: +49-761-47 53 37

Darmstadt Office
Elisabethenstr. 55-57
D-64283 Darmstadt
Tel.: +49-61 51-81 91-0
Fax: +49-61 51-81 91-33

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16. Kurzfassung
Der Beitrag des internationalen Luftverkehrs zum Treibhauseffekt steigt kontinuierlich. Es wird untersucht, wie der Beitrag des Luftverkehrs durch Emissionshandel reduziert bzw. begrenzt werden kann. Dabei werden sowohl die unterschiedlichen Ausgestaltungsoptionen (Handelsregime, Bemessungsgrundlage, Verpflichtete etc.) als auch die Vermeidungskosten und -potenziale verschiedener Minderungsmaßnahmen (Flugroutenoptimierung, frühzeitige Stilllegung, Verbesserung der Aerodynamik etc.) betrachtet. Die Studie zeigt, dass ein Emissionshandelssystem im Luftverkehr möglich und sinnvoll ist. Wichtig ist jedoch, dass dabei die gesamte Klimawirksamkeit des Luftverkehrs erfasst wird, da es sonst zu Fehlsteuerungen kommen kann.

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Emissionshandel, internationaler Luftverkehr, Bemessungsgrundlage, Nachweispflichtige Akteure, Treibhauseffekt, CO_2-Emissionen, NO_X-Emissionen, Wasserdampfemissionen, Kondensstreifen, Zirruswolken, Strahlungsantrieb, Strahlungsantriebsfaktor, Treibhausgaspotenzial, Flugroutenoptimierung, Vermeidungspotenzial

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Deuber, Odette

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Novalisstr. 10
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16. Abstract
The contribution of international aviation to the greenhouse effect is increasing continually. The study investigates how the contribution of aviation can be reduced or limited through emissions trading. Not only are different design options (trading regime, basis for assessment, obligated parties etc.) examined, but also the avoidance costs and potentials of different reduction measures (flight route optimization, early retirement of aircraft, improvement of aerodynamics etc.). The study shows that an emissions trading system for aviation is both possible and sensible. It is important, however, that the total climatic impact of aviation be covered, for otherwise misdirected control might be the result.

17. Key words
Emissions trading, international aviation, basis for assessment, obligated parties, greenhouse effect, CO_2 emissions, NO_x emissions, water vapour emissions, contrails, cirrus clouds, radiative forcing, radiative forcing index, greenhouse gas potential, flight-route optimization, avoidance potential

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Abbreviations

ANCAT	Expert Group on Abatement of Noise Caused by Air Transportation
ATC/ATM	Air Traffic Control/Air Traffic Movement
BMVBW	Federal Ministry of Transport, Building and Housing
CAEP	Committee on Aviation Environmental Protection of the ICAO
CCAP	Center for Clean Air Policy
CDM	Clean Development Mechanism
CNS/ATM	Communication, Navigation, Surveillance/Air Traffic Management
COP	Conference of the Parties
DETR	Department of the Environment, Transport and the Regions
DLR	German Aerospace Center
DNR	Deutscher Naturschutzring
ECAC	European Civil Aviation Conference
EDF	Environmental Defence Fund
ERLIG	Emissions Related Landing Charges Investigation Group

Eurocontrol	European Organization for the Safety of Air Navigation
FESG	Forecasting and Economic Support Group
ft	feet
GDP	Gross Domestic Product
GNP	Gross National Product
GWP	Global Warming Potential
HSCT	High Speed Civil Transport
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ICSA	International Coalition for Sustainable Aviation of T&E
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
JI	Joint Implementation
KP	Kyoto Protocol
LTO cycle	Landing & Take-off cycle
MTOW	Maximum Take-off Weight
MTPWW	Ministry of Transport, Public Works and Water Management
MZFW	Maximal designed Zero Fuel Weight
NASA	National aeronautics and space administration
NGO	Non government organization
nm	Nautical mile
OWE	Operating Weight Empty
pkm	Passenger kilometre
PSR	Performance standard rate
RTK	Revenue Tonne Kilometre
SBSTA	Subsidiary Body for Scientific and Technical Advice of the UNFCCC
T&E	Transport and Environment (umbrella organization of European NGOs in the transport area
tkm	Tonne kilometre
UNFCCC	United Nations Framework Convention on Climate Change
VCD	Verkehrsclub Deutschland
WBGU	German Advisory Council on Global Change

1. Introduction

According to estimates of the Intergovernmental Panel on Climate Change (IPCC), international aviation contributes about 3.5% to global warming.[1] If growth in aviation volume continues at the same rate as in the 1990s, when international aviation grew 4% annually, the contribution of international aviation to the greenhouse effect could, already in 2010, be higher than Germany's contribution to global warming.

International aviation is therefore becoming increasingly responsible for the greenhouse effect, but is nevertheless not covered by the Kyoto Protocol (KP).[2] Fuels used in international air and maritime traffic – so-called bunker fuels – are excluded from reduction and stabilization commitments for the first commitment period (2008 - 2012), because agreement could not be reached on the question of the assignment of such emissions. Since in international aviation at least two states are always involved, assignment could not be made – as in the Kyoto Protocol – according to the territoriality principle. At the same time, however, Article 2.2 of the Kyoto Protocol obliges states listed in Annex 1[3] to stabilize or reduce greenhouse gas emissions brought about by bunker fuels in co-operation with the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO).

A range of policies and measures are currently being discussed at a national and international level, in order to comply with commitments arising from Article 2.2 of the Kyoto Protocol. Besides technical standards for the limitation of greenhouse gas emissions, proposals primarily cover economic instruments, such as taxes and levies for the internalization of greenhouse gas emissions as well as voluntary agreements with the aviation industry (aircraft manufacturers, airline companies). Beyond that, the introduction of an emissions trading system[4] for international aviation is also being discussed. This instrument is of particular significance, since the Kyoto Protocol also foresees, in Article 17, the setting up of an international emissions trading system.

Greenhouse gas trading in international aviation, however, is not compatible with the Kyoto Protocol. At cruise altitude, apart from CO_2 it is above all NO_x, water vapour, contrails and cirrus clouds that contribute towards the greenhouse effect. Of these, only CO_2 is included in the Kyoto Protocol. The radiative forcing of CO_2 represents only a little more than one-third (37%) of the total radiative effect of all climate-impacting avia-

1 In 1990, the share of international aviation in the greenhouse effect was estimated at 2%.

2 In contrast to international aviation, greenhouse gas emissions of national aviation are included in the Kyoto Protocol.

3 In Annex I of the Framework Convention, western industrialized states (in the main, OECD states), Central and Eastern European states as well as the states of the former Soviet Union are listed. The individual reduction targets of Annex I States were laid down in Annex B of the Kyoto Protocol.

4 In English-speaking countries, emissions trading systems are also more precisely described as cap-and-trade systems. This highlights the fact that a limitation on emissions is a prerequisite for their trading.

tion emissions (Lee/Sausen 2000). The restriction of greenhouse gas trading in international aviation to CO_2 could therefore well lead to misdirected control, particularly as the impact on the greenhouse effect of those emissions not covered by the Kyoto Protocol – in contrast to CO_2 – is independent of flight altitude and the geographic point of emission. For instance, the complex impact of NO_x emissions, which give rise to both negative and positive effects, leads to a varying net effect, depending on whether NO_x is emitted in the northern or southern hemisphere (Lee/Sausen 2000).

On account of complex causal connections, the introduction of an emissions trading system for international aviation certainly involves more problems than the introduction of greenhouse gas trading in other sectors. Even when it can be assumed that this fast growing sector will initially emerge as a purchaser of emission rights, the design of an emissions trading system is none the easier as a result, since individual obligated parties (for example, airline companies) with declining traffic volume could well emerge as sellers of emission rights.

The ICAO confirmed at its recent 33rd Assembly that, in the long term, emissions trading is a cost-effective measure for the limitation of greenhouse gas emissions (ICAO 2001b*, p. 14*). It was initially intended, that emissions trading should also be considered as a measure for the fulfilment of commitments arising from Article 2.2 of the Kyoto Protocol. This passage was deleted, however, at the Assembly. In the short term, the ICAO relies on voluntary agreements. Beyond that, members are requested to push ahead with the development of market-based instruments.

The Commission of the European Union also recommends the long-term introduction of greenhouse gas trading for international aviation (COM (1999) 640 final).

2. The political arena of international aviation

The importance of aviation for the global climate has been known since publication of the IPCC Report “Aviation and the Global Atmosphere” (IPCC 1999) at the latest. At the international level, work on concepts for a reduction in its climatic impact has proceeded at the United Nations through the Framework Convention on Climate Change (UNFCCC) and at the International Civil Aviation Organization (ICAO). Non-government organizations (NGOs) are also involved in the political process, as is the aviation industry through representatives of airline companies and aircraft manufacturers.

Since a global solution has to be targeted, for reasons of efficiency and potential market distortion, but at an international level only co-operative solutions are possible, knowledge is required of policy makers and their respective positions in the negotiating process, when the issue is the development of a politically realizable concept on the limitation of the climatic impacts of international aviation.

2.1 The Framework Convention on Climate Change

At the Third Conference of Parties to the Framework Convention on Climate Change in 1997, agreement could not be reached on the assignment of emissions from bunker fuels (emissions from international aviation and shipping) in formulating the Kyoto Protocol. As a result, concrete reduction targets for emissions from bunker fuels were not laid down. Article 2.2 of the Kyoto Protocol requires Annex I States (States with reduction or limitation targets) to pursue limitation or reduction of greenhouse gases through co-operation with the ICAO and the International Maritime Organization (IMO).

The Subsidiary Body for Scientific and Technical Advice (SBSTA) of the UNFCCC is working on methods for improving reporting on bunker fuel emissions, as well as on concepts for the incorporation of these emissions into national inventories of greenhouse gases.

Co-operation between the SBSTA, ICAO and IMO has improved since 1990 through joint participation in meetings and the exchange of information on working plans and progress. In the meantime, representatives of the ICAO and IMO have reported at every SBSTA meeting on their activities concerning emissions from international aviation and shipping. They have also increased co-operation in methodical questions concerning the improvement of reporting (UNFCCC/SBSTA 1999).

According to the SBSTA, the quality of reporting by Annex I states on bunker fuels is in need of improvement with respect not only to accuracy, but also to consistency and comparability. The “IPCC Report on Good Practice and Uncertainty Management in National Greenhouse Gas Inventories”, which also provides information on methods for estimating emissions from bunker fuels, has been available to Parties to the Framework Convention since June 2000.

Issues concerning emissions from bunker fuels were discussed within the setting of the Seventh Conference of Parties to the Convention in Marrakesh in the autumn of 2001. EU representatives referred repeatedly to growing emissions of greenhouse gases from aviation and demanded guidelines for emission assignment compatible with the Kyoto protocol.

According to UNFCCC (2001), with the settlement in Marrakesh the basis was created for necessary work on the improvement of data quality and reporting on emissions from international aviation. In its final report, the UNFCCC also emphasized that further steps towards reconciling conflicting opinions were necessary on the question of what should happen once emissions have been correctly documented. The USA rejects assignment of emissions to states according to the Convention, without proposing appropriate alternatives. So far as emissions trading is concerned, the ICAO is of the opinion that its introduction requires the development of a new legal framework; so this option is not immediately available. The present demand by the USA to include air transport of developing states in the agreement is likely to impede progress (UNFCCC 2001).

According to Article 25 of the Kyoto Protocol (entering into force), it is possible to assign emissions to Parties to the Convention. It is nevertheless unclear how the USA can be involved, should it maintain its present stance (UNFCCC 2001). The withdrawal of the USA from the Kyoto Protocol makes the question of assignment considerably more complicated; and account has to be taken of the implications. By contrast, the introduction of other operational or market-based instruments is not dependent on assignment according to the Framework Convention. The EU should therefore pursue this solution (UNFCCC 2001).

2.2 International Civil Aviation Organization

The ICAO is a specialized agency of the United Nations that was founded in 1944 through the signing of the Chicago Convention on Civil Aviation by 50 states. The ICAO develops new standards, which are adopted in the form of legally binding annexes to the Chicago Convention. Its sovereign body is the Assembly; its governing body is the Council, whose 33 members are elected by the Assembly for a period of three years. Amendments to the annexes of the Chicago Convention require a two-thirds majority of the ICAO Council. The Assembly, which convenes every three years, examines in detail the work of the Organization as a whole and determines the course of the future work of its different bodies. All of the present 186 contracting states have an equal right to be represented at the meetings of the Assembly, and each state is entitled to one vote.

The environmental activities of the ICAO are largely undertaken by the Committee on Aviation Environmental Protection (CAEP), which is composed of experts from 19[5]

[5] Australia, Brazil, Canada, Egypt, France, Germany, Italy, Japan, the Netherlands, Poland, Russia, Singapore, South Africa, Spain, Sweden, Switzerland, Tunisia, Great Britain and USA.

member states and 11[6] observers. The CAEP supports the Council of the ICAO in the formulation of new principles and in the adoption of new standards for noise and emissions from aircraft. Standards and recommended practices concerning issues of environmental protection are contained in Annex 16, Part I (aircraft noise) and Part II (emissions) of the Chicago Convention on International Civil Aviation.

The CAEP presently comprises five working groups and a support group. Two of the working groups deal with noise-related issues and three with emission-related issues as well as market-based approaches to the limitation or reduction of aircraft emissions. The support group advises the CAEP on the economic costs and adverse ecological effects or ecological benefits of measures under discussion.

Reports of the Environment Committee are presented to the Council for examination, which decides on the CAEP's working programme and, assisted by the Air Navigation Commission and the Air Transport Committee, takes action on CAEP recommendations. In the case of recommendations on the introduction of new standards, or the supplementation of existing standards, there is a prescribed procedure for the participation of member states up to and including decisions of the Council.

Around 3,000 bilateral aviation agreements are based on the principles laid down in resolutions of the ICAO. Most of these agreements preclude taxes and levies on fuel for international aviation. Amendments to the agreements are only possible with the approval of the participating parties. So far as voluntary commitments and emissions trading are concerned, there is nothing in the Chicago Convention that prohibits their introduction (ICAO/CAEP 2000).

The work of the CAEP in the area of emissions has been the subject of greater attention since the drawing up of the Kyoto Protocol; in particular Article 2.2, which requires Annex I states to limit greenhouse gas emissions from international aviation in co-operation with the ICAO. As result, the CAEP was given the task of elaborating political approaches to the limitation or reduction of greenhouse gases from air transport, taking into account not only the results of the “IPCC Special Report on Aviation and the Global Atmosphere” (IPCC 1999), but also the demands of the Kyoto Protocol.

At the beginning of 2001, the CAEP presented a report on market-based approaches, such as a tax on aviation fuel, emissions levies, emissions trading, voluntary commitments as well as the development of a basis for assessment for the identification of the strengths and weaknesses of different approaches (ICAO/CAEP 2000). This involves a comprehensive analysis of market-based mechanisms, in which different reduction

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6 Greece, Norway, Arab Civil Aviation Commission (ACAC), Airport Council International (ACI), Economic Commission (EC), International Air Transport Association (IATA), International Co-ordinating Council of Aerospace Industries Association (ICCAIA), International Federation of Airline Pilots’ Associations (IFALPA), European Federation of Environment and Transport (T&E), United Nations Framework Convention on Climate Change (UNFCCC) and World Meteorological Organization (WMO).

targets and regional limitations are discussed, as well as the legal and political framework.

On this basis, the Environmental Committee decided on a working programme (ICAO/CAEP 2001a) for the following five to ten years, which provides for the development of an open emissions trading system in the form of a pilot project. Coordination with the UNFCCC is to be strengthened with a view to integrating an open emissions trading system in aviation into the Kyoto Protocol. Targets for emissions from international aviation should be developed, together with mechanisms for the distribution of emission rights, taking developing states into consideration. In addition, the CAEP intends to develop central elements of an open emissions trading system compatible with the Kyoto mechanism, including reporting, monitoring, compliance and sanctioning.

The development of a flight efficiency factor is also specified in the working programme as the basis for a levy with a neutral effect on revenue. Levies should be orientated towards the costs of remedying the environmental effects of emissions, to the extent that these effects can be identified and clearly assigned to air transport. Studies are to be conducted concerning the necessary monetarization of adverse effects, and guidelines developed for the identification of costs resulting from emissions. The CAEP would further like to provide detailed advice on the levying of charges and their utilization for the reduction of the environmental effects of air transport, which takes account of legal and administrative implications.

The Environmental Committee sees a need for research on the effects of measures for emission reduction on developing states, on the one hand, and on their effects on national and international air transport on the other hand. The effects of the introduction of different methods of emission reduction by individual states should also be investigated. A further area for analysis should be the interaction of market-based solutions for the reduction of CO_2 with control mechanisms for other emissions (such as NO_x, particulates or noise emission, as well as the use of incentives for emission reduction, such as “credit for early action” or “baseline protection”), with the aim of precluding disadvantages for pioneers in environmental protection. All analyses previously conducted by the ICAO have related exclusively to CO_2.

In order to inform and involve states that do not participate in the CAEP process, the CAEP organized a “Colloquium on Environmental Aspects of Aviation” in April 2001, in which around 200 participants from over 50 states and 20 international organizations took part. Here, the global effects of aircraft emissions and different options for the limitation or reduction of greenhouse gases were discussed. Consideration was given to amending Annex 16 of the Chicago Convention to include emissions of global impact.

ICAO principles on environmental protection were laid down at the 33rd Assembly in the autumn of 2001 in Resolution 33-7 (ICAO 2001a). Concerning the limitation or reduction of the environmental effects of emissions from aircraft engines, it was resolved that in recommendations to the Conference of the Parties (COP) to the Climate Convention particular emphasis should be put on the application of technical solutions while market-based approaches are still being examined (ICAO 2001a). Technical solutions are understood to include technologies and standards aimed at ground-level emissions, and they concern, in particular, nitrogen oxide. A CO_2 standard is not planned, however, because CO_2 emission is directly linked to fuel consumption and, as a result, is in any case subject to economic pressure. Operational measures, such as air traffic control and air traffic movement (ATC/ATM) are also mentioned with respect to the reduction of fuel consumption.

The Resolution also contains an appendix on market-based instruments in air transport, in which emissions trading, voluntary commitments and emission charges are discussed. It was decided that the Council should prepare guidelines for states on the introduction of market-based measures; and all participants were called upon to examine the costs and benefits of individual measures, so that emission reduction can be achieved in the most cost-effective way.

The ICAO Assembly is basically of the opinion that, from the long-term point of view, an emissions trading system represents a cost-effective means of limitation or reduction of CO_2 emissions from air transport, so far as it concerns an open emissions trading system. The Assembly therefore approved the development of an emissions trading system for international aviation, and instructed the Council to draw up guidelines for open trading and, at the same time, to pay particular attention to the creation of general structural and legal conditions for the participation of aviation in an open emissions trading system.

The ICAO estimates that voluntary commitments could serve in the short term as an initial step towards future measures and further emission reductions. The Resolution therefore requires the Council to facilitate voluntary agreements through the development of guidelines and a system for voluntary commitment.

Emission-related levies were also the subject of discussion at the 33rd Assembly of the ICAO, and the continuing validity of the 1996 Resolution (ICAO1996) on levies and taxes was confirmed. It is recommended that a levy be chosen in preference to a tax, and that receipts should primarily be used to lessen the environmental effects of air transport. The size of the levy should be related to the costs of remedying environmental effects, to the extent that they can be identified and directly assigned to air transport. Member states were called upon to refrain from unilateral action in the introduction of levies where such action is inconsistent with the present resolution.

Following broad agreement on emissions trading in international aviation, the future work of the CAEP will concentrate on concretizing and defining the form of the emissions trading system. Efforts are particularly required concerning the defining of reduction targets, the method of assignment, clarification of the relationship of international to national air transport and the regulation of flights between a state that participates in emissions trading and a non-participating state (ICAO/CAEP 2001b).

2.3 European Union

With the incorporation of political goals for climate protection into sectoral policy areas, the EU, in its 6th Environmental Action Plan (European Commission 2001c), directed its attention to aircraft emissions. Should agreement on appropriate measures not be achieved within the ICAO by 2002, the EU intends to implement its own measures for the reduction of aircraft emissions.

The European Commission published a Communication in December 1999 on the subject of “Air Transport and the Environment” (European Commission 1999), which was intended to set the direction for the work of the Commission in the following years. For the first time, paths towards coherent and integrated EU policy action in the area of air transport were analysed and identified.

The EC Communication proposes the introduction of economic and regulative incentives to promote environmentally favourable undertakings and state-of-the-art technology. The aviation industry is explicitly called upon to adopt a proactive course for the reduction of the environmental effects of air transport. In order to create fair conditions of competition for all means of transport, work should be undertaken towards the internalization of environmental costs.

The Commission also announced in its Communication that, on the basis of the results of the ICAO Assembly at the end of 2001, it will undertake a reappraisal of global, Community and local measures with a view to ensuring fulfilment of the environmental goals laid down in the Amsterdam Agreement and the Kyoto Protocol, and will update priorities should progress not be made at the international level and/or new scientific evidence emerge on the environmental effects of air transport. Concerning the importance of pending decisions within the ICAO, it was emphasized that the EU should improve the promotion of its interests.

Besides questions of aircraft noise, the development of standards, operational measures and the promotion of industry initiatives, the Communication also addressed economic incentives, such as aviation fuel tax, environmental levies and emissions trading. The Communication emphasized that consideration of emissions trading occurs within the context of implementation of the Kyoto Protocol, and that the fulfilment of emission reduction targets through emissions trading will for the most part be decided at a state level. In practice, this could lead to a varying degree of pressure on the aviation industry, due to different levels of reduction commitments on the part of individual states, and could give rise to unfair competition.

The Communication also looked at possibilities for implementation of an emissions trading system at a national or regional level. Trading in emission rights at airports was also discussed; in which case trading mechanisms ought to be compatible with the rules governing the allocation of slots.

The Commission mentioned carbon offsets as a further possibility for lessening the environmental effects of air transport. This concerns a system that allows emitters to offset the climatic impact of emitted greenhouse gases with investment in carbon storage. Due to insufficient scientific knowledge concerning the effect of such measures on the absorption of CO_2, the Commission pointed out that scientific research was necessary in this area before appropriate political concepts could be developed.

The next step, according to the Commission, will be the continuation of work on the introduction of a European environmental levy in air transport in co-operation with the ICAO. Work is directed, in particular, at determining the point at which the charge is levied, at developing, in co-operation with Eurocontrol,[7] a method for levying the charge and rules concerning decisions on the use of receipts, as well as at examining opportunities for emission levies at airports.

The Commission will continue to work on innovative concepts for economic instruments, such as emissions trading and carbon offsets, taking general legal conditions into consideration, and will examine the appropriateness of these instruments for the solution of environmental problems in air transport. 2001 was mentioned as target date in this Communication of December 1999. Until such time as political concepts have been developed in the areas mentioned, the Commission intended to stick to its proposal for the levying of a tax on aviation fuel (COM (1996) 549 - 1).

In a Commission Communication of March 2000 on the “Taxation of Aircraft Fuel” (European Commission 2000), background information was presented and general conditions for the taxation of aviation fuel described.

The taxation of mineral oil is regulated in the European Union by Council Directive 92/81/EEC of 1992. Member States can, however, introduce regulations that differ from those in the Directive. Article 8(1)(b) of the Directive provides for tax exemption of commercially-used aviation fuel. Article 8(7) of the same Directive demands reconsideration of this tax exemption in the form of a report of the Commission, which ought to consider external costs and implications for the environment and contain a proposal for the abolition of the special treatment of aviation fuel. The Report, which was presented in 1996, recommends extending the tax on oil to cover aviation fuel as soon as international legal instruments permit this for all flights; that is, also for flights from third states.

The findings of the Report are reflected in Article 13(1)(c) of the Commission proposal for the restructuring of the Community framework for the taxation of energy products (COM (1997) 30), which is intended to replace Directive 92/81/EEC. Article 13(2) provides that Member States can tax national flights and flights between Member States on the basis of bilateral agreements.

A study on the taxation of aviation fuel was commissioned at the request of the European Council (European Commission 2000). The study of the consortium “Resource Analysis” (MVA/DNAL/IIAS 1998) comes to the conclusion, that for economic reasons it is neither practicable nor desirable for the EU as a whole to levy a tax only on flights of European airlines within the Community (European Commission 2000). The positive environmental effects of such a tax would also be relatively low. The benefit for the

[7] European Organization for the Safety of Air Navigation.

environment would be considerably greater if all flight movements from European airports were subject to the tax. According to the Commission Proposal, revenue from the tax should be used to reduce other taxes and levies, in particular non-wage labour costs.

Resulting from the study, the Commission has come out in favour of greater efforts on the part of EU States within the ICAO towards the introduction of a tax on aviation fuel and other measures of comparable effect (European Commission 2000). G8 foreign ministers have also spoken out in favour of internalization of the external costs of air transport through the introduction of an international tax on aviation fuel, and have announced greater efforts within the ICAO, which have not yet materialized. The tax rate would have to be at the same level worldwide (Kirwin and Blau 1999).

In March 2000, following negotiations on the part of finance, transport and environment ministers, only Germany, the Netherlands and Belgium expressed full support for a Community tax on aviation fuel. Spain demanded the introduction of the tax at an international level, fearing distortions in competition from an aviation fuel tax restricted to the EU (Kirwin 2000).

In the period leading up to the 33rd Assembly of the ICAO, the European Commission informed ICAO member states (European Commission 2001a) of the EU position on market-based instruments in air transport and on European initiatives in this area. The EU emphasized the necessity for incentives for the reduction of emissions from air transport and reiterated its attitude towards the equal treatment of all fuels, included aviation fuel, with reference to current examination of the introduction of an EU tax.

In the same paper, the EU welcomed ICAO work on innovative concepts for environment-related economic instruments, such as emissions trading, through which ecological effects could possible be achieved identical to those expected from levies or taxation, but with lower costs (European Commission 2001a). The Commission had been requested by the European Council to work within the ICAO on the introduction of a tax on aviation fuel or of measures of similar effect. Within the EU, work was already proceeding on the creation of legal instruments for the introduction of a Community tax on aviation fuel. Due to international regulations, however, international flights would be excluded.

The European Union took the view that until work within the ICAO had been concluded, all options – whether aviation fuel tax or other instruments – should remain open. Finally, the EU requested the 33rd Assembly to enable Annex I states to fulfil their commitments with regard to Article 2.2 of the Kyoto protocol. The EU had prepared a corresponding paper on emission standards (European Commission 2001b), in which it requested the Assembly to continue work on the development of new emission standards. Such standards should cover different gases in all flight phases; that is, not only the landing and take-off phase (the so-called LTO cycle). In addition, the EU proposed a non-production rule, which should affect all aircraft manufactured after 2007 that do not fulfil the CAEP/4 NO_x Standard.

Following the 33rd ICAO Assembly, in the period leading up to the COP 7 in Marrakesh, the European Council of Environment Ministers emphasized the absolute necessity for action to curb growth in aircraft emissions (RAC-France 2001). It welcomed the progress achieved at the 33rd Assembly and urged the CAEP to set a definite time frame for acceptance of the measures by the ICAO Council.

As already resolved by the European Council of Transport Ministers in April 2001, the Council of Environment Ministers reiterated the necessity for the speediest possible elaboration of guidelines on voluntary commitments and emission levies, taking account of economic, ecological and competition-policy issues. The EU would work towards necessary decisions in all forums. Furthermore, the Council of Environment Ministers advocated unilateral European action on the reduction of greenhouse gases from air transport, should the ICAO not agree to such measures by 2002 (RAC-France 2001).

Moreover, the European Civil Aviation Conference (ECAC) strives for close cooperation between the EU and the ICAO. Similar to the ICAO, the ECAC pursues the goal of ensuring safe and economic air transport for Europe that is also beneficial to the environment. The resolutions passed by the ECAC are, however, not legally binding on Member States. Within the ECAC, an "Expert Group on the Abatement of Nuisance Caused by Air Transportation" (ANCAT) concerns itself with the reduction of aviation-related environmental problems.

2.4 Federal Republic of Germany

A Resolution of the German *Bundestag* of 19. March 1997 instructed the federal government to speed up the introduction of an EU tax on aviation fuel (Kulick 2001a). A similar commitment is to be found in the coalition agreement of 1998, where mention is made of the general dismantling of subsidies such as turnover tax exemption for cross-border air transport. In the coalition agreement of 2002 the parties agreed to press for the introduction of a tax on aviation fuel at the European level. In addition, emission-related landing charges were to be introduced in Germany and the exemption from turnover tax of cross-border flights within the EU lifted.

The Green Party (*Bündnis 90/Die Grünen*) had already formulated in 2000 a "Proposal for a Community air transport levy", which would have a similar effect to that of aviation fuel tax, but easier to realize legally, as it does not affect bilateral agreements (Kulick 2001b). The levy should be calculated on the basis of the total emissions of all flights, and charged for every take-off and landing at EU airports. A rate of 2.5 to 7.5 cents per litre of aviation fuel was initially proposed. Markups were to be calculated specific to aircraft type, flight route and flight altitude, in order to create an incentive to fly in a manner more favourable to the environment and to develop aircraft that give rise to less pollution. With the introduction of the levy, 25 to 50% of emissions were to be saved compared with the trend (Kulick 2001b), which is a very high estimate.

The Federal Ministry of Transport, Building and Housing (BMVBW) is currently developing a method of introducing emission-differentiated landing charges on the basis of a report by an ANCAT working group (ERLIG, Emissions-Related Landing Charges Investigation Group).

The *Bundestag* Fact-finding Committee on the Global Economy recommends limiting aircraft emissions to one-half of growth in trend development to 2012 (Enquete Kommission 2002). It proposes an emission-related levy that should at least apply throughout the EU. Alternatively, an open emissions trading system could be established that is compatible with the Kyoto Protocol. If possible, all climatically-relevant aircraft emissions should be taken into account, not only CO_2. This applies, in particular, to the second commitment period. Furthermore, the ICAO should tighten up current NO_x standards. On account of the incomparably greater impact of supersonic aircraft on the climate, their use in civil aviation should be renounced.

The Fact-finding Committee also supported the proposal of the German Advisory Council on Global Change (WBGU) for the introduction of fees for the use of global public goods (WBGU 2002). Moreover, consumer awareness should be strengthened by providing information on the climatic impact of each flight on flight tickets.

2.5 Non-government organizations

Environmental associations and non-government organizations (NGOs) have urged for some considerable time that direct and indirect subsidies of air transport be dismantled, the resultant distortion in competition between different transport systems corrected and the internalization of the external costs of air transport tackled (DNR 2001).

Environmental associations such as Transport and Environment (T&E) and those that have joined forces in the *Deutschen Arbeitskreis Flugverkehr* [German Working Group on Air Transport] – *Deutscher Naturschutzring (DNR)*, *Verkehrsclub Deutschland (VCD)*, Germanwatch, *Bundesvereinigung gegen Fluglärm* and Robin Wood) – demand European initiatives and, if necessary, unilateral action by the EU on environmental protection in air transport. The European Commission should speedily present a proposal for a directive on the introduction of a European levy on aircraft emissions. The European Parliament, EU Environment Council and EU Transport Ministers have already made similar demands (DNR 2001).

2.5.1 Transport and Environment (T&E) and the International Coalition for Sustainable Aviation

Transport and Environment (T&E), the umbrella organization of European NGOs in the transport area, co-ordinates within the framework of UN climate negotiations the NGOs that are active in this area and enjoys observer status with the CAEP (Treber 1999). In this function, T&E has presented a position paper (CAEP/5-WP/82) on market-based approaches and made the following recommendations (T&E 2001):

- The ICAO should define a CO_2 goal for the first commitment period in accordance with the Kyoto Protocol (5% below the level of 1990).
- The ICAO should further facilitate the two-stage introduction of market-based mechanisms for the reduction of CO_2 emissions:
  1. An emissions levy not only for the landing and take-off phase (LTO cycle), but also for the cruise phase (cruise cycle), and its introduction by the 34th Assembly in 2004 at the latest.
  2. Attainment of the 5% reduction target (reference year 1990) through continuation of the levy and/or the establishing of an open emissions trading system, which should begin with the first commitment period in 2008.
- For the purpose of controlling all other greenhouse gas emissions in aviation, the ICAO should introduce not only a NO_X standard for the cruise phase, but also develop market-based mechanisms and, if necessary, carry out an assessment of CO_2 emissions, in order to cover the sector's total greenhouse gas potential.
- The ICAO should inform the COP 7 of the manner by which emissions should be reduced and also of the size of the reduction. Should an appropriate solution not be achieved at the 33rd Assembly, the COP 7 should come to a decision on emission assignment and present a corresponding plan.

The Director of T&E also directed these demands at the 15 EU environment ministers in a letter of 15. February 2001 (T&E 2001), in which the necessity of European commitment to the search for a global solution was emphasized.

After assessing the ICAO process, however, the T&E director came to the conclusion, that for a global solution not enough major steps are being undertaken to turn air transport into an ecologically sustainable sector in the near future. To accelerate developments in the ICAO and the UNFCCC, the environment ministers are called upon to urge the COP to resolve the question of assignment, and to include aircraft emissions in the emission inventories of the contracting States. The environment ministers are also requested to support the European Commission in the position it has taken within the ICAO/CAEP, with particular regard to the introduction of a worldwide levy. From both an administrative and a political point of view, a levy would be easy to introduce and implement.

Environment ministers are further called upon to contact transport and finance ministers at the European level, whose responsibility also extends to this area, and to implement measures for the introduction of an environment levy for air transport. They should also request the Commission to put forward a proposal by the end of 2001 for the introduction of a European environment levy for air transport, which should take effect in 2002.

The International Coalition for Sustainable Aviation (T&E ICSA Project) was founded in 1998 to assume the role of an NGO with observer status in the Environment Committee of the ICAO. T&E has fulfilled this function on a representative basis since 1999.

ICSA is an international network of environmental NGOs from the areas of atmospheric pollution, climate change and aircraft noise. In a paper published in 2000 (ICSA 2000), the ICSA criticized the ICAO process on the following issues:

- CAEP concentrates primarily on market-based approaches, neglecting control mechanisms, which are necessary to achieve the environmental goal, and measures for the promotion of alternative means of transport.
- Market-based instruments relate only to CO_2 emissions. Due to flight altitude, however, aircraft emissions produce an effect that is three times as intense as that of carbon dioxide alone.
- It is unlikely that the ICAO will approve measures that find global application. On the contrary, during the first commitment period (2008-2012) it will confine itself to developed states.
- The question of the assignment of international emissions is still unresolved, with the result that individual states have no clear responsibility for their contribution.

2.5.2 Center for Clean Air Policy (CCAP)

The Center for Clean Air Policy (CCAP), based in Washington DC, was founded in 1985 by progressive state governors to develop market-based approaches to the reduction of acid rain. CCAP concerns itself in the meantime with market-based solutions for the reduction of ozone, greenhouse gases and toxic atmospheric contaminants. As a part of ICSA, CCAP plays an active role in climate negotiations and is an acknowledged pioneer in the application of flexible mechanisms for the reduction of greenhouse gases. CCAP is currently working on different options for the registration of aircraft emissions by way of emissions trading and other flexible mechanisms.

Within the framework of the “Policy Options for Reducing Aviation Emissions” project, CCAP is also working at an international level on cost-effective measures for the registration of CO_2 and nitrogen oxide from air transport. In this connection, CCAP also analyses reduction potentials through emissions trading at the airport level.

CCAP is an official observer with CAEP, where it puts forward proposals to the responsible working group and strives for close co-operation not only with the ICAO, but also with NGOs and the aviation industry, in order to make headway with a programme on emission reduction.

2.5.3 Germanwatch

The North-South action group Germanwatch, which, among other issues, is actively involved in climate protection, regards the results of the 33rd Assembly of the ICAO as unsatisfactory. It criticizes, in particular, the failing link to the Kyoto Protocol and the lack of target dates for further steps towards climate protection in the air transport sector (Treber 2001). Germanwatch also draws attention to the fact, that it is generally transport ministers that are sent to ICAO negotiations, who have less to do with climate issues than representatives of environment ministries, which themselves take part in UNFCCC negotiations (Treber 1999).

The Resolution nevertheless allows unilateral action by the EU on the issue of emission levies, in so far as the guidelines are covered by the Resolution of the ICAO Council on taxes and levies of 1996 (ICAO 1996).

In a press release of September 25th, 2001, Manfred Treber, the Germanwatch advisor on climate and transport, supported the EU position in the air transport sphere. An EU levy on aircraft emissions could very well be linked with the climate-compatibility of emissions, and would be in line with international law. This way, emissions such as nitrogen oxide and contrails (condensation trails) could even be considered, which are not referred to in the Kyoto Protocol (Germanwatch 2001).

2.6 The Aviation industry: airline companies and aircraft manufacturers

The International Air Transport Association, IATA fears unilateral action at a national level, through which different standards could emerge due to inadequate co-ordination. Despite high rates of growth, airline companies operate in a highly competitive market that leaves little room for pioneers and unilateral action (Treber 1999).

IATA emphasizes that in the last ten years fuel efficiency has been increased by 17%, and that a further increase of 10% is expected in the period to 2010 (Cowe 2001). As a result, aircraft are already 65% more efficient in terms of passenger kilometres than in 1970. Other sources, however, claim lower increases in efficiency for this period. According to IATA, fuel waste is primarily caused by poor air traffic management (air traffic control and tailbacks), as a result of which aircraft have to remain longer in the air. Improvement in this respect is not possible on the part of airline companies, but is the responsibility of individual governments (Cowe 2001).

IATA largely rejects the limitation of growth through taxes or levies on the grounds of growing demand and, in many places, a lack of alternative means of transport. IATA relies, above all, on improvement in system efficiency through operational measures and on increases in the efficiency of fuel consumption, and it commissioned a report on these issues in 1999 (Dobbie 1999). Through CNS/ATM,[8] a decrease in fuel consumption of 8 to 18% could be achieved. According to IPCC (1999), through optimization of weight, capacity utilization and flying speed, further savings of 2 to 6% are possible.

On the other hand, voluntary commitments on the part of airline companies are advocated. Certain airline companies have already laid down efficiency targets for fuel consumption. British Airways, for instance, has set itself the target of a 30% improvement in fuel consumption by the year 2010 (British Airways 2001b). IATA has also an-

8 CNS/ATM (Communication, Navigation, Surveillance/Air Traffic Management) defines the individual elements and mode of operation of a future air traffic control system.

nounced the introduction of voluntary productivity-related targets for CO_2 control (Dobbie 1999).

The largest airline company, British Airways, refers in its statement, “British Airways and Climate Change: Our Views” (British Airways 2001a) to a further need for research on the dispersion and effect of NO_x and water vapour. An international inventory for the assignment of aircraft emissions is favoured, since it would facilitate necessary control measures.

Taxes on aviation fuel are rejected as not cost-effective. Hugh Somerville, head of the environment department at British Airways, regards them, in fact, as ecologically ineffective (Somerville 2001). An open emissions trading system at an international level, on the other hand, is not only fully effective from the ecological point of view, it also fulfils the criterion of cost-effectiveness. According to Somerville, the integration of the flexible mechanisms of Joint Implementation and Clean Development Mechanism is also conceivable.

The airline endorses the British emissions trading system and has financed a report on it by the Institute of Public Policy Research, which came to the conclusion that emissions trading is the best option for air transport (British Airways 2001b).

Somerville (2001) admits that the problem is not to be solved just by an improvement in technology. The external costs of air transport have to be identified. A package of measures has therefore to be developed comprising a combination of emissions trading, voluntary measures and an alteration of the regulation of fees. Parallel to this, aircraft manufacturers should strive for an improvement in fuel efficiency, which will allow fuel savings of 40 to 50% by the year 2050. Through operational measures, on the other hand, only a relatively low improvement of 6 to 12% is possible, which will primarily be achieved through improvements in Air Traffic Control and Air Traffic Movement Systems (ATC/ATM) (British Airways 2001b).

Long-term alternatives, such as hydrogen, methane or biomass are described as technically feasible, but they are not considered to be options for the short or medium term (British Airways 2001b).

Lufthansa has a modern fleet, and thus relatively efficient aircraft. Due to membership in Star Alliance, however, its freedom to support general conditions favourable to the climate is limited (Treber 1999).

Aircraft and engine manufacturers, such as Airbus and Boeing, should be interested in the accelerated introduction of fuel-saving aircraft, since this would increase their turnover. In fact, however, no increased involvement in this area is to be observed.

Some engine manufacturers, such as SNECMA, have developed engines that are considerably less harmful to the climate, but the market has not responded due to general conditions (Treber 1999).

2.7 General political conditions for the introduction of an emissions trading system

The starting position for the introduction of an emissions trading system is quite complex. This is shown by the above review. Many of the relevant parties recognize the growing contribution of air transport to the greenhouse gas effect and environmental pollution, and they also see the necessity to take measures for their reduction.

The demands of environmental NGOs go the furthest. They demand a CO_2 reduction target for international air transport comparable to the Kyoto Protocol and the introduction of market-based mechanisms (taxes or emissions trading) that cover all greenhouse gases from air transport, supported by the laying down of extensive standards (NO_X).

The aviation industry points out in return, that specific emissions have been considerably reduced in the past, and that further increases in efficiency are also to be expected in the future. They recognize, however, that this will not be enough to reduce or limit increasing aircraft emissions. They reject the limitation of growth through taxes or levies and plead instead for voluntary agreements or open emissions trading, through which the aviation sector can acquire emission rights from other sectors.

The necessity and urgency of measures in air transport have also been long recognized in the EU and by the German government. In the EU, for instance, the introduction of a Community tax on aviation fuel is being discussed; a proposal that is supported by the German government but rejected by other Member States, such as Spain, on the grounds that this could lead to distortions in international competition. An EU position was elaborated in preparation for the 33rd ICAO Assembly, in which the introduction of emissions trading in aviation was also supported.

The question of emissions trading was examined together with other free-market instruments at the ICAO. Discussions on the issue were conducted in the Committee on Aviation Environmental Protection, which had been instructed by the Assembly to develop central elements of an open emissions trading system, including reporting, monitoring, compliance and sanctioning, that are comparable with Kyoto mechanisms.

Despite these differing – in part, diverging – interests, nearly all parties are open-minded about an emissions trading system that is compatible with the Kyoto Protocol. What is missing at the present time, however, is a detailed conception of the form of such a system and of how it could be linked with emissions trading under the Kyoto Protocol.

3. Aviation emissions relevant to the climate

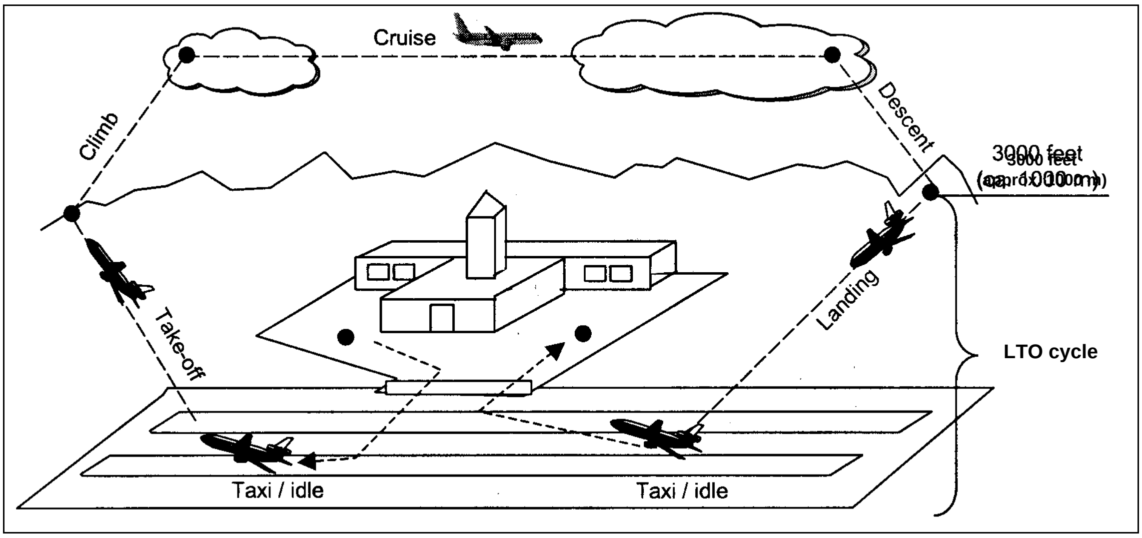
As a result of aviation, emissions are expelled into the global atmosphere that contribute to climate change and the destruction of the ozone layer. Emissions and expelled particulates alter the concentration of greenhouse gases – carbon dioxide (CO_2), ozone (O_3) and methane (CH_4). They also trigger off the formation of contrails and can encourage the occurrence of cirrus clouds. All of this contributes to climate change (IPCC 1999).

In developing an emissions trading system, the particular challenge is to be found in the fact that the causal connections as well as the greenhouse effect of aviation emissions are highly complex and dependent on numerous exogenous physical and chemical factors, such as temperature and chemical composition of the atmosphere. In this chapter, following an introductory description of aviation, qualitative and quantitative causal connections are described, in order that an appropriate basis for assessment can be established for an emissions trading system.

3.1 Geographic point of origin of aviation emissions

In aviation, fuel consumption and emissions are generally subdivided into zero altitude (ground level), landing and take-off (LTO cycle up to 3,000 feet / 915 metres), climb and descent, as well as cruise phases. In Figure 1, the different flight phases are displayed.

Figure 1: Flight phases



Source: AEIG 2001a

During cruising, as well as at the end of the climb phase and at the beginning of the descent phase, an aircraft in international traffic flies predominantly at an altitude of between 9 and 12 km above sea level. Only supersonic aircraft fly at a higher altitude of around 17 to 20 km.[9]

Emissions from subsonic aircraft affect, for the most part, the upper troposphere, those of supersonic aircraft the lower stratosphere. The boundary layer between both spheres, the tropopause, is also greatly affected. Ozone chemistry, in particular, reacts more sensitively to anthropogenic emissions in these spheres than at ground level. This is attributable to slower blending processes, lower temperatures and more limited background contamination (Schumann 2000a). The altitude of the tropopause depends on geographical latitude, time of the year and current weather conditions. On the equator it lies at an altitude of around 16 km, at the poles at around 8 km. (Schmidt 1994).

The chemical composition of the spheres differs. Since this has a decisive influence on the effect of aviation emissions, the point of emission plays an important role with reference to their greenhouse gas effect. Differentiation according to flight altitude and geographic latitude is of fundamental importance for effect analysis.

3.2 Impacts of aviation on the greenhouse gas effect

Climate change due to aviation can basically be attributed to three types of process (IPCC 1999):

- Direct emissions of a radiatively active substance (carbon dioxide and water vapour).
- Emissions of a chemical substance that forms or breaks down radiatively active substances (nitrogen oxide).
- Emissions that increase the formation of aerosols or lead to a change in the natural formation of clouds (particulates and water vapour).

The effect of individual aviation emissions on the greenhouse gas effect during cruising are described and corresponding causal connections explained below. Analysis of impacts on the greenhouse gas effect is focused on the effects of subsonic aircraft; those of supersonic aircraft are mentioned only in passing.

Carbon dioxide is the most important greenhouse gas, which prevents long-wave radiation from the earth into outer space. It has a long retention time in the atmosphere of the order of one hundred years. This has the consequence that carbon dioxide accumulates and unfurls a global effect.

So far as the greenhouse gas effect is concerned, no difference in effect is to be established between carbon dioxide emissions from aviation and those from anthropogenic

9 In 1996, 13 supersonic aircraft were in operation in international civil aviation (UNFCCC/SBSTA/1996/9/Add.2). The operating airlines, British Airways and Air France, have announced (British Airways, 10.04.2003) the discontinuation of supersonic flights at the end of October 2003 “for commercial reasons”.

sources (IPCC 1999, p. 202), since persistent carbon dioxide is independent of the geographic point of emission. The impact of carbon dioxide on the greenhouse gas effect grows steadily with increasing emission. Apart from a low saturation effect, a doubling of atmospheric concentration also leads to a doubling of the greenhouse effect (Brockhagen/Lienemeyer 1999). The effect as a whole can be described as good in comparison to many other emissions (Tsai et al. 2000, p.783).

Similar to carbon dioxide, **water vapour** is a direct product of the combustion of fuel. It is emitted by subsonic aircraft for the most part into the troposphere, where it is washed out relatively quickly – within one to two weeks – by precipitation. The negligible proportion of water vapour that is emitted into the lower stratosphere, in particular from supersonic aircraft, can compress to greater water vapour concentrations and contribute to ozone depletion. Since water vapour is a greenhouse gas, greater concentration can increase the negative effect on climate change. Water vapour can also encourage the formation of contrails and cirrus clouds. With supersonic aircraft, the disruption of the water balance in the lower stratosphere probably represents the most serious problem for the greenhouse gas effect. On the whole, however, chemical dependencies have not yet been sufficiently researched (IPCC 1999, p.188).

Contrails form in sufficiently cold air through the warm and humid water vapour emissions of aircraft. As a result of an increase in the relative humidity of the cold ambient atmosphere air crystals are created, which are visible as lines of clouds. Ice particles evaporate quickly in dry air, and contrails last for only a short period. The contribution to climate warming is negligible. When the ambient atmosphere is saturated with ice and very humid, contrails can persist and spread out (Schumann 2000a). Once they have lost their characteristic lined form through convective processes, they are no longer to be distinguished from cirrus clouds. Persistent contrails reduce not only solar radiation onto the earth's surface, but also the quantity of long-wave radiation from the earth into outer space. On average, they increase the greenhouse effect, in particular during the night and over warm and light surfaces.[10] The radiation effects of contrails depend on surface covering and on their optical properties; and too little is known about both (Schumann 2000a).

A necessary prerequisite for the formation of contrails is the existence of condensation nuclei in the form of particulates, which make possible the formation of drops of water (EPA 2000). Models have shown, however, that contrails also develop without the emission of soot and sulphates from aviation; the background concentration of particulates in the troposphere and stratosphere can alone be enough (IPCC 1999, p.111). However, aircraft emissions of soot and sulphate have, on average, a greater climatic

[10] During the period following the terrorist attacks of 11. September 2001, when all commercial aircraft were grounded, scientists discovered pointers to the influence of air transport on temperature. Vapour trails reduce the difference between daytime maximum and night-time minimum temperature on average by more than one degree (Travis/Carleton/Lauritsen 2002). Because the period of observation was very short, this can be treated only as an indication, and not as scientific evidence.

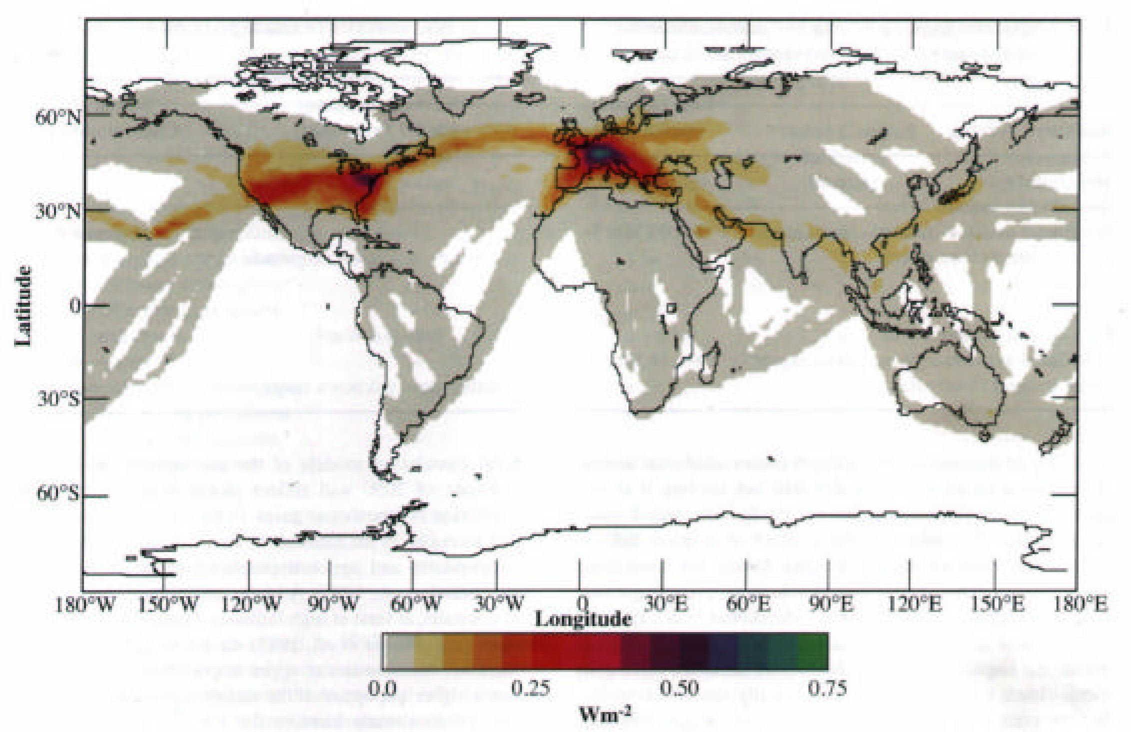
impact due to their optical properties. The mechanisms that lead to the formation of contrails are very complex. Nevertheless, the formation of contrails can be accurately predicted for given atmospheric temperatures and conditions of humidity (IPCC 1999); the estimation of their climatic impact is, however, fraught with uncertainty.

The development of **extensive cirrus clouds** from persistent contrails can be observed in air layers saturated with ice. Ice particles develop through the absorption of water vapour from the environment. According to the latest scientific knowledge from the TRADEOFF Project, it is assumed that aviation-related aerosols act as seed crystal in the formation of cirrus clouds (Mrasek 2003). Several studies have reached the conclusion that a positive correlation exists between aircraft emissions and growth in cirrus clouds. Cirrus clouds intensify the greenhouse effect, because, similar to contrails, they reflect radiation onto the earth. However, up to now the mechanisms that lead to growth in cirrus clouds and the causal connections between contrails and greenhouse gas effect are not yet sufficiently researched (IPPR 2001).

Only clarification of the development mechanism can ultimately confirm the causal connection between aviation emissions and the formation of cirrus clouds. The mechanism is difficult to analyse, however, since aviation-related emissions and the formation of cirrus clouds do not occur simultaneously. Contrails can disappear from the sky, only to re-emerge later as cirrus clouds (FR 16.07.2003).

The extent of covering with contrails and cirrus clouds is influenced not only by the global spread of ice-saturated air masses, but also by the number of flights through these air layers. Ice-supersaturated air masses, in which persistent contrails and cirrus clouds can be formed, are variable in time and space. Where ice saturation of the ambient atmosphere is upwards of 30%, ice crystals develop from excessive water vapour that are visible as persistent contrails. Ice supersaturation in regions highly frequented by aircraft is often too low for the occurrence of natural persistent contrails and cirrus clouds. When water vapour is additionally emitted by aircraft, however, ice saturation of 15% is sufficient for aircraft emissions to cause the formation of cirrus clouds (CE 2002a). Regions in which contrails and cirrus clouds can be caused by aircraft are predominantly found in the upper troposphere and tropopause; that is, at an altitude of 16 km in the tropics and at 10 km in moderate latitudes. Because an altitude of 10 km is a typical cruising altitude, the formation of contrails and cirrus clouds through aviation is favoured in the northern hemisphere. Ice-saturated regions, in which contrails have occurred in the past mainly as a result of air transport, can be reliably localized: USA, Europe and the North Atlantic (Figure 2).

Figure 2: Global distribution of net instantaneous radiative forcing at the top of atmosphere and in daily and annual average for present (1992) climatic conditions and analyzed contrail cover



Source: IPCC 1999, p. 105

Measurements of humidity have shown, however, that only about 14% of flight time was in air masses that were ice-supersaturated with a mean value of 15% (IPCC 1999, p. 88), in which potentially persistent contrails and cirrus clouds can occur. Other sources (IPCC 1999, p.91) state that 10 to 20% of air masses in Central Europe and 16% on global average are cold and humid enough to allow persistent contrails to form. CE assumes that 13.5% of flight time is in regions that are sufficiently saturated, and, moreover, that in 75% of flight time through ice-saturated regions (so-called critical flight time) contrails are in fact formed (CE 2002a). Based on the assumption that flight time is proportional to covered flight kilometres, CE comes to the conclusion, that total radiative forcing as a result of the formation of contrails occurs only during about 10% of flight time (CE 2002a).

As in the case of contrails, **nitrogen oxides** (NO_x, a compound of NO and NO_2) have a very much shorter retention time in the atmosphere than carbon dioxide, and they concentrate, therefore, in the area around air traffic corridors. So-called “hot spots” – local peak loads – can arise, particularly in the mid-latitudes of the northern hemisphere (IPCC 1999) where aviation is most intensive. Nitrogen oxide concentration in the upper troposphere is roughly 1,000 times lower than in urban regions; the retention time of nitrogen oxide on the earth's surface is about 10 times lower than near the tropopause. For these reasons, the relatively low NO_x emissions from aircraft have a considerable influence on nitrogen oxide concentration in the proximity of the tropopause (Schumann 2000a).

Nitrogen oxide emissions act as a precursor; that is, as a substance that may participate in or influence a chemical reaction in air to produce a new substance, which can have a significant influence on the greenhouse gas effect. In the troposphere and the lower stratosphere, nitrogen oxides contribute to the formation of ozone; at higher levels, on the other hand, they hasten the destruction of ozone (IPCC 1999). Due to the short retention time[11] not only of nitrogen oxides, but also of ozone, it is primarily regional climatic conditions that change because of nitrogen oxide emissions. In addition, nitrogen oxide emitted through aviation leads indirectly to a reduction in the concentration of methane in the upper troposphere. Current understanding of the effect of nitrogen oxide and its by-products can be viewed as fair in the case of ozone, and poor so far as methane is concerned (IPCC 1999).

At ground level emitted nitrogen oxides have no climatic impact, but as a precursor for ozone they represent a risk to human health, since high concentrations of ozone can lead to respiratory disease. Nitrogen oxides can also result in acidification. This risk exists particularly in the vicinity of airports.

Ozone protects the earth's surface against harmful UV radiation. It is also a powerful greenhouse gas, whose concentration is highly variable. Ozone concentration is determined by the dynamic force of atmospheric chemistry, which, in turn, is influenced by latitudinal and longitudinal position, altitude and background ozone concentration. Nitrogen oxide emissions from aviation accelerate the local photochemical formation of ozone in the troposphere and lower stratosphere.

Since ozone is the product of secondary reaction and its greenhouse gas effect depends not only on geographical point, but also on the time of year, the effect of ozone is difficult to compare with that of persistent greenhouse gases such as carbon dioxide (Sledsen 1998). Based on average values for time of year, time of day, background concentration etc., a proportional relation was found between nitrogen oxide emissions from aircraft and the increase in tropospheric ozone (Grewe et al. 1999). When this correlation was investigated at different latitudes, however, different effects were observed in the northern and southern hemispheres. This can be attributed, among other things, to the fact that the formation of ozone in the upper troposphere is very much dependent on the background concentration of NO_x, which varies at different latitudes. Ozone concentration in the northern hemisphere turns out to be much greater, due to heavier air traffic (Figure 4, Section 0). On the other hand, in the southern hemisphere, where lower background concentrations of NO_x predominate, considerably more additional ozone is formed through newly added quantities of NO_x emissions than in the northern hemisphere (AE 2000). Due to the short retention time of ozone in the atmos-

11 The average retention time of ozone in the troposphere, which varies with altitude and latitude, is of the order of one month.

phere, adjustment of concentration through atmospheric circulation is only possible within one continent (Brockhagen/Lienemeyer 1999).

The greenhouse gas **methane** has, similar to carbon dioxide, a long retention time in the atmosphere and therefore a global effect. The reduction of CH_4 concentration in the troposphere, which is caused by nitrogen oxide emissions from aircraft, counteracts the global greenhouse gas effect, but the effect is delayed. Models have shown that the reduction of this greenhouse gas – similar to the formation of ozone – is proportional to the emission of nitrogen oxide (IPCC 1999).

The quantity of emitted **sulphur oxide** depends, in aviation, directly on the sulphur content of the fuel used. It has an acidifying effect, which, compared to nitrogen oxides, is relatively small (Sledsen 1998).

Table 1: Impact of aviation emissions and their reaction products on the greenhouse gas effect

Emission/ reactions products		**Description**	**Radiative Forcing**		**Impact on climate change**		
			negative = cooling	**positive = warming**	**Global**	**Local/ Regional**	**Geographic point**
CO_2	**Carbon dioxide**	Radiatively-active aviation emission		X	X		
H_2O	**Water vapour**	Radiatively-active aviation emission, emissions that lead to change in natural clouds		X		X	
	Contrails	Change in natural cloud formation		X		X	predominantly in the northern hemisphere/ mid-latitude
	Cirrus clouds	Change in natural cloud formation		X		X	
NO_x	**Nitrogen oxide**	Aviation emission that encourages the formation and degradation of radiatively-active emissions					
O_3	Ozone	Radiatively-active substances that is encouraged or degraded by aviation emissions	X supersonic	X predominantly international aviation		X	predominantly in the northern hemisphere/ mid-latitude
CH_4	Methane	Radiatively-active substances that is degraded by aviation emissions	X because of $[CH_4]\downarrow$		X		
	Soot aerosol	Emissions that lead to an increase in the formation of aerosols and to a change in natural cloud formation		X		X	
	Sulphate aerosol		X			X	

Source: Öko-Institut presentation based on IPPR 2001; IPCC 1999

Regarding the impact on the greenhouse gas effect of **particulates** and **aerosols** resulting from aviation, two mechanisms are relevant, which are well founded scientifically. On the one hand, particulates and aerosols directly absorb and reflect solar radiation and long-wave radiation. On the other hand, they play an important indirect role as far as contrail and cloud formation is concerned. They can act as cloud as far as contrail and cloud formation is concerned. They can act as cloud condensation nuclei and modify the physical and radiative properties of clouds (IPCC 1999, p.204). Whereas, with incomplete combustion of fuel, soot aerosols result in a heating effect, sulphur aerosols generally reflect solar radiation back into space, and thus have a cooling effect (IPPR 2000). Table 1 presents a summarized view of relevant emissions and their effects.

3.3 Quantification of the impact on the greenhouse gas effect

The impact of aviation on the climate is overlapped by that caused by other anthropogenic greenhouse gas emissions and particulates, and also by natural variability. It is therefore not possible to separate the effect of aviation on global climate change from that of all other anthropogenic activities. It is assumed, however, that aviation's contribution to climate change is roughly proportional to its contribution towards radiative forcing.[12] IPCC (1999) assumes that in 1992 the radiative forcing of aviation made up about 3.5% of total anthropogenic radiative forcing. The greenhouse effect of individual emissions from aviation is quantified below to provide a detailed effect analysis. In this connection, the measure of quantification is initially discussed.

3.3.1 Measure of quantification

To enable the quantification of the impact on the greenhouse effect of gases covered by the Kyoto Protocol, so-called global warming potential (GWP) was laid down. In determining GWP, not only is the radiative forcing of the gases and substances in question considered, but also their retention time.

This concept for the quantification of the greenhouse effect is only usefully employed with gases that have a retention time in the atmosphere of more than two years, which guarantees good blending and spreading in the atmosphere (Cicero 2001). For this reason, the GWP concept is not effectual in the case of aerosols and non-persistent gases, or with indirect effects of chemical reactions such as occur to a great extent in aviation (IPCC 1995).

To be able, nevertheless, to compare all gases and particulates with each other and with other emissions, recourse is made solely to radiative forcing (IPCC 1999). The concept of radiative forcing is based on the findings of climate models, namely, that a roughly linear relation exists between global average radiative forcing in the troposphere and the change in global average temperature on the earth's surface. If one falls back on the measure of radiative forcing, as is suggested by the IPCC, the effect of complex global change can be reduced to a global quantity, namely average global temperature. Although retention time is not explicitly considered in this concept, the following closer consideration of emission effects over a prolonged period of time

[12] Radiative forcing is a measure of the disturbance of or change in the energy balance of the earth's atmosphere in watt per square metre (W/m^2) (IPCC 1999).

shows that this simplification, at least so far as aviation is concerned, does not call into question the comparability of emission effects.

In 1992, the radiative forcing of CO_2 was, at +0.018 W/m², of the same order as that of contrails at +0.02 W/m². A comparison of radiative forcing does not at first appear to be permissible, since, as a result of the short retention time of contrails, radiative forcing of 0.02 W/m² is only effective for a few hours; whereas the somewhat lower radiative forcing of CO_2 persists over a period of some 100 years. In the assessment of radiative forcing, however, further factors have to be considered.

Basically, two overlapping and – in their impact – intensifying effects lead to the situation that concentration of radiatively-active substances in the atmosphere increases, thus producing a greater effect on the climate: firstly, the accumulation of emission in the atmosphere due to retention time, and secondly, the increasing quantity of emission. If, for instance, the same quantity of CO_2 is always emitted, an accumulation of CO_2 occurs due to long retention times, which has the effect that concentration in the atmosphere increases over several decades (up to 100 years). When the emission quantity constantly increases, as in the case of aviation, concentration is additionally intensified through the second effect.

The same effects apply, in principle, to contrails and nitrogen oxides. With regard to contrails and ozone, however, accumulation is hardly of relevance, due to their short retention times. In the case of contrails, however, it has to be considered, that the growth in aviation, according to current forecasts, occurs disproportionately in regions that are particularly sensitive to contrail formation. Furthermore, increases in engine efficiency tend to lead to lower exhaust gas temperatures, which in turn result in an increase in the formation of contrails. With contrails, a disproportionate growth effect – also known as sensitivity effect (Brockhagen/Lienemeyer 1999) – is to be recorded, which has the result that radiative forcing – despite the comparatively insignificant accumulation effect of contrails – grows, from a relative perspective, more strongly than that of CO_2.

In a Special Report of the IPCC (1999), climatic impact was investigated and compared for three periods of observation (1992, 2015 and 2050). In the case of CO_2, not only were aviation emissions at these points in time considered, but also the emissions that have accumulated since 1950. With contrails, on the other hand, only emissions from 1992, 2015 and 2050 were considered on account of their short retention time. It turned out that, for all periods of observation, the radiative forcing of contrails is greater that that of CO_2. This can be attributed to the fact that the sensitivity effect of contrails is more intense than the accumulation and growth effects of CO_2.[13] Similar observations can be made for the comparison of the climatic impact of CO_2 and that of NO_x or Ozone. This suggests that, despite non-consideration of the extremely different reten-

[13] According to the latest scientific knowledge, the radiative forcing of contrails is no longer greater than that of CO_2 (Marquart et al. 2003). The sensitivity effect of contrails is nevertheless relatively greater than the accumulation and growth effects of CO_2.

tion times of emissions, the measure of radiative forcing is highly convincing, and that comparability of the radiative forcing of individual emissions is not affected. A detailed description of these affects can be found in Brockhagen/Lienemeyer (1999).

As with GWP, the concept of radiative forcing provides no differentiated evidence on specific regional greenhouse gas effects. These can be of great relevance, however, in the case of certain aviation emissions and their by-products, such as ozone, particulates and contrails, due to their short retention times. Despite its restricted informative value concerning regional effects, radiative forcing is regarded by IPCC (1999) as a useful measure that, in a first approach, aggregates different atmospheric disturbances (for example, through aerosols, changes in cloud cover, ozone, water vapour and methane) and then compares them with the global climatic impact.

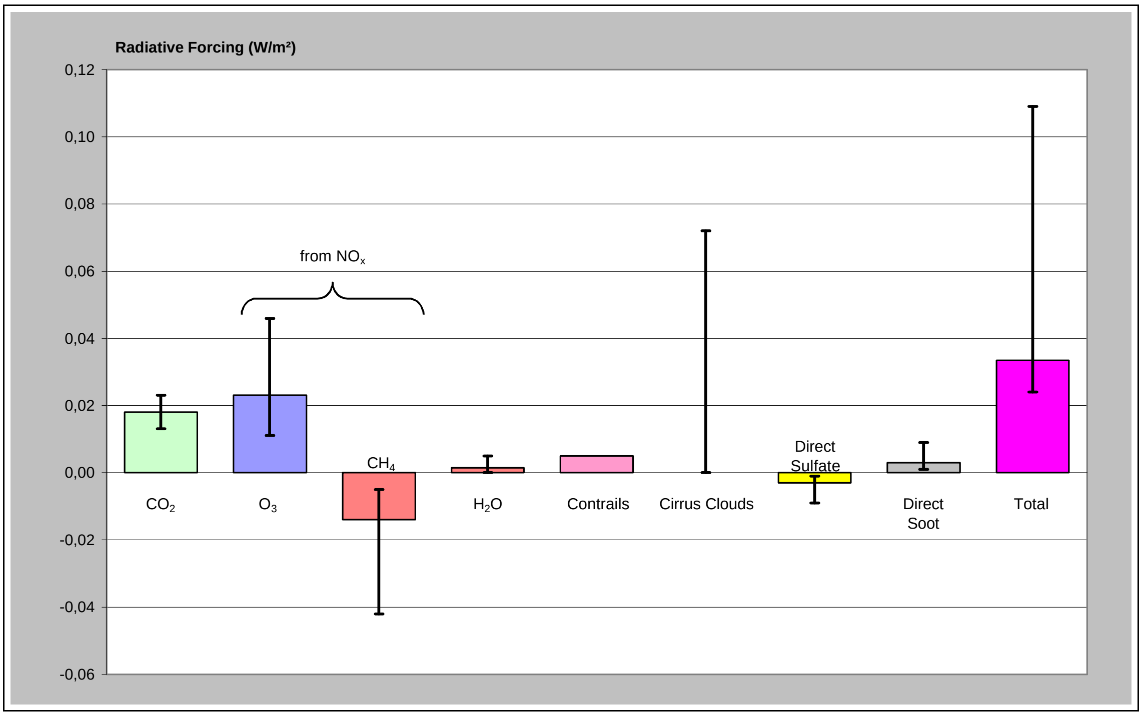
The radiative forcing index (RFI) serves as an alternative to radiative forcing for the representation of the greenhouse gas effect of aviation emissions. The radiative forcing index is a measure of the importance of the aviation-related greenhouse gas effect that goes beyond the emission of carbon dioxide. It is defined as the relation of total radiative forcing to the radiative forcing of carbon dioxide alone.

3.3.2 Quantification of impact in 1992

The contribution of individual aviation emissions and their reaction products to total radiative forcing in 1992 is shown in Figure 3.

It can be seen that the quantitative estimation of the radiative forcing of individual emissions and reaction products is fraught with great uncertainty. Emissions brought about by aviation can basically show both positive and negative radiative forcing; that is, they can encourage the greenhouse effect (heating effect) or counteract it (cooling effect). It is obvious, however, that radiative forcing of carbon dioxide (at 0.018 W/m^2 +/- 30%) represents only a part of the total radiative effects of all aviation emissions that affect the climate. IPCC (1999) estimates that the radiative forcing of aviation as a whole is two to four times greater than the radiative forcing of carbon dioxide alone; that is, the radiative forcing index lies between 2 and 4. IPCC (1999, p. 213) concretized its estimate to the effect that the radiative forcing of aviation in 1992 was 2.7 times greater than that of carbon dioxide alone, but with an uncertainty of at least +/- 1.5. This estimate means that carbon dioxide makes up only about one-third (37%) of radiative forcing from aviation emissions. At the time of IPCC estimates, the possible contribution of additional cirrus clouding – which, according to recent research findings, can be even greater than assumed by IPCC (1999) – was still so uncertain, that it was disregarded. Furthermore, a higher radiative forcing of contrails was assumed (0.02 W/m^2). Most recent scientific knowledge indicates, however, that the radiative forcing of contrails is 0.0035 W/m^2.

Figure 3: Radiative forcing from aviation in 1992



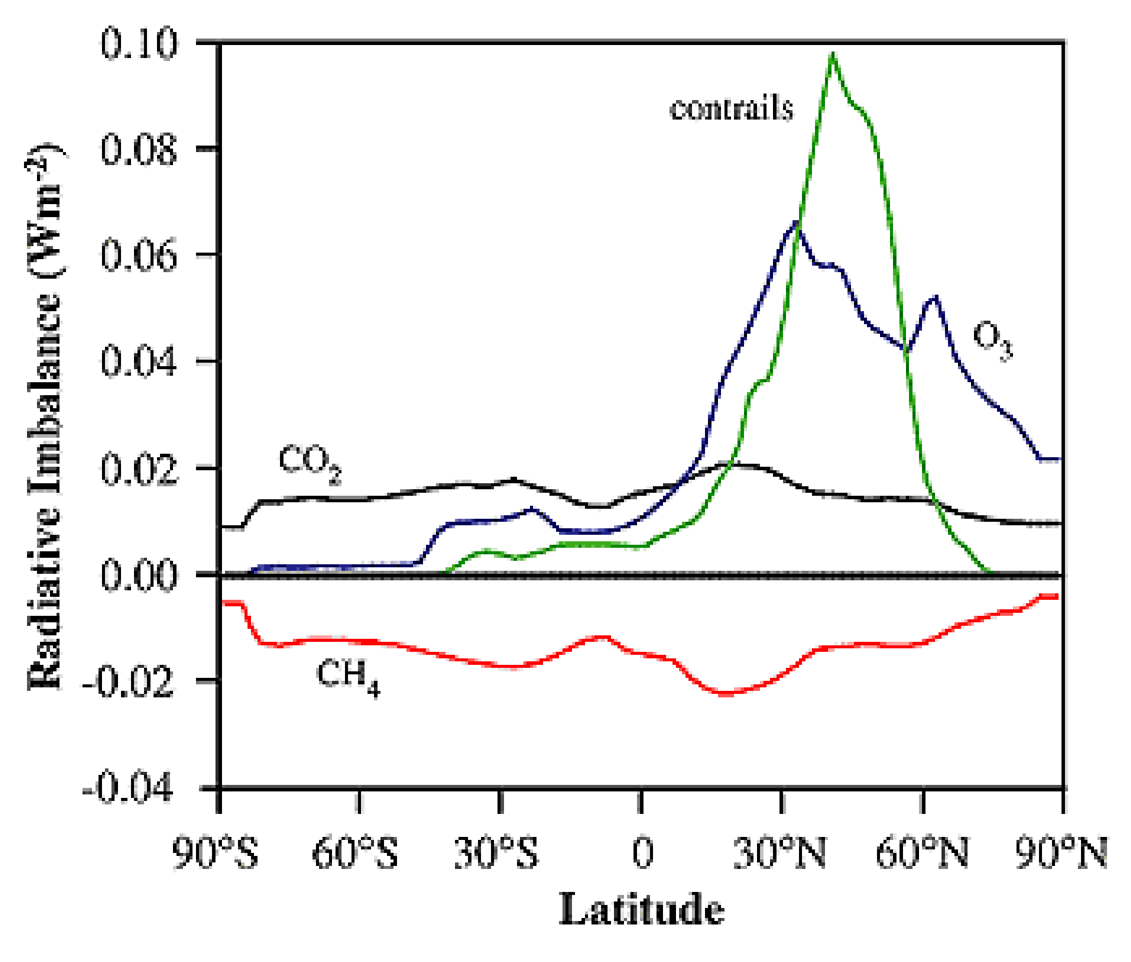
Note: No error indicators concerning the effect of contrails are presently to be found in specialist publications

Source: IPCC 1999, p. 210; Marquart et al. 2003; Mannstein 2003b; CAEP 2003; Öko-Institut presentation

The climatic impact of methane degradation and ozone formation, which are caused by nitrogen oxide emissions, should be separately considered. To begin with, they have their effect in different time horizons: methane reduction has a delayed effect (IPCC 1999); ozone formation, on the other hand, has an almost immediate effect. Whereas methane degradation occurs in both northern and southern hemispheres, ozone formation contributes to radiative forcing from aircraft particularly in the northern hemisphere. The reaction of the climate system to such inhomogeneous radiative forcing is unknown. Regional climate change is to be expected; but consequences at a global level can also not be excluded. There are even indications, that inhomogeneously distributed radiative forcing has a greater effect on the climate than that distributed homogeneously (Ponater et al. 1999 in AE 2000).

At this point, the concept of radiative forcing reaches its limits, since with this measure differentiated statements on regional and global climate change are not possible. Figure 4 shows the radiative imbalance of different emissions in 1992 according to latitude.

Figure 4: Zonal and annual mean radiative imbalance (W/m^2) at the tropopause (after adjustment of stratospheric temperature) as a function of latitude, resulting from air traffic in 1992



Source: IPCC 1999

Irrespective of latitude, the radiative imbalance of carbon dioxide and methane is more or less constant, whereas radiative forcing of ozone and contrails greatly increases in the mid-latitudes of the northern hemisphere. The maximum for ozone lies at a northerly latitude of 30 degrees, that for contrails at a northerly latitude of around 40 degrees.

According to IPCC (1999), the contribution of contrails to radiative forcing is roughly equivalent, on average, to that of CO_2 emissions. Recent scientific research by Marquart et al. (2003) shows, however, that radiative forcing – at least for line-shaped contrails – has to be amended to 0.0035 W/m^2 (Figure 3).[14] Radiative forcing varies regionally to a significant extent (Figure 4).[15] If, as assumed in CE (2001a), aircraft contrails are formed during only 10% of total flying time (Section 3.2), then the impact on the greenhouse gas effect of one flight kilometre with contrail formation is, on average, approximately twice as strong as that of one flight kilometre without contrails.

The contribution of cirrus clouds to the greenhouse gas effect is even more difficult to quantify, since the formation of these clouds has not been sufficiently researched. IPCC (1999) estimates that cirrus clouds have an average radiative forcing of between 0 and 0.04 W/m^2. According to the most recent scientific knowledge (Mannstein 2003b), the possible range has to be broadened to 0 - 0.75 W/m^2.[16] The possibly very high radiative forcing of cirrus clouds is only partly caused by flight movements through ice-saturated regions. Assuming higher values of radiative forcing, and taking into account that this radiative forcing is caused by only a small proportion of total worldwide aviation, the specific climatic impact of one flight kilometre with contrails must be extremely high.

Sulphur aerosols contribute to the greenhouse gas effect with radiative forcing of roughly -0.003 W/m^2 and an uncertainty of between -0.001 and +0.009 W/m^2. Soot aerosols have a radiative forcing of the same order, but with a positive sign.

In Table 2, the radiative forcing of different aircraft emissions and by-products is summarized in absolute values together with their shares in total radiative forcing. These values correspond with the latest scientific understanding, but as already displayed in Figure 3, they are partly affected by considerable uncertainties.

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14 Marquart et al. (2003) have determined the radiative forcing of line-shaped contrails. Differences between IPCC (1999) and Marquart et al. (2003) regarding the radiative forcing of contrails can be attributed to the fact, that in determining radiative forcing, IPCC (1999) did not differentiate between the radiative forcing of contrails and of natural clouds below them. In other words, the climatic impact of line-shaped contrails was overestimated in those cases where natural clouds were to be found below contrails, since these natural clouds are responsible for the warming effect, and not contrails. Furthermore, with IPCC (1999) no distinction was made between the radiative forcing of line-shaped contrails and of older, no longer line-shaped contrails (Sausen 2003).

15 The values, in absolute terms, for radiative forcing of contrails in Figure 4 correspond with the values of IPCC (1999), and, strictly speaking, must be adapted to latest research findings.

16 Mannstein (2003) has been able, with the help of flight statistics and satellite photos, to establish a connection between flight movements and the spread of cirrus clouds over Europe. Evaluation shows, that cirrus clouding over Europe is ten times greater than covering with line-shaped contrails. The validation of scientific knowledge requires further research regarding the determination of the optical depth of these clouds. Only through the evaluation of optical depth can the radiative forcing and thus the climatic impact of cirrus clouds be quantified.

Table 2: Radiative forcing from aircraft in 1992

Emissions, products of secondary reactions		Average radiative forcing				Share of total radiative forcing						Radiative forcing index (RFI)					
		1)	1), 2), 3)			excl. cirrus clouds			Incl. cirrus clouds			excl. cirrus clouds			Incl. cirrus clouds		
			lower bound	aver-age	higher bound	lower bound	aver-age	higher bound	lower bound	aver-age	higher bound	lower bound	aver-age	higher bound	lower bound	aver-age	higher bound
		- W/m² -				- % -											
CO_2		+0.0180	+0.0130	+0.0180	+0.0230	58	56	65	58	37	21	1.0	1.0	1.0	1.0	1.0	1.0
NO_x	Ozone	+0.0230	+0.0110	+0.0230	+0.0460	27	28	11	27	18	4	0.5	0.5	0.2	0.5	0.5	0.2
	Methane	-0.0140	-0.0050	-0.0140	-0.0420												
H_2O	Direct	+0.0015	+0.0000	+0.0015	+0.0050	0	5	14	0	3	5	0.0	0.1	0.2	0.0	0.1	0.2
	Contrails	+0.0200	+0.0035	+0.0035	+0.0035	16	11	10	16	7	3	0.3	0.2	0.2	0.3	0.2	0.2
	Cirrus clouds	0 to +0,0400	+0.0000	+0.0170	+0.0750				0	35	68	0.0	0.0	0.0	0.0	0.9	3.3
Sulphate aerosols		-0.0030	-0.0010	-0.0030	-0.0090	as a whole neutral			as a whole neutral			as a whole neutral			as a whole neutral		
Soot aerosols		+0.0030	+0.0010	+0.0030	+0.0090												
Total excl. cirrus clouds		**+0.0480**	**+0.0225**	**+0.0320**	**+0.0355**	**100**	**100**	**100**	**100**	**65**	**32**	**1.7**	**1.8**	**1.5**	**1.7**	**1.8**	**1.5**
Total incl. cirrus clouds		**+0.0880**	**+0.0225**	**+0.0490**	**+0.1105**				**100**	**100**	**100**				**1.7**	**2.7**	**4.8**

1) IPCC 1999, 2) Marquart et al. 2003, 3) CAEP 2003

Source: IPCC 1999; Marquart et al. 2003; ACEP 2003; Öko-Institut presentation

These values represent an important starting point for the basis for assessment of the emissions trading system. It has to be considered, however, that the radiative imbalance described by these values is caused not only by international aviation, but also, to a certain extent, by military flights and national aviation.

How existing uncertainties and the climatic impact of cirrus clouding are treated in a quantified statement on climatic impact is a matter of judgement. At the present level of scientific understanding, the basis for assessment of an emissions trading system will inevitably result in intensive discussion, since, due to scientific uncertainty, one cannot ascertain beyond doubt whether the climatic impact of aviation is overestimated or underestimated. If one applies radiative forcing of 2.7 – that is, if one relies on the above-mentioned values – one can assume that, although with this value the climatic impact of contrails is overestimated, the effect tends to be underestimated, since the climatic impact of cirrus clouds is not taken into account. Due to the data situation, and for the purpose of a conservative procedure, this approach appears, however, to be a necessary and sensible compromise.

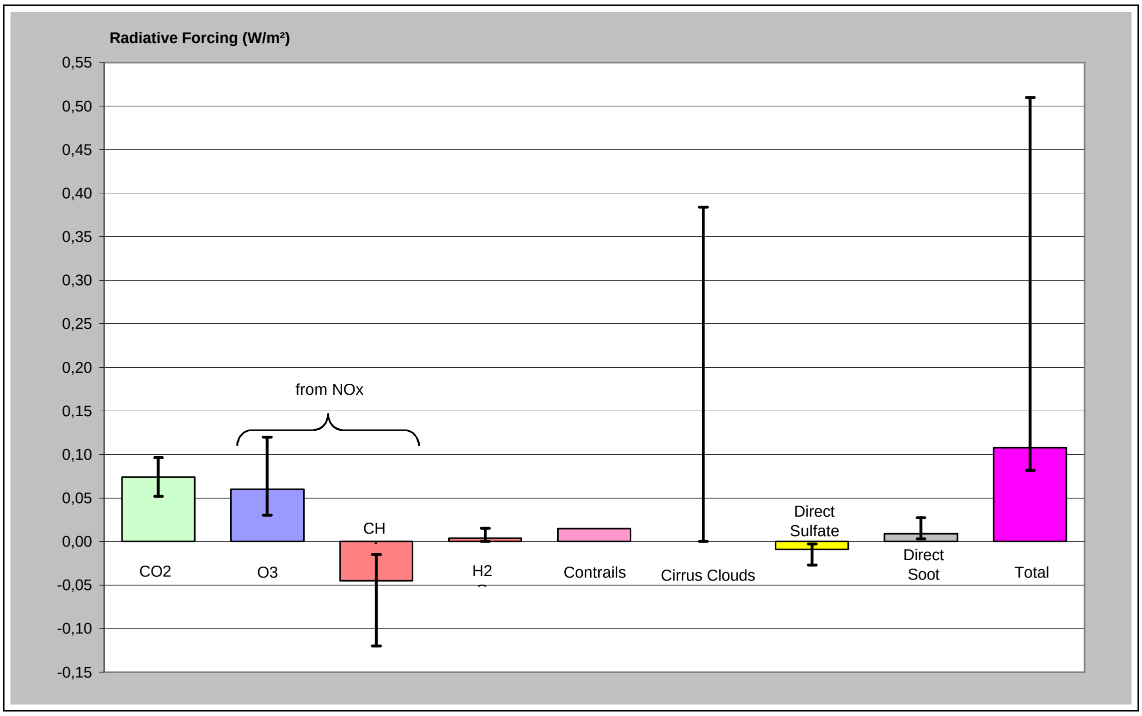
At a later point in time, when either the climatic impact is better understood, or there is a change in the climatic impact of individual emissions due to increased background concentration and emission quantities (see the next Section), such changes should be taken into account by way of adjustment of the basis for assessment.

3.3.3 Quantification of impact in 2050

In the IPCC Report (1999), different emission projections are presented for 2050, which vary over a broad range. The share of aviation in the total anthropogenic radiative imbalance in 2050 varies in different scenarios between around 4% and 15%. In Figure

5, the radiative forcing of aviation emissions in 2050 is shown in scenario Fa1.[17] In this scenario, radiative forcing of aviation grows to 0.19 W/m^2 by the year 2050. The share of aviation in anthropogenic radiative forcing increases in this projection to 5% (IPCC 1999, p. 210). Not all partial effects grow to the same extent. In 2050, as can be seen in Figure 5, radiative forcing of ozone is below that of carbon dioxide. At the same time, the share of contrails grows to almost 53%.[18]

Figure 5: Aviation-related radiative forcing in the year 2050



Note: No error indicators concerning the effect of contrails are presently to be found in specialist publications

Source: IPCC 1999, p. 210; Marquart et al. 2003; Mannstein 2003b; CAEP 2003; Öko-Institut presentation.

Apart from these computations for subsonic aircraft, IPCC (1999) has also investigated the effects of increased employment of **supersonic aircraft** (high speed civil transport: HSCT). In the models used, linear growth is assumed from 2015 to 2040 to a total of

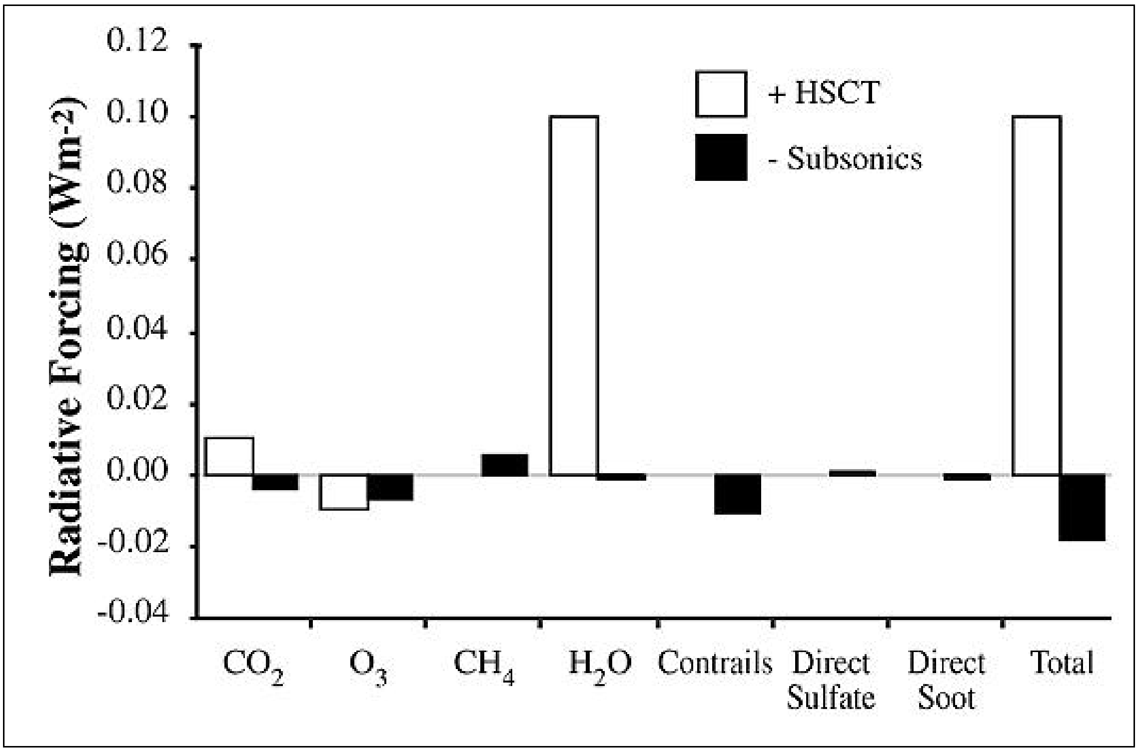
[17] Scenario Fa1 is based on the assumption, that following market saturation the increase will be proportional to growth in GDP. For the period 1990-2025, annual growth in GDP of 2.9% is assumed, for 1990-2100, 2.3%. The number 1 refers to the assumed level of technology: fuel efficiency and the reduction of NO_X emissions are pursued with the same priority.

[18] According to recent research findings (Marquart et al. 2003), the radiative forcing on contrails in 2050 is estimated at only 14.8 mW/m² for the year 2050. The possible range of the climatic effect of cirrus clouds must be broadened.

1,000 aircraft, which will replace part of the subsonic fleet. The use of the latest technology was assumed, with just 5g of NO_x emissions per kg of burnt fuel.

The computations of this scenario show an additional 0.08 W/m^2, since each supersonic aircraft produces five times the radiative forcing of the subsonic aircraft it displaces. In Figure 6, the direct effects of supersonic aircraft (HSCT) for the year 2050 – assuming a fleet of 1,000 aircraft – are displayed with a white bar. The black bar displays the change resulting from the displaced subsonic air traffic.

Figure 6: Radiative forcing from supersonic aircraft (HSCT) and displaced subsonic aircraft for the year 2050



Source: IPCC 1999

At a flight altitude of about 20 km, supersonic aircraft cause accumulations of water vapour in the stratosphere that can only be quantified with considerable uncertainty. According to computations, the emission of water vapour is the predominant HSCT climatic impact, climate factor of supersonic aircraft, which, for a fleet of 1,000 aircraft, is estimated at about 0.1 W/m^2 (0.03 – 0.3 W/m^2) (IPCC 1999, p. 203).

4. Main design options

An emissions trading system is based on emission rights that allow a certain amount of emission and can be freely traded. Emission rights can be auctioned or issued free of charge commensurate with historic emissions (grandfathering). It is important that the quantity of emission rights in circulation corresponds with the emission target, with a fixed upper limit for emissions. Market participants, whose avoidance costs are lower than the market price for emission rights, will realize their avoidance options and offer emission rights or the corresponding allowances for sale. Parties whose avoidance costs are higher than the market price for emission rights will purchase emission rights in order to meet their respective obligations.

Despite this quite simple basic idea for emissions trading, a number of details have to be clarified before implementation of such a system. A decision has to be reached, for example, on the emissions target – cap – to be achieved by the emissions trading system. For aviation, in particular, it has to be determined which emissions should be covered by the trading system. It has also to be decided, whether the emissions trading system will be based on fixed or relative targets, who will be obliged to hold emission rights, how emission rights will be issued, where the precise limits of the emissions trading system are to be set, how emission rights can be traded, how compliance with rules will be monitored and which sanctions will be effective in the case of non-compliance. All these questions will be discussed and assessed in the following sections regarding the detailed design of an emissions trading system for international aviation.

The following criteria are important for the assessment of individual design options:

- Ecological effectiveness: The target should be clearly achievable through the trading system.
- Economic efficiency: The ecological goal should be achieved using a minimum of economic means. It has to be ensured, in particular, that transaction costs – that is, expenditure on the administration, control and processing of the system – are not higher than efficiency gains of emissions trading compared with other environment policy instruments.
- Practicability: Individual design options must be operationable and capable of being implemented.
- Political acceptance: The emissions trading system should be designed in such a way that it is acceptable, in principle, to participating states and affected parties in those states. This includes fair distribution, where applicable, of financial burdens.
- Compatibility with the Kyoto Protocol: The emissions trading system should be compatible with the provisions of the Kyoto Protocol, irrespective of whether the trading system is directly, or only indirectly linked to the trading system under the Kyoto Protocol.

- An appropriate emissions trading system for international aviation can only be developed when all criteria are equally considered and, in the case of conflicts concerning objectives, attention is paid to adequate consideration of conflicting criteria.

4.1 Limitation

Aviation can be differentiated according to the following categories:

- Civil aviation, which covers the commercial transportation of goods and people.
- Military air traffic.
- Visual flights, which cover leisure and company aircraft.

Civil aviation can, in turn, be divided into national[19] and international aviation. International civil aviation is responsible for the greatest number of flight movements. It gives rise to an estimated 80 to 85% of aviation emissions.

Visual flights account for less than 5% of fuel consumption and environmental pollution from aviation (Kalivoda 1997). Their emissions are predominantly effective at ground level. Because it is above all emissions of carbon dioxide from aviation that have a climatic impact at ground level, visual flights contribute considerably less than 5% to the climatic impact of aviation. The share of military aircraft in CO_2 emissions from aviation currently amounts to about 10 to 12%, while their share of NO_X emissions is even lower, at roughly 6 to 10%. NO_x emissions of this category are also predominantly effective at ground level, and they therefore have less effect on the climate than those of international civil aviation.[20]

Several reasons can be put forward for including only international civil aviation in an international emissions trading system. Visual flights are predominantly national flights. CO_2 emissions from these flights are consequently registered within the scope of national greenhouse gas inventories, and are therefore already subject to national reduction commitments under the Kyoto Protocol. The same applies to military flights, in so far as these are not international flights.

Furthermore, data availability for visual and military flights is considerable worse than for civil aviation. Whereas for visual flights hardly any data is available, appropriate data on military flights is classified.

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[19] According to the IPCC (2000), national air traffic comprises flights whose take-off and landing take place in the respective country. Where landing represents a stop-over before a flight to another country, the domestic flight falls under national air traffic when passengers embark or disembark, or when freight is loaded or unloaded. Where this does not happen, the flight falls under international air traffic.

[20] Emission inventories were drawn up by NASA, ANCAT and DLR [German Aerospace Center] for the years 1992 and 2015 (IPCC 1999, p. 303). In 1992, the share of CO_2 emissions from air traffic attributable to military flights amounted to between 13 and 18%; for 2015 a share of 5 to 7% is forecast. The share of NO_x emissions from military aircraft amounted in 1992 to between 11 and 13%; for 2015 the share is forecast at about 4.5%.

The ecological control function of an emissions trading system for international aviation would be considerable, even were emissions from visual and military aircraft to be ignored, since instrument flights are responsible for by far the largest proportion of aircraft emissions affecting the climate. Flight movements of the other two categories account for a negligible share of the climatic impact of aviation, due to the much smaller number of flights and lower cruise altitude.

Provided that the emissions trading system starts with the emitter (downstream), airline companies could – in contrast to visual flights – be obliged to hold emission rights. The fact that this group of parties is highly homogenous makes the operationalizability of the emissions trading system very much easier.

Similar to CE (2002b), a *de minimis* limit is proposed for the formal differentiation of international aviation (instrument flights) and visual flights: only civil flights with 40 or more seats and a total weight of at least 9 tonnes would be registered. Aircraft below this size are almost exclusively employed in national aviation (CE 2002b), and they should therefore not be covered by an emissions trading system.

This trading system should also only cover subsonic aircraft. Basically, it could be applied to supersonic aircraft, but since the climatic impact of supersonic aircraft is fundamentally different, the basis for assessment for these flights would also have to be different. This limitation also appears acceptable, since there are presently only very few supersonic aircraft in operation (cf. Footnote 9). Although, in the IPCC scenario, an increase to 1,000 supersonic aircraft between 2015 and 2040 is assumed, it is currently quite uncertain whether new supersonic aircraft will in fact be built for civil aviation (The Economist, 27. April 2002). Should the emergence of a substantial market for civil supersonic aircraft become foreseeable in the future, such aircraft would have to be belatedly incorporated into the emissions trading system through the development of an adequate basis for assessment.

It is quite unimportant for the design of an emissions trading system, which, or how many states participate in the system. Such a system can only be established, however, when a minimum number of states participate in it; otherwise the free-riding option would be too tempting for all potential participants. This minimum number must be of the same order as that of Annex I, namely, 30 to 35 states. So far as the targeted fixed emission reduction is concerned, the number of participating states is of enormous importance. For the fact is, the more states that participate the greater the greenhouse gas reduction that will be achieved. What is more, the economic efficiency of an emissions trading system improves – as quite a few empirical studies and models show (Cames et al. 2001) – the more states and sectors are covered by the system.

Regarding the geographical limitation of the emissions trading system, it can be reasonably assumed that all those Annex I states that have ratified the Kyoto protocol will also participate in emissions trading in international aviation. Other states should also be given the opportunity to participate in international emissions trading in civil aviation. In this way, evasive reactions can be reduced and the targeted emission reduction as well as the efficiency of the system increased. There appears to be a possibility of voluntary participation on the part of the USA. Although the USA has unambiguously declared its intention not to ratify the Kyoto protocol, it appears to be basically interested in participating in an international emissions trading system in aviation.[21]

In the case of a closed emissions trading system, it is basically irrelevant whether the group of participating states coincides with the group of Annex I states, since in this case a parallel, independent emissions trading system is set up. In the case of an open emissions trading system, however, additional complications arise when the group of participant states differs from the group participating in emissions trading under the Kyoto Protocol. In this case, it would have to be ensured that emission rights of both systems are recognized reciprocally and are convertible. Despite the resultant higher administrative costs, the linking of two emissions trading systems should not pose an insurmountable hurdle even for varying groups of participating states.

4.2 Trading regime

In designing an emissions trading system for international aviation the basic question arises, whether the system should interact with emissions trading under the Kyoto Protocol, and if so, in which form. Three alternatives can be differentiated:

- Closed emissions trading: The emissions trading system relates only to international aviation. There is no interaction with emissions trading within the framework of the Kyoto Protocol. Emission rights issued within the scope of emissions trading under the Kyoto Protocol cannot be used in fulfilment of commitments within the scope of emissions trading in international aviation, and vice versa.
- Open emissions trading: Emission rights issued under the emissions trading system in international aviation can also be used in emissions trading under the Kyoto Protocol; just as Kyoto Protocol emission rights can be used for the fulfilment of commitments within the framework of emissions trading in international aviation.
- Half-open emissions trading: Because aviation emissions that aggravate the greenhouse gas effect can possibly not be directly compared with greenhouse gases covered by the Kyoto protocol, the third alternative is that emission rights from emission trading under the Kyoto Protocol are recognized in emissions trading in international aviation, but that, conversely, emission rights from international aviation

21 The voluntary participation of certain city states, such as Hong Kong and Singapore, also appears to be advantageous for the emissions trading system, since the possibility of evasive reaction is lessened. Due to the strong turnover of the airline companies of these states, the share of flights incorporated into the system will be noticeably increased.

may not be used in emissions trading under the Kyoto Protocol.[22] This possibility could be useful, particularly because of the quite complex climatic impact of aviation emissions.

A closed emissions trading system in aviation has the result, that efforts are in fact made towards reducing emissions in this sector, since sector growth is directly limited. Such a system offers a strong incentive for flight optimization from the climate policy point of view, for technical efficiency and for air traffic avoidance.

The advantage is that such a system can be set up independent of and parallel to the Kyoto Protocol. Administration would be comparatively simple, since compatibility with the Kyoto Protocol need not be ensured. Significant disadvantages of a closed system for aviation are to be found in the area of cost-efficiency. The marginal avoidance costs of emission reduction measures in aviation – as in transport in general – are high compared with those in other sectors. Demand, or a part of demand for medium- to long-haul flights is largely inelastic, since there are no alternative means of transport. In so far as targeted emission reductions cannot be attained through technical and organizational optimization, they can only be achieved through avoidance; that is, through a reduction in the number of flights. From an economic point of view, a considerably lower emission reduction or limitation goal would have to be set in a closed system than in an open system.

The ICAO/CAEP, however, clearly favours an open system. An open emissions trading system, according to the CAEP, offers a considerably more efficient trading regime, since emission reductions occur at exactly those points in the economy where they are most economical. The quantitative reduction target (cap) of an emissions trading system can be much more ambitious in an open system, since reductions do not actually have to take place in aviation, but can be substituted through the purchase of emission rights from other sectors, in which marginal avoidance costs are lower. Market liquidity would also be strengthened through inter-sector trading (ICAO/CAEP 2000). With this approach, however, an absolute limitation of aviation cannot be achieved.

In order to successfully establish an open trading system, various regulations on the comparability of emission rights must be laid down at the interface between emissions trading in aviation and emissions trading under the Kyoto Protocol, to ensure compatibility of trading regime (Section 4.3).

One can also consider establishing a half-open system. Losses in efficiency are not to be expected with such a system, if disproportionate growth on the part of the international aviation market is assumed as well as comparatively low avoidance potential and

[22] The advantage of a half-open compared to an open trading system lies in the fact that, taking the measure of climatic impact as starting point, Kyoto emission rights are more likely to be admitted to emissions trading in international aviation as the other way round. This can be explained by the fact that global warming potential (GWP) describes the climatic impact in greater detail than radiative forcing, because with GWP retention time is considered additional to radiative forcing (Chapter 3).

relatively high marginal avoidance costs, so that aviation as a whole will in all probability emerge as a net buyer of emission rights. International aviation would not be limited absolutely and would be burdened only with the costs of emission allowances, with the effect that, due to comparatively low elasticity in international aviation, avoidance activities could only be expected to a limited extent.[23]

4.3 Approach

An emissions trading system can be based upon fixed or relative reduction targets. In the first case, one speaks generally of a "cap-and-trade system". An absolute level of emissions is laid down by government, or by international agreement, which should not be exceeded (cap, or reduction target). Emission rights are issued in a corresponding quantity and allocated to those parties obliged to participate in the trading system. With the help of market mechanisms, these emission rights flow to wherever specific avoidance costs are higher than the market price for emission rights, so that, in the end, there is an equalization of the marginal avoidance costs of the respective parties.

An emissions trading system can also be based upon relative reduction targets. In this case, one speaks of a "baseline-and-credit system". Here, a baseline is laid down by government, or by international agreement, in the form of a specific emissions value, a so-called "performance standard rate", in short PSR (for example, x kg of CO_2 equivalents per thousand km). Parties, whose specific emission value is lower than the PSR, can in this way generate emission credits,[24] which they can then sell to parties whose specific emission value is above the PSR. Parties, whose specific avoidance costs are lower than the market price for emission credits, will realize the reduction potential and sell generated emission credits to parties with comparatively high specific avoidance costs, so that with this approach, too, an equalization of marginal avoidance costs takes place.

The advantage of the baseline-and-credit approach from the point of view of the parties is that the reduction target is independent of cyclical or other changes in the production process, whereas with the cap-and-trade approach, the goal is fixed and thus more

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[23] A half-open system is, to a certain extent, a "safety valve" for emissions trading in international aviation. When sufficient cost-effective reduction potentials can be exploited in aviation, a price differentiation arises between the "aviation market" and "Kyoto trading". Due to one-sided convertibility, the more cost-effective emission rights of the aviation sector are exclusively available to the aviation sector. If, however, cost-effective reduction potentials in aviation are exhausted, and if the price in the aviation market threatens to rise above the level in Kyoto trading, participants in emissions trading in aviation are able to take advantage of the more cost-effective emission rights of Kyoto trading. It is thus ensured, that the price of emission rights in international aviation is at no time above the price of emission rights in Kyoto trading.

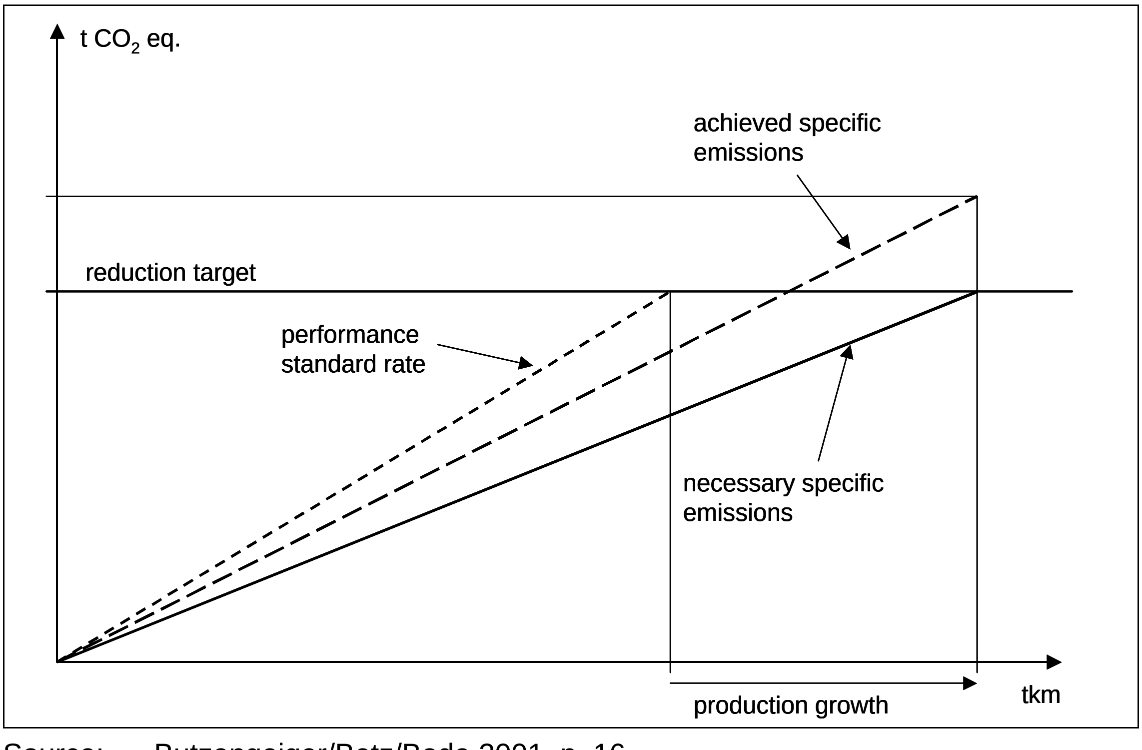
[24] For this purpose, the difference between current specific emission value and corresponding PSR is multiplied by the level of activity (in our example, thousand km) in the corresponding commitment period.

ambitious when the level of production increases. Secondly, with the baseline-and-credit approach, parties do not incur costs for the purchase of allowances as long as their specific emissions lie below the respective PSR. In contrast to the cap-and-trade approach, where, in the case of the auctioning of emission rights (Section 4.6), costs arise for every emitted unit, with the baseline-and-credit approach costs only arise for emissions above the PSR.

Where, with a cap-and-trade approach, emission rights are not auctioned but issued free of charge, for instance on the basis of grandfathering or benchmarking procedures (Section 4.6), parties also incur costs only for emissions that exceed the emission rights they have been allocated. In this respect, the baseline-and-credit and cap-and-trade approaches are comparable.

The difference between both approaches comes down to the question of how changes in production volume are considered. An advantage of the baseline-and-credit approach from the point of view of the parties is at the same time a disadvantage from the ecological point of view compared with the cap-and-trade approach. With the baseline-and-credit approach, the actual achievement of the fixed emission target is not ensured. For if production volume increases strongly enough, the emissions target can also be exceeded even when specific emissions, on average, are below the prescribed PSR (Figure 7).

Figure 7: Ecological disadvantages of relative targets



Source: Butzengeiger/Betz/Bode 2001, p. 16

With closed emissions trading for international aviation, the baseline-and-credit approach could have the effect of a “safety valve”, since it ensures that fixed emission targets do not limit production growth in the form of increasing traffic. With an approach involving fixed targets, an increase in transport demand would lead to higher prices for emission rights, with the effect that traffic would not grow to the same extent. With a baseline-and-credit approach, on the other hand, the increase in traffic is not additionally limited. Reduction efforts would therefore be focused on technical and operative measures. Transport avoidance and switching would only occur to the extent that technical and operative measures give rise to higher costs. An approach with a relative target would also mean that the reduction contribution of international aviation could not be reliably forecast.

Open emissions trading offers the opportunity to purchase emission rights from other sectors. An increase in the demand for transport would therefore have the result, if reduction potentials in the aviation sector were already exhausted, that additional emission rights are purchased from other sectors. Because aviation has an increasing, but still small share in total greenhouse gas emissions, it would act on the market for emission rights as price taker. The price for emission rights will therefore be influenced, if at all, to only a negligible extent. Increase in the demand for transport will therefore not be additionally dampened through increasing prices for emission rights, so that traffic should increase proportional to transport demand. An additional “safety valve” would therefore not be necessary in the case of open or half-open emissions trading for aviation.

Because emissions trading under the Kyoto Protocol is founded on a cap-and-trade approach, in the case of an open emissions trading system in international aviation, the only approach that is likely to be considered for aviation is one based on fixed targets. For only in this way can the reduction contribution of international aviation to a global reduction in the greenhouse effect be reliably ascertained. In addition, the linking of two emission trading systems based on fixed targets could prove to be considerably easier than the linking of one approach based on relative targets with another based on fixed targets.[25] With simpler administration of two systems based on a cap-and-trade approach, transaction costs would also be lower, so that, in the case of open emissions trading, the approach based on fixed targets in aviation is also to be preferred in terms of efficiency.

[25] The example of the British emissions trading system shows that a system based on absolute targets can also be combined with a system based on relative targets. Butzengeiger/Betz/Bode (2001, p. 17f) indicate, however, that the combination of both approaches considerably increases the complexity of the system as a whole and also induces additional uncertainties of price and quantity for trading participants.

4.4 Basis for assessment

The comments in the last chapter have made clear, that the causal connections between aircraft emissions and the greenhouse gas effect are highly complex. For the inclusion of international aviation in an emissions trading system, an appropriate basis for assessment must therefore at first be identified, which, on the one hand, adequately reflects the complex connections of cause and effect, and on the other hand should be practicable and compatible with international emissions trading. In the following section, different parameters and combinations of indicators are discussed and assessed as a possible basis for assessment. The consideration of bases for assessment should focus on the respective climatic impact as global environmental pollution. Local air pollution, noise load and other environmental effects of air traffic at airports, on the other hand, are generally not considered.

4.4.1 Demands made on a basis for assessment

Despite persisting, and in part considerable uncertainties regarding the climatic impact of individual emissions, it is proposed – in line with the methodology of the Kyoto Protocol – to formulate the effect of emissions and their reaction products in CO_2 equivalents. Whereas in the Kyoto Protocol the effect of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorated carbons (PFC), partly halogenated hydrofluorocarbons (HFC) as well as of sulphur hexafluoride (SF_6) is expressed in CO_2 equivalents, restriction to these greenhouse gas is not enough to illustrate the entire greenhouse effect of aviation. For complete and extensive presentation, the effect of nitrogen oxide, water vapour, contrails and particulates should also be expressed by means of the CO_2 reference value.

Brockhagen/Lienemeyer (1999) have drawn up important criteria in connection with the internalization of the external effects of different aircraft emissions: In the basis for assessment, only those emissions should be considered whose climatic impact is significant (criterion for relevance). This way it should be guaranteed that only really relevant effects of aviation are considered. In addition, radiative forcing should grow constantly with the emission quantity of the substance, so that a reduction in emission leads to a reduction in the climatic impact. It is also of advantage when there is sufficient scientific understanding of causal connections. According to Brockhagen/Lienemeyer (1999), however, this is not an essential condition for the internalization of external costs.

The different approaches to the formation of the basis for assessment should be evaluated by means of the following criteria:

- In choosing a basis for assessment, the ecological control effect should be provided in such a way that misdirected control does not occur. This means that the climatic impact of aircraft emissions may not be increased through misdirected control, and that other adverse environmental effects of aviation (such as noise, for example) may also not be excessively increased on account of the chosen basis for assessment. This demand on a basis for assessment can be fulfilled in so much as it reflects actual environmental effects as precisely as possible. .

- A further aspect, which is of great relevance for the composition of the basis for assessment, is the operationalizability of the system. The variables of a basis for assessment should be easily measurable and foreseeable, and the procedure in determining the basis for assessment should also be uniform, so that monitoring and control of the system is not too elaborate. In this way, transaction costs are kept to a minimum and an important prerequisite is created for an efficient system.

In choosing a basis for assessment, the fundamental decision has to be made, whether compatibility with the Kyoto Protocol should be aimed for, or not. As far as the design of the emissions trading system is concerned, this is concomitant with the question, whether an open or closed trading system is to be aimed at. As already explained in Section 3.3.1, it has to be considered that radiative forcing, which represents an appropriate measure for aircraft emissions in their entirety, is formally incompatible with global warming potential, the measure adopted in the Kyoto Protocol. For the integration of the emissions trading system into emissions trading under the Kyoto Protocol, a “gateway mechanism” has therefore to be established that formally ensures uniformity of units of measure. From a legal point of view, such a gateway mechanism can be developed and established, for instance, within the framework of negotiations on the second commitment period. A prerequisite for this, however, is that all negotiating partners accept the procedure, and that scientific consensus can be reached on the values that have to be agreed.

4.4.2 Comparison of bases for assessment

Alternative bases for assessment, which reflect the above demands, are outlined and evaluated below. These alternatives differ in the extent to which they take account of different aircraft emissions and their greenhouse gas effects.

4.4.2.1 Carbon dioxide

There are reasons in favour of, and others against a basis for assessment restricted exclusively to CO_2 emissions. It is argued in favour, that CO_2 is the only aircraft emission whose impact on the greenhouse gas effect is independent of the geographic point of emission. In comparison to other aircraft emissions, the emission quantity of CO_2 is precisely determinable due to its proportionality to fuel consumption, and its climatic impact is scientifically well founded. One also has recourse to excellent documentation on CO_2 emission quantities, which could be of advantage in initial allocation on the basis of grandfathering. These factors greatly simplify operationalization.

With regard to the selection of parties obliged to participate in an emissions trading system for aviation, a basis for assessment restricted to CO_2 opens up more options than when further emissions, such as nitrogen oxide, are considered. Due to the proportionality between quantities of CO_2 emissions and fuel consumption, parties at all stages of trading in fossil fuels (downstream to upstream) can be obliged to possess emission allowances, and not only those at the point of emission (downstream).

Because carbon dioxide is responsible for only about one-third of the climatic impact of aviation, and two-thirds are therefore not considered in this basis for assessment, ecologically misdirected control would be the inevitable result. In the case of closed emissions trading within international aviation, this misdirected control would be within reasonable limits, since CO_2 itself displays a kind of "control effect". A reduction in CO_2 emissions would be accompanied by a reduction in other substances harmful to the climate, such as water vapour, sulphur dioxide and soot.

On the other hand, with NO_X emissions, and also partly with contrails, these synergistic effects do not occur. Increases in fuel efficiency often result in higher NO_X emissions (IPCC 1999).[26] New technologies, however, are able to avoid this trade-off. Moreover, aircraft with fuel-optimized performance emit cooler exhaust fumes, with the effect that already at low altitudes, or in warmer atmospheric layers, contrail formation is possible (Schumann 2000b). Were CO_2 to be selected as the sole basis for assessment, it would appear essential to supplement the emissions trading system with other instruments, such as strict NO_x standards or a restriction on flight altitude, in order to compensate or at least restrict undesired effects.

With *open* emissions trading, in which emissions rights can be traded between international aviation and the emissions trading system under the Kyoto Protocol, the non-consideration of emissions accompanying carbon dioxide leads to very considerable ecologically-misguided control. In an open regime, in which the aviation sector, due to its high avoidance costs and great growth potential, will probably act as a net buyer, carbon dioxide will display no "control effects" whatsoever. With trading based purely on CO_2, the outcome will be an increase in global radiative forcing, despite an upper limit for global emissions, when emission rights are purchased from other sectors and used for CO_2 emissions from aviation.

Ecologically misguided control in an open emissions trading system could only be limited by weighting CO_2 emission rights proportionate to the climatic impact of other emissions. It would be possible, for instance, to credit only one-third of emission rights from other sectors. Aviation companies would then have to produce three emission rights, each for one tonne of CO_2 equivalent, from other sectors to cover one tonne of CO_2 emission in aviation. With such an approach, the incentive effect would nevertheless not be differentiated enough from the climate policy point of view. To achieve an adequate ecological control effect, it appears to be essential to structure the basis for assessment according to actual climatic impacts.

Compatibility with the Kyoto Protocol is easier to guarantee at a formal level with CO_2 as the sole basis for assessment, since CO_2 is one of the six greenhouse gases cov-

[26] Due to the physical characteristics of the combustion process, carbon dioxide and nitrogen oxide emissions are directly connected to each other. Attempts at reducing one type of e-mission can lead unintentionally to an increase in the other (IPPR 2000).

ered by the Kyoto Protocol. If CO_2 is selected as the basis for assessment, there would be no need for a gateway mechanism, since with CO_2, in contrast to other climatically relevant emissions, GWP values are applied.

Compatibility of emissions trading in international aviation with emissions trading under the Kyoto Protocol is only important, however, when both systems interact or are integrated. With closed emissions trading in international aviation, compatibility with the Kyoto Protocol plays a subordinate role. With an open emissions trading system there remains, however, the risk of ecologically misdirected control, which in the end calls into question the actual compatibility of the system.

4.4.2.2 Carbon dioxide and water vapour

A basis for assessment that relates to carbon dioxide emissions and the direct effects of water vapour emissions, but excludes contrails and cirrus clouds, has advantages and disadvantages compared to one that relates only to carbon dioxide. The quantity of emissions can also be precisely determined from fuel consumption. However, the inclusion of water vapour is not formally compatible with the Kyoto Protocol, where water vapour is not included in greenhouse gases. The direct effect of water vapour is negligible, however, in comparison to its indirect effect on contrails and cirrus clouds.

Regarding the parties that could be obliged to possess emission allowances, the same options exist as with CO_2 alone (upstream to downstream).

As to the ecological control effect, the inclusion of water vapour has only minor advantages compared to a basis for assessment restricted to carbon dioxide, because the share of recorded greenhouse gas effect will be increased by only about 4%. The problem of ecologically misdirected control with an open emissions trading system remains practically unchanged, due to the non-inclusion of NO_X emissions and contrails.

4.4.2.3 Carbon dioxide, water vapour, contrails and nitrogen oxides

A basis for assessment founded not only on CO_2, but also on NO_x and water vapour emissions, including contrails as a reaction product of water vapour, would have the advantage that, in quantitative terms, the total climatic impact of aviation that is at present scientifically quantifiable would be represented. Particulates and aerosols are disregarded, since they cancel each out. Cirrus clouds also remain unconsidered in a conservative approach, since their contribution to the greenhouse effect caused by aviation is scientifically still not proven.

With this basis for assessment, the climatic impact of CO_2 and H_2O (water vapour) is considered directly, that of methane, ozone and contrails indirectly. Scientific understanding of the formation of ozone through NO_x emissions is sufficient, whereas further research is required on methane degradation. A connection between the reduction in NO_x emissions and the decline in radiative forcing can also only be observed in the formation of ozone. Due to the cooling effect of methane degradation, on the other hand, a reverse proportionality exists between emission quantity and radiative forcing. On account of the overall warming effect, the inclusion of NO_x emissions is nevertheless possible. Against the background of harmful effects that are only estimated, the uncertainty of methane degradation can be tolerated.

The inclusion of nitrogen oxides is made additionally difficult by the dependence of ozone formation on geographical latitude, the existing concentration of nitrogen oxides (background concentration) and flight altitude. As already discussed in Section 3.2, radiative forcing from ozone is considerably higher in northerly mid-latitudes than in the southern hemisphere. There are also indications that inhomogeneously distributed radiative forcing has a greater climatic impact than that distributed homogeneously (AE 2000), so that incentives for the avoidance of NO_X emissions could be taken into consideration in the northern hemisphere. The fact that the build-up of ozone – or the radiative forcing of ozone – per unit of NO_x emission is much greater in the tropics than in regions with a relatively high background concentration of NO_x (such as in the northern hemisphere) is, however, an argument against the increased burdening of flights in northerly mid-latitudes. (AE 2000).

Due to scientific knowledge of the regional variability of NO_x effects, but also for reasons of operationalizability, it is difficult to take account of regional aspects of NO_x in the basis for assessment. It is therefore recommended, that with this basis for assessment a global average value should be applied for the radiative forcing of NO_x emissions.

Because the climatic impact of NO_x emissions greatly depends on atmospheric composition in the troposphere and stratosphere, flight altitude also plays an important role as far as the effect of emissions is concerned. The dependence of emission effect on atmospheric composition is, however, highly complex. It is therefore proposed, that with the inclusion of NO_x emissions in the basis for assessment, an average value be adopted concerning the climatic impact of NO_x emissions in the troposphere and stratosphere.

From the climate policy point of view, the inclusion of contrails in the basis for assessment appears to be absolutely essential; for through the avoidance of air layers in which in all probability contrails arise, low-cost behavioural reduction potentials can be exploited. Even when, according to the latest scientific knowledge, the climatic impact of contrails is no longer as great as assumed by IPCC (1999), through the avoidance of contrails the formation of aviation-related cirrus clouds can be prevented. Because cirrus clouds tend to have a great climatic impact, a substantial reduction in the climatic impact of aviation could be achieved. Beyond that, according to IPCC estimates, the radiative forcing index of contrails will increase disproportionately in the coming decades. This can be put down to the fact that the 30% increase in fuel efficiency between 1992 and 2050 (IPCC 1999) will have the effect that emissions of water vapour by aircraft will be of a lower temperature and a higher humidity (Schumann 2000b). As a result, the probability of contrail formation will increase, since contrails develop with the least ice saturation, and broader contrail-bands will occur in the troposphere.

A basic problem with the inclusion of contrails is the uncertainty that still exists in the scientific quantification of their climatic impact. What is more, the formation or avoidance of contrails can only be predicted or examined on an individual basis for every flight movement, relying on external factors. These aspects tend to involve transaction costs, so that the operationalizability of this basis for assessment is made more difficult. It nevertheless appears to be possible to design, at a reasonable cost, a basis for assessment that takes into account the climatic impact of contrails (Section 4.4.3.4).

With this basis for assessment, the emitter is obliged to participate in emissions trading, because the quantity of NO_x emission is very much dependent on the aircraft engine, the total weight of the aircraft and the flight phase, as well as the effect of NO_X emission on the geographic point of emission. These factors can only be established plausibly at the emitter. With knowledge of fuel consumption, engine, aircraft weight and flight route, the quantity of emission and its climatic impact can be reliably determined.

Such a system is not formally compatible with the Kyoto Protocol, because water vapour and nitrogen oxides are not listed in the Kyoto Protocol. This can be remedied by relating the climatic impact of NO_X and water vapour emissions to a CO_2 reference value and creating a gateway mechanism for the transition from radiative forcing to global warming potential.

4.4.2.4 Carbon dioxide, water vapour, contrails, nitrogen oxides and particulates

In comparison to the basis for assessment described in the previous section, operationalization becomes more difficult with the inclusion of particulates (soot, sulphur), with roughly the same ecological control effect. With such a basis for assessment, the total, scientifically-validated climatic impact would be covered, but the ecological control effect would be only marginally improved, since the negative and positive effects of the different types of particulates cancel each other out. Operationalization is made particularly difficult, however, by the fact that there is little data available on soot, and also because the emission quantity cannot be derived from easily applicable values. This is possible in the case of sulphur, but because sulphur aerosols have a predominantly positive effect on the greenhouse effect, there is no immediate reason to reduce them. The indirect effect of particulates on the formation of contrails is not sufficiently understood scientifically, and is not directly dependent on the emitted quantity. Their influence on natural cirrus cloud cover is difficult to quantify, and is also not scientifically validated. Consideration of particulates in the basis for assessment would therefore appear to be pointless.

4.4.2.5 Greenhouse gases of the Kyoto Protocol

Formal compatibility with the Kyoto Protocol is the only argument in favour of Kyoto greenhouse gases as the basis for assessment. Of the Kyoto greenhouse gases only carbon dioxide and methane are of any importance. Whereas carbon dioxide is directly emitted, secondary reactions of NO_x emissions influence the concentration of methane in the upper troposphere. Changes in the concentration of these greenhouse gases have opposite signs: carbon dioxide concentration increases and therefore contributes to warming, while the concentration of methane decreases as a result of nitrogen oxide emissions, producing a cooling effect.

This basis for assessment would lead to very considerable ecologically-misguided control, since, in addition to the negative effect of CO_2, only the positive effect of NO_x emissions on the greenhouse effect – the degradation of methane – but not the negative effects of NO_x emissions – the formation of ozone – would be considered. On the whole, with this basis for assessment there are incentives to emit more nitrogen oxides. From an ecological point of view, this basis for assessment does not appear to be adequate, since it leads to an increase in climatic impact. Compatibility with the Kyoto Protocol, which appears to represent the only advantage of this basis for assessment, is, for the same reason as in the case of CO_2, strongly qualified at the operationalization level. In view of the great risk of ecologically-misdirected control and greater complexity compared with the reference emission CO_2, this basis for assessment does not appear to be suitable.

4.4.2.6 Suitability of the bases of assessment

The discussion on bases of assessment with regard to the ecological control effect, compatibility with the Kyoto Protocol as well as operationalizability has shown that, in the final analysis, only two of the options discussed can be seriously considered. An emissions trading system for international aviation should therefore take into consideration either CO_2 emissions alone (Section 4.4.2.1), or, with a more comprehensive approach, CO_2, H_2O and NO_X emissions including their reaction products, contrails, ozone (O_3) and methane (CH_4) (Section 4.4.2.3). In Table 3 (page 57), the main aspects of both alternative bases for assessment are surveyed.

The choice of basis for assessment is therefore not independent of other design options for the emissions trading system. Of particular importance is the question, whether the system of emissions trading for international aviation should be open or closed. In an open emissions trading system for international aviation, the more complicated and elaborate but also more comprehensive basis for assessment should be chosen, on account of possible ecologically-misdirected control with a basis for assessment restricted solely to CO_2 emissions. In the case of closed emissions trading within international aviation, on the other hand, recourse can well be made to the more simple variation, although only a part of the impact of aviation on the greenhouse gas effect is covered.

Table 3: Comparison of selected bases for assessment

Criteria		Basis for assessment: CO_2	Basis for assessment: CO_2, H_2O, NO_x (incl. contrails)
Basis of assessment is formally compatible with the Kyoto Protocol		Yes	No, only with weighting and gateway mechanisms
Part of the registered climatic effect		17 - 56% (depends on radiative forcing of cirrus clouds)	30 - 100 % (depends on radiative forcing of cirrus clouds)
Effect is scientifically validated		Yes	No, partly uncertain
Effect of emissions is dependent on geographic location and flight altitude		No	Yes
Parameter for determining emissions		Fuel consumption	Fuel consumption, engine, weight, flight route
Documentation of emissions is available		Yes	Yes, for contrails, but not in the past
Feasible obliged parties		Upstream to downstream	Only downstream
Ecological control effect	Positive	CO_2, soot, H_2O	CO_2, soot, H_2O, NO_x, ozone, contrails, partly cirrus clouds
	Negative	SO_2, trade-off with NO_x contrails and partly cirrus clouds	SO_2 (reduction), methane
Trade-related, ecologically-misdirected control	Open system	Air traffic as buyer increases climatic effect despite global cap	depends on radiative forcing of cirrus clouds
	Closed system	None	None
Necessity of complementary instruments for the reduction of the climatic effect of international air traffic		Yes, e.g. NO_x standard or limitation of cruise altitude	No

Source: Öko-Institut compilation

4.4.3 Determination of emission quantities

Depending on the selected basis for assessment, procedures must be laid down by which emission quantities of specific gases harmful to the climate, as well as the development of reaction products, can be adequately determined. The determination of emission quantities is important for control of the emissions trading system. For only when it can be clearly determined, how much emission a particular party has caused, can it be ascertained whether or not obligations have been fulfilled.

Because parties subject to the emissions trading system anticipate compliance control, they must also continually control their emission quantities, in order to be able to adjust their behaviour and their investment decisions in accordance with the incentive effects of the emissions trading system. For obligated parties, a clear link to the climatic impact of their emissions is therefore just as important as a consistent and transparent method for the determination of emission quantities (Brockhagen/Lienemeyer 1999).

Where emission rights are issued free of charge on the basis of historic emissions (grandfathering), or by means of so-called benchmarks, quantities of emissions and their reaction products that aggravate the greenhouse gas effect have also to be determinable for past years. If this is no longer possible, due to inadequate availability of data, procedures will have to be found by which historic values can be estimated, or which allow allocation to take place according to other principles.

It has previously been either impossible, or very costly to directly measure individual, climatically relevant emissions during a flight. The continual recording of emission quantities during flights would therefore give rise to very high transaction costs. In the following sections, methods are described with which individual emission quantities and their reaction products can de determined from known or otherwise recorded quantities through recourse to internationally agreed standard values.

4.4.3.1 CO_2 and water vapour emissions

Quantities of CO_2 and water vapour emissions can be determined independent of load by means of the stoichiometric measurement of combustion, according to which 3.155 kg of CO_2 and 1.237 kg of water vapour are emitted per kg of burnt aviation fuel (UNFCCC/SBSTA/1996/9/Add.2).

With an upstream approach, quantities of fuel delivered to aviation operators have to be separately registered by the respective parties. This requires in most states practically no additional cost or effort, since such quantities already have to be separately recorded in great detail on account of exemption from tax on oil.

With a downstream approach, the question arises of whether actual fuel consumption should be measured or an estimated average value taken as a basis, depending on aircraft, engine and flight route. A standardized procedure with internationally recognized, engine-specific and route-dependent fuel consumption values[27] would considerably facilitate monitoring of the system. An argument in favour of average values is that they provide airline companies with greater planning security. Airline companies would not be called to account for additional fuel consumption due to external factors such as weather conditions or holding patterns at airports. With presently available

[27] Corresponding lists with engine-specific and route-dependent consumption parameters are already prepared by engine manufacturers and the ICAO.

data,[28] CO_2 and H_2O emissions can be determined not only for current flight movements, but also for all flights in a past base year or period.

On the other hand, exact measurement of fuel consumption would guarantee that total CO_2 and water vapour emissions are in fact taken into account. Such detailed measurement corresponds with the polluter-pays principle and is desirable from an ecological point of view.

Although, on purely economic grounds, incentives always exist for minimizing fuel consumption, also through the use of standardized average values, in practice, flights are not always operated in a manner that minimizes fuel consumption.[29] The precise measurement of fuel consumption would counteract this behavioural problem, but would also tend to lead to higher monitoring costs. In addition, allocation could only be based on the emission data of future flight movements, since up to now the precise fuel consumption of individual flights has not been statistically recorded.

Ultimately, a balance has to be struck between an improved ecological control effect and generally higher transaction costs.

4.4.3.2 NO_x emissions

NO_x emissions are altogether more difficult to determine, since they depend to a great extent on the type of engine and its load factor. The data situation is generally a great deal better for emissions during the LTO cycle than during cruising, since they have already been extensively investigated in connection with local environmental pollution at airports. So far as the LTO cycle is concerned, recourse can be made to the ICAO Engine Exhaust Emission Data Bank (1995); in short “ICAO Data Bank”, in which specific information is provided on all jet engines with a thrust in excess of 26.7 kN that have been licensed since 1983. Even when no data has been available at an international level and accepted by the ICAO concerning the cruise, climb and descent phase, reliable estimates can be made on the basis of engine type, engine and aircraft combination, take-off weight and flight distance.

There are different methods for determining NO_x emissions (IPCC 1999, Section 7.7.2 and 7.7.3). With correlation methods, calculation is possible on the basis of pressure and temperature for a given aircraft design and engine with a margin of error of less than 5%. Alternative, simpler methods are based on the correlation of emissions with the fuel consumption of an engine, for which data from the official ICAO data bank is used. The margin of error in this case is 5% to10%.

[28] Data from airline companies, airports, the IATA (World Air Transport Statistics) and the ICAO, as well as flight security statistics, for example from Eurocontrol.

[29] Flight speed, in particular, is often optimized with regard to flight (cruising) time, but not with regard to fuel consumption.

NASA and ANCAT[30] have also drawn up emission indices for NO_x (EI NO_X), on the basis of fuel consumption, for the climb, cruise and descent phase of the twenty most widely operated types of aircraft, using a semi-empirical *fuel flow method* developed by the German Aerospace Center. With the help of an assignment table for aircraft and engine types (AEIG 2001b), the NO_x emissions of a huge number of flight movements can be reliably determined, depending on distance categories (IPCC 2000, p. 267). Emission indices can then be taken from tables. Table 4 displays exemplary EI NO_x for two widely operated aircraft types.

Table 4: Selected NO_x emission indices for the calculation of NO_X emissions on the basis of fuel consumption

Standard flight distance											
	Nautical Miles	125	250	500	750	1,000	1,500	2,000	2,500	3,000	3,500
	km	232	463	926	1,389	1,852	2,778	3,704	4,630	5,556	6,482
A 310											
Fuel consumption	kg	2,811	3,900	5,990	8,081	10,172	14,533	18,982	23,699	28,675	33,764
LTO	kg	1,541	1,541	1,541	1,541	1,541	1,541	1,541	1,541	1,541	1,541
Climb/Cruise/Descent	kg	1,270	2,359	4,450	6,541	8,632	12,992	17,441	22,159	27,135	32,223
NO_x Emission Index											
LTO	g/kg fuel	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
Climb/Cruise/Descent	g/kg fuel	23.7	20.8	14.5	13.5	13.1	12.8	12.3	12.3	12.5	12.7
B 737 400											
Fuel consumption	kg	1,603	2,268	3,613	4,960	6,303	9,188	12,168			
LTO	kg	825	825	825	825	825	825	825			
Climb/Cruise/Descent	kg	778	1,443	2,787	4,135	5,477	8,362	11,342			
NO_x Emission Index											
LTO	g/kg fuel	10.1	10.1	10.1	10.1	10.1	10.1	10.1			
Climb/Cruise/Descent	g/kg fuel	12.2	10.7	10.3	9.8	9.5	9.3	9.4			

Source: AEIG 2001b

Fuel consumption during the LTO cycle, as well as during the climb, cruise and descent phase, is provided for every distance category. In addition, average emission indices are listed for individual distance categories. To calculate the NO_x emissions of a specific flight, the distance category is selected that best corresponds with the actual flight. The average NO_x emission value is then multiplied by the fuel consumption of the respective flight phase. The German Advisory Council on Global Change also recommends this procedure for the calculation of an emission levy on aviation (WBGU 2002).

Because emissions indices differ by a maximum of 20% between distance categories, inaccuracy in the case of discrete distance categories amounts in the worst case to 10%. Taking into consideration inaccuracy in determining NO_x emission indices using the fuel consumption method, the maximum error increases to 20% (Brockhagen/Lienemeyer 1999).

For the introduction of an emissions trading system for international aviation, NO_x emission indices as a whole should be further developed, by taking account of the de-

30 Expert group on the Abatement of Noise Caused by Air Transportation within the European Civil Aviation Conference.

pendence of emission indices on engine type, and thereby generally minimizing the uncertainty of the indices.

The standard values established by ANCAT could be called into question by affected parties (for instance, airline companies), because they are not yet internationally recognized. This problem could be resolved by allowing parties to use lower emission indices if they furnish appropriate proof verified by a third party. With the free issue of emission rights, it has to be ensured that such proof is produced prior to initial allocation, so that the same emission indices are applied both in the allocation of emission rights and in proof of compliance. This procedure would also have the advantage that a data bank with verified emission indices is gradually built up, to which recourse can be made in later commitment periods.

This method of calculation has the further advantage that recourse can be made to existing data. It can be used not only for current flights movements, but also for flight movements in a past base year or period. At the same time, the data quantity is kept at a low level through restriction to several distance categories, and as a result, despite lower transaction costs, a positive ecological control effect is achieved.

4.4.3.3 Contrails

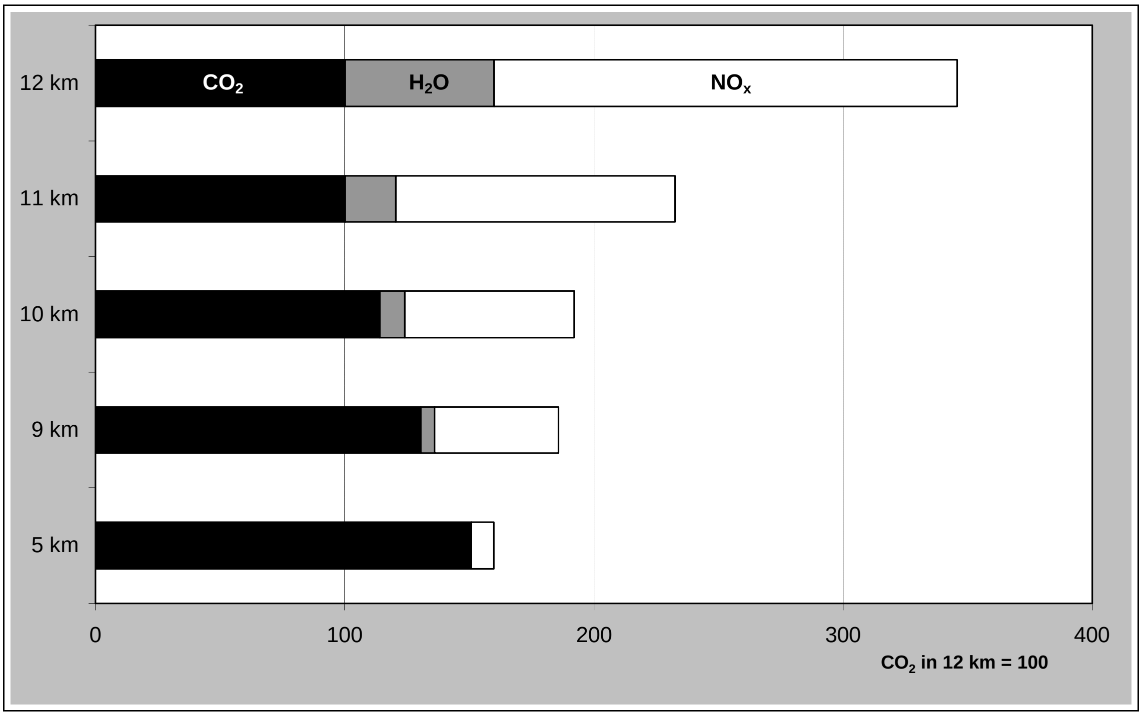
Whereas with carbon dioxide and water vapour only direct emission quantities are determined, in the determination of contrails, which occur in secondary reaction, other factors have also to be considered. Besides emissions of water vapour, sulphur and particulates, the development of contrails is particularly dependent on temperature and humidity. Because these meteorological factors can nowadays be determined in advance for the whole world by means of digital weather forecasting, the formation of contrails can also be accurately predicted. For military air traffic in Europe and the USA, flight altitudes at which contrails are likely to develop are at present ascertained on a regular basis for reasons of security (Sausen 2002).

Brockhagen (1996) assumes that the atmospheric layers in which contrails occur are normally not thicker than 500 metres. If airlines avoid flying through these layers, the formation of contrails can be largely reduced. According to information from *Deutsche Flugsicherung (DFS)* (Lindenmayer 2002), a change in flight level of this order is nothing unusual. Flight security is able at any time to order a change in flight level depending on the weather situation. Extensive avoidance of certain flight levels, or altitudes, in which contrails mainly occur, is basically possible when traffic density allows.

With evasive reactions, trade-offs might possibly occur with other emissions harmful to the climate. Brockhagen/Lienemeyer (1999) assume that with flights at an altitude 500 metres higher or lower, fuel consumption and CO_2 emissions increase by about 2% and NO_x emissions by 5%. With NO_x emissions at lower flight altitudes the climatic impact is also lower, despite the somewhat higher specific emission quantity (Grewe

2002). Figure 8 displays the relative climatic impact of CO_2, H_2O and NO_x emissions depending on the altitude of emission.[31]

Figure 8: Relative greenhouse effect depending on flight altitude



Source: IPCC 1999

Despite higher CO_2 and NO_X emissions with flights at lower altitudes, the joint climatic impact of these emissions declines. A reduction in flight altitude for the avoidance of contrails results in higher emissions of CO_2 and NO_X in absolute terms, but not, however, in a greater climatic impact of these emissions. On the contrary, through the reduced greenhouse gas impact of NO_X at lower flight levels additional CO_2 emissions can be fully compensated. Because this impact is negligible in comparison to that achieved from the avoidance of contrails, in a conservative approach it can initially be ignored in recording the reduction effects of avoided contrails.

There are several possibilities to incorporate contrails into the basis for assessment. Were account to be taken only of water vapour emissions (perhaps also sulphur and particulates), the result, on average, would be an equal charge on all flight movements depending on fuel consumption. Alternatively, only those flight movements could be charged, in the course of which contrails most probably form; that is, external factors would be included. Brockhagen/Lienemeyer (1999) recommend the first possibility within the framework of a levy system for aviation. In developing an emissions trading

31 The effect of contrails is not considered in this presentation.

system, however, it would appear to be essential for an adequate incentive effect to include the probability of contrail formation; for in this way, incentive effects can be created that are more or less adequate to actual climatic impacts. For this approach, recourse is made to CE findings and model computations (CE 2002a, 2002b).

CE (2002b) describes specific circumstances under which contrails occur. Through consideration of humidity, temperature, flight altitude and flight routes, CE comes to the conclusion that the formation of persistent contrails occurs during about 10% of worldwide aggregated flight time. In contrast to other environmental effects, the formation of contrails is mainly dependent, irrespective of aircraft size, on flight duration. Assuming that flight duration is proportionate to flown kilometres, 10% of flight kilometres are responsible for radiative forcing through contrails.

For the calculation of the external costs of aviation, the CE concept (CE 2002a) distinguishes between situations with and without contrail formation. Table 5 displays the findings taking into account the latest scientific knowledge.

Table 5: Global average radiative forcing of aviation with and without the occurrence of contrails

Radiative forcing		Average fligt with contrails during 10% of the fligt time	Situation **without contrails** (90% of flight time)	Situation **with contrails** (10% of flight time)
CO_2	W/m²	+0.018	+0.0162	+0.0018
O_3 (from NO_x)	W/m²	+0.023	+0.0207	+0.0023
CH_4 (from NO_x)	W/m²	-0.014	-0.0126	-0.0014
H_2O	W/m²	+0.002	+0.0018	+0.0002
Contrails (Mix of H_2O, SO_2 and soot)	W/m²	+0,0035	+0.0000	+0.0035
Cirrus clouds	W/m²	0 bis +0,075	+0.0000	0 bis +0,075
SO_2	W/m²	-0.003	-0.0027	-0.0003
Soot	W/m²	+0.003	+0.0027	+0.0003
Total (without cirrus clouds)	**W/m²**	**+0.033**	**+0.0261**	**+0.0064**
Aircraft performance (1992)	billion km	20.70	18.63	2.07
Specific radiative forcing (without cirrus clouds)	**picoW/m²/km**	**+1.6**	**+1.4**	**+3.1**

Source: CE 2002a; Öko-Institut calculations

On the assumption of proportionality between flight duration and the route flown, the radiative forcing of one flown kilometre with contrails (+3.1 picoW/m^2) is double (2.2) that of one flight kilometre without contrails (+1.4 picoW/m^2). This factor applies for average aircraft found on the market. For aircraft with greater fuel consumption – that is, for old or large aircraft – the factor is smaller; for small or fuel-efficient aircraft the factor is greater than 2.2.

If one looks at an average flight kilometre during which contrail formation occurs, the radiative forcing of contrails (+0.0035 W/m^2) is almost twice as great as the radiative forcing of CO_2 (+0.0018 W/m^2). Average aircraft emit about 22 kg of CO_2 per flight kilometre (IPCC 1999, p. 302). The additional radiative forcing of contrails thus corresponds to the radiative forcing of around 42.8 kg of CO_2 (1.94 x 22 = 42.78).

For the assessment of the climatic impact of one flight kilometre with contrail formation, it is recommended, in accordance with the CE method (CE 2000a), that climatic impact be initially calculated without contrails, and that climatic impact be subsequently added equivalent to the emission of 42,8 kg of CO_2 per km.

Because contrail formation cannot be measured and documented during every flight, differentiation according to situations with and without contrails is only useful, when it can be determined during which flights contrails occur, and to what extent. For this purpose, the development of specific probability factors is necessary, analogous to ANCAT NO_x emission indices. With the help of such factors, the probability of contrail formation can be portrayed depending on flight route and altitude. The parameters to be considered are humidity and temperature at cruise altitude, flight route and cruise altitude as well as engine and water vapour emissions. Table 6 shows the data availability of different parameters.

Table 6: Data availability of parameters for the determination of contrail indices according to the probability method

Parameter	Data availability
Meteorologic data (humidity, temperature in flight level)	Numeric weather forecast
Flight level	Derived from engine and distance category
Route	Also necessary for the calculation of NO_x emission indices
Engine (exhaust temperature)	Also necessary for the calculation of NO_x emission indices
Water vapour emissions	Can be calculated by fuel consumption

Source: Öko-Institut

Digital weather forecasting allows every airline to forecast conditions during a scheduled flight. Information on temperature and humidity at flight altitude is available. Flight altitude, flight route and engine type are needed for the calculation of NO_x emissions according to ANCAT (see Section 4.4.3.2), so data is available for the calculation of contrails. The quantity of emitted water vapour can be calculated from fuel consumption.

With the respective contrail index, the probability of contrails occurring is then determined. By multiplying this value by flight distance, the number of flight kilometres with contrails can be calculated. For each of these kilometres, the respective party's emission allowance obligation increases by 42.8 kg CO_2.

For the systematic recording of contrails, a forecasting and monitoring system has to be established on the basis of digital weather forecasting, with the help of which regions with a very strong probability of contrail formation can be reliably forecast. By matching this data with the actual flight route, the number of flight kilometres with contrail formation – which has later to be covered with emission rights – can also be calculated ex post.

It is also conceivable that the formation of contrails could be monitored by satellite in real time with the help of infrared cameras. Here, however, it has to be examined whether the technical requirements for realization of such a system already exist, and also what costs are to be expected

Though this method of calculation can be employed for present and future flight movements, it is questionable whether it can also be used to determine the climatic impact of contrails from past flights. Because contrail formation is directly dependent on weather conditions, it can hardly be reconstructed in retrospect from existing data.

4.4.3.4 Determination of CO_2 equivalents

The procedures presented in previous sections, concerning the determination of quantities of greenhouse gas emissions from aviation and their by-products, have now to be assessed regarding their specific impact on the greenhouse effect. This assessment takes place with the support of the radiative forcing of individual greenhouse gases and their by-products, and allows comparison with CO_2 (Section 3.3.1).

The specific radiative forcing of greenhouse gas emissions from aviation has previously been determined on the basis of the global radiative imbalance of aviation as a whole in the year 1992 (Table 2). For an emissions trading system that merely covers international aviation, the radiative imbalance should only be included that is caused by international aviation. At present, greenhouse gas emissions of individual aviation categories (instrument flying, visual flights, military flights) can be differentiated, but not radiative imbalance, which has not previously been separately estimated or modelled for individual emission sources. In order, nevertheless, to be able to calculate the specific radiative forcing of civil aviation, the radiative imbalance attributable to this category is cautiously estimated. According to the emissions inventory of the German Aerospace Center for 1992, 13% of CO_2 and 11% of NO_X emissions are caused by military flights (IPCC 1999). This share is declining, however, due to the strong growth in civil aviation. Because military aircraft generally fly lower than civil aircraft, the specific climatic impact of their emissions is lower than that of civilian flights. At a conservative estimate, it is assumed that around 12% of radiative imbalance is induced by military flights. The established average radiative forcing of civil aviation is somewhat lower. The accompanying uncertainty appears to be acceptable, within the framework of an emissions trading system for international aviation, since it underestimates rather than overestimates greenhouse gas effects.

In calculating the basis for assessment, only climate-impacting emissions may be considered. CO_2 emissions have a climatic impact throughout the total flight cycle, and should therefore be fully covered. NO_X and water vapour emissions, on the other hand, only have a climatic impact in the troposphere and stratosphere; and because no appropriate data is available, in this case it is simply assumed that total emissions during the climb, cruise and descent phase have a climatic impact. NO_X and water vapour emissions during the LTO cycle are therefore disregarded.[32]

Taking account of these aspects, the CO_2 equivalents[33] of NO_x and water vapour can be calculated for 1992 (Table 7): one tonne of water vapour emitted during cruising thus corresponds to 3.178 t CO_2 eq., and one tonne of NO_X to 136.46 t CO_2 eq.

Table 7: Derivation of specific radiative forcing and CO_2 equivalents for the year 1992

		CO_2	H_2O (direct)	NO_x
Determined quantity	Mio. t	413,1	145,9	1,5
Global radiative forcing (excl. military)	W/m^2	0,0158	0,0018	0,0079
Specific radiative forcing	pW/m^2t	0,0383	0,0121	5,2326
Specific radiative forcing	$CO_2 = 1$	1,00	0,31	136,46
Emission quantity corresponding to one t CO_2 equivalent	t	1,000	3,178	0,007

Source: Öko-Institut computations; Data: NASA 1992 without military flights, factored with 1.15 (IPCC 1999, p.194 and 303); proportional assignment of emission quantities to LTO and climb/cruise/descent in 1992: DLR 2002; method: CE 2002a

Through the determination of CO_2 equivalents for international aviation, the climatic impact of CO_2, NO_X and water vapour emissions can be compared and added up. At the same time, a gateway mechanism is created for open trading with other sectors. The owner of an emission right to one tonne of CO_2 may therefore emit either 1 tonne of CO_2 or 3.178 tonnes of water vapour or 7 kg NO_x during the climb, cruise and descent phase. The greenhouse gas effect of contrails is calculated by means of flight distance and the predicted probability of the occurrence of contrails; and every contrail-inducing flight kilometre is charged with 0.24 t CO_2 eq. (cf. Section 4.4.3.3)

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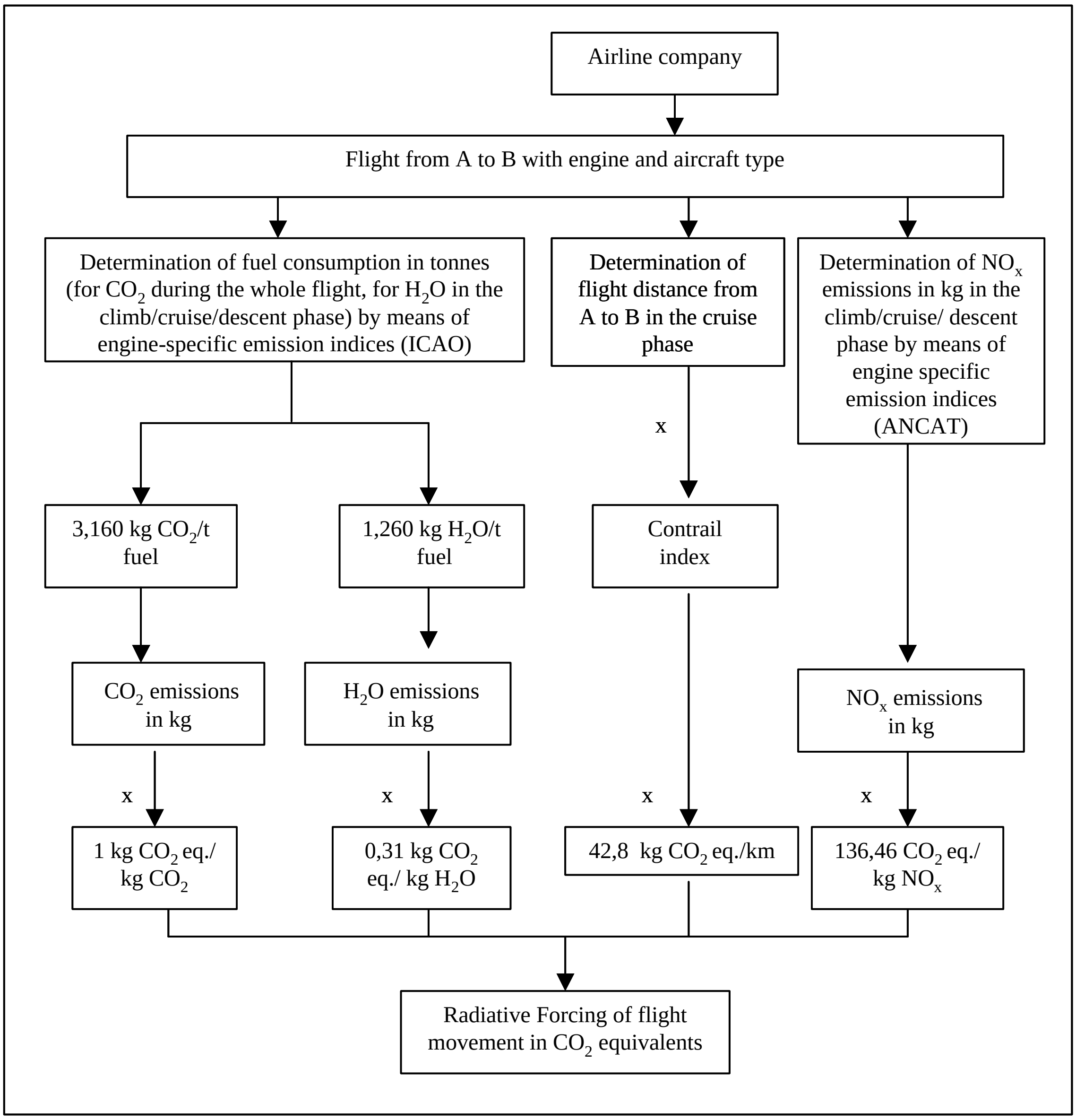
32 Non-consideration of NO_X and water vapour emissions in the LTO cycle is consistent from a climate policy point of view. It also has the effect that short-haul flights, which generally have higher specific NO_X emissions than long-haul flights, are still charged less than long-haul flights. Incentive effects for the avoidance of NO_X emissions in the LTO cycle are not derived from emissions trading for international air traffic. In this case, therefore, the support of emissions trading in greenhouse gases through emission-related landing fees could be considered for the avoidance of ground-level NO_X emissions.

33 These CO_2 equivalents are not determined on the basis of the concept of global warming potential, but rather by way of the radiative forcing of substances. They represent a measure of the momentary climatic impact of emissions. If aviation grows as forecast, however, and the sensitivity effect of ozone and contrails is relatively greater than the accumulation effect of CO_2 (cf. Section 3.3.1), then these CO_2 equivalents represent a measure not only of momentary climatic impact, but also of long-term change of temperature.

Figure 9 displays the different steps in the calculation of the greenhouse effects of a flight in CO_2 equivalents.

Figure 9: Method for the calculation of CO_2 equivalents for the climatic impact of international aviation



Source: Öko-Institut

Many of the parameters that flow into the calculation of the greenhouse impact of aviation in CO_2 equivalents are still the subject of scientific debate. The method of calculation is still reliable because, in the case of doubt, the more conservative parameter is always taken as a basis; that is, with an effect that has not been scientifically validated the lower value is always used. Nevertheless, with improved scientific understanding the parameters should be examined anew and, where necessary, adjusted.

Table 8 provides an exemplary calculation, on the basis of this system, of the CO_2 equivalents of two flights.

Table 8: Exemplary calculation of the CO_2 equivalents of two flights

Flight		Berlin - New York	Berlin - Zurich
Distance	km	5,000	1,000
Distance category	nm	2,500	500
Airplane		Airbus 310	Boeing 737 400
Engine		CF6-80C2	CFM56-3B-2
Emissions			
Fuel consumption	t	23.7	3.6
Cruise	t	22.2	2.8
Remainder	t	1.5	0.8
Carbon dioxide emissions	t	75	11
Water vapour emissions (cruise)	t	27	3
Nitrogen oxide emissions (cruise)	kg	273	29
Nitrogen oxide emission index (cruise)	g/kg fuel	12	10
Distance with contrails	%	50	0
Distance with contrails	km	2,500	0
CO_2 equivalents	**t CO_2 eq.**	**228**	**16**
Carbon dioxide	t CO_2 eq.	75	11
Water vapour	t CO_2 eq.	9	1
Nitrogen oxides	t CO_2 eq.	37	4
Contrails	t CO_2 eq.	107	0

Source: Öko-Institut computation; data from Table 4 and Table 7

A flight from Berlin to New York with an Airbus 310, a CF6-80C2 engine and an assumed 50% probability of contrail formation, has a climatic impact of approximately 228 t CO_2 eq. (0.045 CO_2 eq./km). Since it is assumed that contrails occur with this flight, the climatic impact of the flight is three times greater than the climatic impact of CO_2 alone. This shows that a considerable reduction in the climatic impact of aviation is possible through the avoidance of regions and flight altitudes in which there is a great possibility of contrail formation.

The second example, a flight from Berlin to Zurich with a Boeing 737 400, a CFM56-3B-2 engine and an assumed zero probability of contrail formation, shows on the other hand a distinctly smaller climatic impact, not only in absolute terms (16.4 CO_2 eq.) but also per flight kilometre (0.016 CO_2 eq./km). Because contrails do not form, the climatic impact of the flight as a whole is also only 1.44 times greater than the climatic impact of the CO_2 emissions of this flight.

With an assumed market price of between 3 and 30 euros for an emission right for the value of 1 t CO_2 eq., a charge of between 680 and 6,830 euros would have to be expected for the Berlin – New York flight, and one of between 50 and 500 euros for the Berlin – Zurich flight. With 400 passengers on the flight to New York, the cost per passenger would amount to between 1.70 and 17 euros; in the case of the flight to Zurich, with 100 passengers, the cost per passenger would amount to between 0.50 and 5 euros.

4.5 Parties obliged to hold emission rights

Having laid down the basis for assessment associated with a selected cap (Section 4.9), and thus determined the quantity of available emission rights, the question then arises as to who is obliged to possess these rights. The obligated party is subject to the control of the supervisory authorities. At the end of a given period, it has to prove that the emissions for which it is responsible are covered by a corresponding amount of emission rights. Those obliged to possess emission rights are therefore, primarily, the parties who trade in them.

The choice of those obliged to participate in an emissions trading system is therefore a central and also difficult issue, since it has to satisfy different, partly inconsistent criteria. On the one hand, the level of transaction costs of the emissions trading system – that is, expenditure on the procurement of information, monitoring, controlling etc. – depends on the resolving of this issue. The group may not be too large, since the efficiency benefits of emissions trading are easily overcompensated by transaction costs. On the other hand, the group of obligated parties may also not be too small, since insufficient competition might otherwise be the result, and new entrants might be excluded from the market through restrictive practices. Also dependent on the resolving of this issue is the question of whether avoidance potentials can be fully exploited. For when parties are obliged to participate, who themselves cannot directly realize technical and organizational avoidance potentials, the efficiency of the system as a whole is limited. Furthermore, with the choice of parties obliged to participate, questions of distribution are largely decided in advance. The choice of obligated parties thus ultimately affects political acceptance of the emissions trading system.

At the same time, the choice of obligated parties – especially in the case of an international trading system – is very complex, since commitments have to be established at different levels. The question arises, whether participating states enter into commitments that are binding under international law, whose fulfilment they can then delegate to legal entities in their respective states. It is basically conceivable, that legal entities enter into commitments within the framework of an international agreement.

Assuming that only one group of selected states participates in emissions trading, while another group remains excluded (developing countries, for instance), the question arises as to who will be responsible, and to what extent, for emissions from flights between these two groups of states. The question also arises: What should emission rights relate to? Should they relate to passengers, to freight, to airports, to sales of fuel or to the flight itself? Different options have already been identified within the framework of the UNFCCC, each of which has advantages and disadvantages. Finally, the question of who is to be obliged to possess emission rights – and thus to become a major participant in an emissions trading system – has also to be dealt with.

4.5.1 Commitment structure

The fundamental question arises as to who will be obliged, at an international level, to undertake emission reductions and made liable in the case of non-compliance. In principle, two options are conceivable:

- States: Emission rights can be assigned to states. These (as laid down in the Kyoto Protocol) can empower legal entities to trade directly in emission rights.
- Legal entities: Emission rights can also be issued directly to legal entities (airline companies, for instance).

The latter option would have the advantage that the difficult issue of the assignment to states of emissions from international aviation, which has been the subject of controversial debate in the past, could be avoided. Assignment to individual airline companies on the basis of historic emission data, would, on the other hand, be comparatively easy to realize, because civil aviation emissions can be clearly assigned to individual airlines.

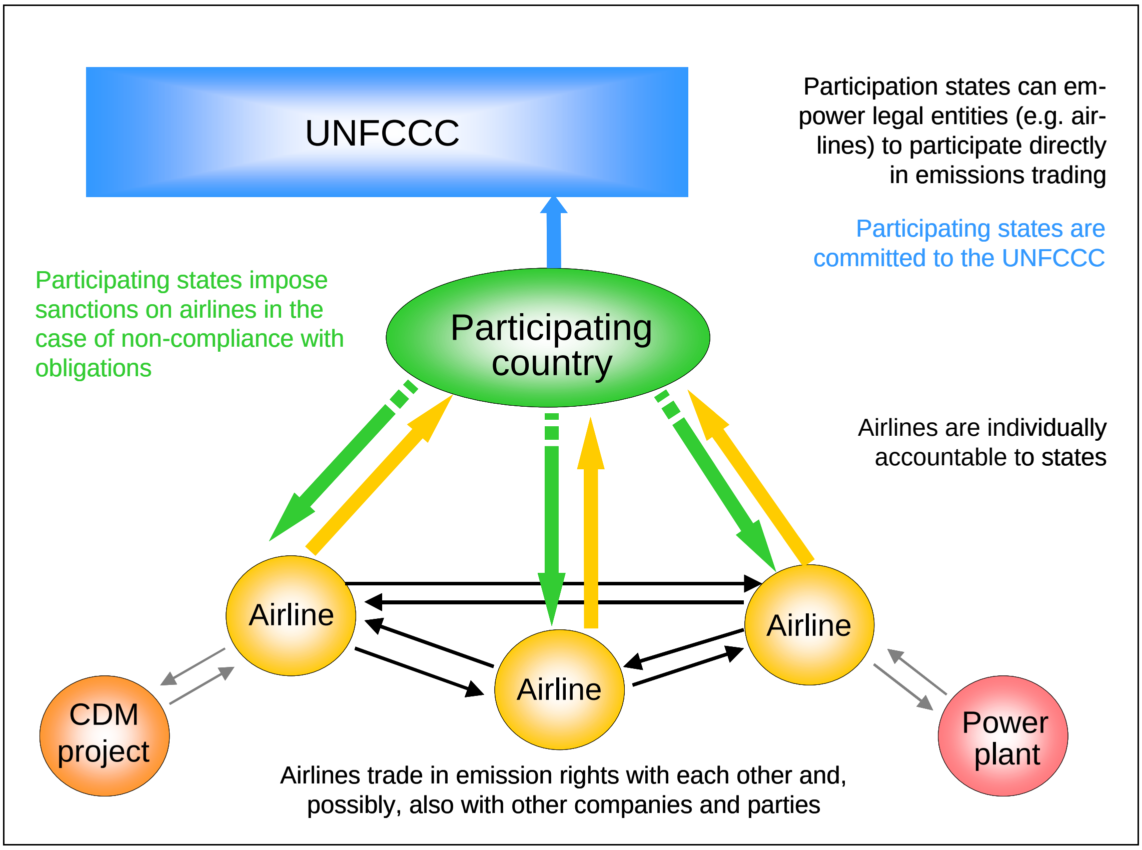
A number of legal and political reasons can be put forward against the direct assignment of emission rights (IPPR 2000). This method of assignment would represent a considerable departure from the structure of the Kyoto Protocol and also from international legal practice, because emissions affecting the climate would be assigned to private enterprises and not to states. However, aviation will in any case enjoy a special status. It is also difficult to guarantee compliance with commitments at an international level when the respective states are not involved, because, ultimately, only they dispose of the power of sanction required to enforce such obligations.

Another approach would be to call in an international body, which would take responsibility for the allocation of emission rights to airline companies as well as for monitoring the system. The ICAO would be a prime choice for this task, since it disposes of broad specialized competence in aviation field. For such an approach, however, it needs to be examined whether the ICAO is legally in a position to enforce sanctions against parties such as national airlines.

Although a commitment structure is therefore theoretically possible, through which legal entities are directly accountable to an international body, the practical relevance of this option must be negligible, since it demands considerable uniformity of interests on the part of all participating parties. But even if such uniformity were to be achieved, the participation of the ICAO raises legal problems – in particular with the integration of the emissions trading system for aviation into the Kyoto Protocol – since, in contrast to Annex I states, the ICAO is neither a member of the UNFCCC nor a party committed to the Kyoto Protocol. It is also unlikely that the COP will admit the ICAO as a special party to the Kyoto Protocol (IPPR 2000), in which only governments are eligible to vote. Even less likely is the admission of airline companies themselves. Such a model would be conceivable only within the framework of closed emissions trading within international aviation, where no connection would exist to emissions trading under the Kyoto Protocol.

Accordingly, there are legal and political grounds for supporting assignment to states. Figure 10 displays the commitment structure, by means of which participating states initially undertake reduction or limitation commitments that are binding under international law, and then, where applicable, empower legal entities (airline companies, for instance) to participate directly in emissions trading.

Figure 10: Proposed commitment structure



Source: Öko-Institut

This commitment structure is comparable with that of the Kyoto Protocol, in which states, as contracting parties, have also committed themselves to greenhouse gas reduction or limitation. At the same time, however, the Kyoto Protocol also allows legal entities to participate directly in the use of flexible instruments. Legal entities thus empowered are nevertheless not accountable to the COP, but rather to their respective states. Cross-border transactions have therefore to be processed in the emission registries of the states involved.

In this way, on the one hand, a high level of commitment to emission reductions is guaranteed; on the other hand, however, it is left up to the contracting states – in line with the principle of subsidiarity – to decide on the instruments with which they fulfil their commitments. National sovereignty is therefore not affected by this procedure. No country is required to fulfil its commitments with particular instruments.

It is conceivable that certain states will decide that they will participate in emissions trading or the use of flexible instruments at state level only. Legal entities in these states would then neither obtain emission rights nor participate directly in emissions trading. Nevertheless, transactions could be executed between such states and legal entities in other states. This commitment structure thus offers considerable flexibility, and, in view of strongly diverging interests at an international level, is best suited to bring about an appropriate balancing of interests.

With an emissions trading system, where commitments are made by only a few states, the question arises as to which flights should be covered by the emissions trading system, and which should not be covered. For it has to be taken into account whether flights take place between participating states, or whether a non-participating country is also involved. The question further arises, whether or not registration in the emissions trading system is dependent on the nationality of the airline company.[34] Table 9 surveys possible flight categories depending on these issues.

Table 9: Flight categories depending on the nationality of the airline company as well as on points of departure and destination

Flight	Nationality of airline company	Flight between	
		Country A	Country B
1	participating country	participating country	participating country
2	non-participating country		
3	participating country	non-participating country	participating country
4	non-participating country		
5	participating country	non-participating country	non-participating country
6	non-participating country		

Source: Öko-Institut

Flights 1 and 6 are not contentious. When a flight takes place between participating states and is operated by an airline company based in one of these states, it should be

34 According to the Chicago Convention, airline companies have the nationality of the country in which they are registered (Chicago Convention 1944).

covered by the emissions trading system. It is also clear, that a flight between two non-participating states will not be covered by the emissions trading system.

But with flight 2, where a flight between two participating states is operated by an airline company that is based in a non-participating country, the question could be raised, whether or not such flights should be covered. However, disregarding flights between participating states operated by airlines from non-participating states would result in flights of airlines based in participating states being edged out by flights of airlines based in non-participating states. Moreover, airline companies from participating states would be tempted to move their headquarters, or place of registration to a non-participating country. In the end, only very few flight movements would be covered by such an emissions trading system, and the system would become absurd. These considerations show that airline companies from participating and non-participating states have to be treated equally, since massive avoidance strategies would otherwise be the result, which would ultimately make the emissions trading system ineffective. On this assumption it is obvious that flight movements 5 and 6 should initially also not be included in an emissions trading system.

It must also be questioned, whether an emissions trading system should cover flights whose place of departure or destination is not in a participating country (flights 3 and 4). The partial responsibility of these flights for greenhouse gas emissions cannot basically be disputed. According to the polluter-pays principle, these flights should at least be partially covered. It would be possible that only inbound, or only outbound flights are covered, or that in each case half of the emissions of a flight between a participating and a non-participating country are covered. The assignment of the total emissions of both inbound and outbound flights to the participating country could also be considered. This would go beyond the polluter-pays principle, but could be important as a measure for mitigating undesired avoidance strategies (Section 4.5.2.5).

4.5.2 Assignment of emissions

The question of which greenhouse gases can be covered and how they can be measured or calculated was dealt with in the discussion on a basis for assessment. Later, the question of who could or should assume responsibility for greenhouse gas emissions was also discussed. The question of the quantity of emission rights to be allocated to individual participants in emissions trading, however, is still unresolved. For this purpose it has to be decided, where emissions will be registered and who will ultimately be held responsible for them.

In the Kyoto Protocol, a simple and straightforward method was chosen to resolve this issue, which is largely undisputed and enjoys widespread acceptance. Emissions were assigned to the country in whose territory they have occurred. There are inaccuracies and injustices even with the territoriality principle, but these are comparatively minor and therefore acceptable.

Unfortunately, the territoriality principle cannot easily be applied to civil aviation,[35] since 70% of the earth is covered by oceans that are not assigned to a particular state. Apart from that, the territoriality principle already reaches its limits in the case of transit flights, because emissions would have to be assigned proportionately to the country that is flown over, which could considerably increase administrative costs.

In the run-up to the Kyoto Conference, alternatives were therefore sought to the territoriality principle for the assignment of aviation emissions.[36] Altogether eight options were identified (UNFCCC/SBSTA/1996/9/Add.2):

1. No assignment of emissions.
2. Assignment of emissions from bunker fuels to the contracting parties in proportion to their national emissions.
3. Assignment to states selling bunker fuels.
4. Assignment according to the nationality or domicile of the airline company.
5. Assignment according to the place of aircraft departure or destination; alternatively, division of emissions between places of departure and destination.
6. Assignment according to the place of departure or destination of passengers or freight; alternatively, division between places of departure and destination.
7. Assignment according to the nationality of the passenger or the owner of freight.
8. Assignment according to the point of origin of emissions

The second, as well as the seventh and eight options were rejected from the beginning due to inadequate possibilities for registration, or on account of poor data availability. The first, third, fourth, fifth and sixth options, on the other hand, were short-listed within the scope of the UNFCCC debate as possible methods of assignment (UNFCCC/SBSTA/1996/9/Add.2). Agreement on just one of these options has not yet been reached in the UNFCCC/ICAO debate. The advantages and disadvantages of these five individual options are analysed below.

4.5.2.1 No assignment of emissions

This option corresponds with the status quo. CO_2 emissions from international civil aviation are recorded in national inventories on the basis of national fuel sales, but, because they are considered neither in the base year nor in the commitment period, assignment does not take place. It is evident that this option cannot provide the basis of an emissions trading system, since there would be simply nothing to trade in.

35 This applies also to international shipping.

36 The assignment of emissions is of importance not only during the realization phase of the emissions trading system, but also – in the case of the free issue of emission rights on the basis of historic emissions (Section 4.6.2.2) – with so-called initial allocation.

4.5.2.2 Assignment to states selling bunker fuels.

The assignment of emissions to states selling bunker fuels is based on the so-called turnover principle, according to which a balance is made of a given country's import, production and export of aviation fuels, while stocks are ignored. The result tallies with the amount of fuel sold in that country. The ICAO already records these values on a regular basis.

The problem with this method of assignment is that sales in a country do not necessarily tally with actual consumption, since “aviation-fuel tourism” and tankering strategies can be of considerable significance. Were virtually all states to participate in the emissions trading system, such strategies would present no problem from an ecologically point of view, since they would cancel each other out (BUWAL 2000). Where only a relatively small group of states takes part in emissions trading, however, obligated parties could partly evade their emission reduction obligations through the exploitation of permissible reserves (leakage) when refuelling in non-participating states.

Due to such possibilities of evasion, this assignment method is hardly appropriate for an emissions trading system intended to support the Kyoto Protocol, and encompassing only a restricted group of participating states. Furthermore, this method of assignment is inappropriate when a basis for assessment is selected that extends beyond carbon dioxide and water vapour, since emissions that are dependent on specific flight conditions – aircraft type, turbine engine, flight level, weather etc. – cannot be registered.

4.5.2.3 Assignment according to the nationality or domicile of the airline company

Alternatively, emissions could be assigned on the basis of the nationality or domicile of the airline company. Such an approach, which includes airline companies from non-participating states, is favoured by Tsai et al. (2000).

This manner of assignment would be comparatively easy to realize, since civil aviation emissions can be clearly assigned to individual airline companies, and these, in turn, to their respective states. It is also of advantage that the ICAO already registers the kilometres flown by individual airline companies on a regular basis (CAEP 2001, Table 5). Table 10 (page 76) surveys the cases to be differentiated with assignment of greenhouse gas emissions according to the nationality or domicile of the airline company.

With this method of assignment, however, not only the airline companies of non-participating states have to be incorporated into the system, but also the states themselves, because airline companies could otherwise evade reduction or limitation obligations by out-flagging in non-registered states. The involvement of non-participating states is only foreseen for the second commitment period, however, due to the principle of joint or shared responsibility that forms the basis of the Kyoto Protocol. Since it has to be assumed, for the time being, that for the second commitment period, too, not all developing states will adopt binding reduction targets, the problem could persist in the medium term.

Table 10: Assignment of emissions to participating and non-participating states according to the nationality or domicile of the airline company

Case	Nationality of airline company	Flight between		assignment of emissions
1	participating country	participating country	participating country	participating country
2	non-participating country			non-participating country
3	participating country	non-participating country	participating country	participating country
4	non-participating country			non-participating country
5	participating country	non-participating country	non-participating country	participating country
6	non-participating country			none

Source: Öko-Institut

4.5.2.4 Assignment of emissions according to the place of aircraft departure or destination

This assignment approach corresponds best with the territoriality principle and also appears to be quite practicable. In accordance with the so-called “flight-schedule principle”, emissions are wholly assigned to either the place of departure or the place of destination.[37] It would also be possible to divide emissions equally between place of departure and place of destination. In the case of a flight between a non-participating and a participating country, it would have to be considered whether the participating country should be charged with all emissions or merely half of them.

Table 11: Assignment of emissions according to the place of departure or destination of aircraft

<table>
<tr><th rowspan="2">Case</th><th colspan="2">Flight between</th><th rowspan="2" colspan="3">Asignment of emissions</th></tr>
<tr><th>Country A</th><th>Country B</th></tr>
<tr><td rowspan="2">1</td><td rowspan="2">participating country</td><td rowspan="2">participating country</td><td colspan="3">50% country A</td></tr>
<tr><td colspan="3">50% country B</td></tr>
<tr><td>2</td><td>non participating country</td><td>participating country</td><td>100% country B</td><td>50% country B</td><td>none</td></tr>
<tr><td>3</td><td>non participating country</td><td>non participating country</td><td colspan="3">none</td></tr>
</table>

Source: Öko-Institut

[37] Just which of these alternatives is selected is ultimately irrelevant. The most important thing is that a clear decision is made in favour of one of the alternatives.

This assignment method offers the advantage that it is also realizable when only a small group of states, such as Annex I states, set the emissions trading system in operation; for possibilities of evasion are relatively limited and can be additionally restricted by supporting measures. Table 11 (page 76) shows the different cases that can arise with this assignment method, where emissions of flights between participating states are equally divided, and those of flights between participating and non-participating states are wholly assigned to the participating country.

With this assignment method no differentiation is made on account of the nationality or domicile of airline companies. Airlines from non-participating states that fly between two participating states are obliged to hold emission rights to the same extent as an airline from a participating country.

Airlines could partially evade their obligations through strategic stopovers in non-participating states. A flight from Europe to Australia, for example, could first stop over in Israel and then stop over again in Indonesia. Long-haul flights would benefit from this strategy. Such strategies could be restricted, however, through the use of a variety of accompanying measures. For instance, flights with the same flight number could be assigned emissions in full, irrespective of stopovers; or this could be made dependent on whether flights continue with the same aircraft. The effect of these evasion strategies would also be limited in the case of flights between participating and non-participating states by 100 % assignment of emissions to the participating country.

Such strategies are also limited by other factors. Stopovers restrict the comfort of passengers, and airlines would therefore not fully exploit this tactic simply for marketing reasons. Moreover, the applicability of this evasion strategy could well be partly restricted by limited capacity at those airports that would be of particular interest. The possibility to evade emission obligations through stopover logistics therefore exists,[38] but this strategy will only play a minor role in practice, in particular with the (predominately) free issue of emission rights. Moreover, since the options for this evasion strategy diminish as the number of participants increases, they could be accepted in the medium term.

Beyond that, with this method of assignment all greenhouse gas effects of a particular flight could be covered. As a result, and in contrast to the assignment of emissions to "the country selling bunker fuels" (Section 4.5.2.2), there are no restrictions regarding the choice of the basis for assessment, with the effect that a basis for assessment can be chosen that largely covers all greenhouse gas effects of a flight.

On the whole, this assignment method is not only inherently consistent; it is also compatible with the Kyoto Protocol, both at present and in the future. In designing an emis-

[38] Such strategies are an issue whenever an emissions trading system covers only particular segments (in this case, a group of states). They cannot be entirely prevented, and they are not related to design, but are rather of a systematic nature. All the same, the range of options for the use of such evasion strategies can be reduced through appropriate design.

sions trading system for international civil aviation it should therefore be seriously considered.

4.5.2.5 Assignment according to the place of departure or destination of passengers or freight

The difference to the preceding assignment method is relatively minor. This method is also quite similar to the territoriality principle of the Kyoto Protocol, and greenhouse gas emissions can likewise be assigned equally to places of departure and destination. In contrast to the preceding assignment method, however, data requirements for the implementation and realization of the emissions trading system are greater, since each flight movement has to be divided among passengers and individual freight consignments. In addition, with this method of assignment, evasion strategies cannot be prevented, because a journey, like a flight, can be split into separate stages. This method would make sense, however, were the emission rights obligation to be imposed on air travellers and freight shippers.

4.5.3 Obligated parties

In Section 4.5.1, the question was discussed of whether reduction and limitation commitments should apply to states participating in the emissions trading system, or directly to individual legal entities. Irrespective of how this question is resolved, it has still be decided which legal entities are to be considered; for this issue is also important when participating states transfer national commitments to domestic legal entities.

The decision on who is to be obliged to participate is a key factor in the design of an emissions trading system. There is significant interaction with other design options, such as the basis for assessment, assignment of emissions, allocation of emission rights and commitments. In the case of obligated parties, emissions are measured or estimated. Obligated parties are registered and controlled by the administrators of the emissions trading system, and their selection greatly influences the transaction costs, effectiveness and realizability of the system.

The obligation should apply, moreover, at the point where the greatest influence on reduction potentials exists and where relevant and consistent emission inventories can be compiled. In selecting participants it should be ensured that institutional structures for trading in emissions rights exist, or can be developed in each individual case, and that they are compatible with the structures of the Kyoto Protocol. It should also be ensured that the system could be brought into line with national and international law.

In order to guarantee long-term market liquidity, the number of participants must be sufficiently large; a condition that is always fulfilled in an open system, but not necessarily in a closed system. On the other hand, the number of participants should not be too large, since control and transaction costs could then easily exceed the efficiency benefits of emissions trading.

Quantitative control of an emissions trading system can basically take effect directly with emitters (downstream approach) or at different points in the trading chain (mid- and upstream approach). In each of these cases, different parties are obliged to hold emission rights. The obligation could apply to fuel producers and importers, to airports and airline companies, to passengers and freight shippers as well as to aircraft manufacturers.

4.5.3.1 Upstream approach: fuel producers and importers

The so-called upstream approach obliges fuel producers and importers to hold emission rights.[39] With this model, approximately 70 to 100 parties (UNFCCC/SBSTA 1996a) would participate in emissions trading. Transaction costs should therefore turn out to be quite low. It has to be borne in mind, however, that this model can only be chosen when the basis for assessment is restricted to carbon dioxide alone, or to carbon dioxide with water vapour (Section 4.4.2.1). The regionally varying effect of water vapour, as well as that of nitrogen oxides occurring in combustion, could not be taken into account with this approach, however, since there is no connection to a specific flight.

It has also to be considered, that in the case of free issue of emission rights this approach generates windfall profits for fuel producers and importers, since the respective companies receive tradable certificates without a direct quid pro quo. This monetary benefit flows into the optimization strategy of the company in the form of opportunity costs – as forgone receipts; that is receipts that the sale of emission rights would produce – and manifests itself, as a result of modified production, in output prices. (Cames et al. 2001). The resultant financial burdens on civil aviation cannot – as is the case with auctioning – be redistributed; as a result, the political realizability of such a system is no doubt limited.

With the upstream approach it also has to be considered, that airline companies can partly evade emission obligations through changes in tank logistics within the scope of permissible quantities (tankering strategies), and that the effect of the emissions trading system as a whole would therefore be limited.

4.5.3.2 Midstream approach: engine and aircraft manufacturers

The midstream approach takes effect not at the point of emission (downstream) or at further points in the trading chain (upstream), but rather with the processes through which products are transformed. In the case of civil aviation, manufacturers of engines or aircraft could be obliged to hold emission rights.

With this approach, emission reduction is mainly achieved through technological innovation.[40] The allowances obligation could relate to the specific CO_2 and NO_x emissions

39 Alternatively, final sellers of aviation fuel could also be subject to the emissions allowances obligation. Since this option does not significantly differ from the option described here, a separate presentation is not made.

40 For instance, optimization of engines, weight and aerodynamics.

of aircraft and engines. However, because emission quantities, in absolute terms, are beyond the influence of engine and aircraft manufacturers and can only be estimated in advance with great uncertainty, with this approach a cap, in absolute terms, is hardly possible. Due to the long service life of aircraft, an emissions trading system based on the midstream approach would be very sluggish, since it would initially be restricted to new aircraft and engines, and only subsequently be extended to the fleet as a whole.

Besides, airline companies can achieve reductions in greenhouse gas emissions not only through technological innovation, but also, on a large scale, through operational and organizational measures, such as the optimization of flight altitude and routes and the avoidance of air traffic congestion (ICAO 2002). These operational and organizational reduction potentials are not covered with this approach, since no incentive is provided for optimized operation of aircraft or engines without climatic effect.

Since there are only a small number of engine and aircraft manufacturers worldwide,[41] each of whom disposes of a large market share, with a closed midstream approach the danger arises that individual parties could use their market power in emissions trading to drive out smaller manufacturers. Compatibility with the Kyoto Protocol is hardly to be achieved with this approach, so that an open emissions trading system should in any case be renounced.

4.5.3.3 Downstream approach: airline companies

An important feature of the downstream approach is that emissions are registered and monitored at the point where they occur; that is, with the emitter. In a broader sense, "emitters" of air-traffic pollutants comprise different target groups, including airline companies, passengers, freight shippers and also, in the abstract, airports.

It is passengers and freight shippers, after all, who provide the demand for air transport. Their inclusion in an emissions trading system in accordance with the polluter-pays principle would be desirable but, for administrative reasons, it would not make economic sense, since the transaction costs of emissions trading between so many participants would greatly exceed the efficiency gains achievable with emissions trading.

Theoretically, it would be possible to locate the emissions allowance obligation at airports, which would then be dependent, however, on the provision of data by airline companies, but could not have a direct influence on emission reductions. Furthermore, there would then be considerably more traders than in the case of airlines, with a possible negative effect on market transparency.

There are therefore a number of reasons for imposing the emissions allowance obligation on airline companies. Not only do they dispose of the greatest amount of information on emissions, they also have the widest range of opportunities to influence emis-

[41] There are altogether about 4 large aircraft manufacturers and 15 engine manufacturers (AEIG 2001; Federal Office for Civil Aviation Switzerland 2000); and within each of the two groups of manufacturers there is, in turn, strong market concentration in a subgroup.

sion reduction. What is more, the quantity of emissions can be more easily scrutinized at airline companies. Bearing in mind that international civil aviation is a highly competitive market, the 150 to 200 airlines companies worldwide (UNFCCC/SBSTA 1996/9/Add.2) would appear to be sufficient to guarantee market liquidity, even with a closed emissions trading system. The number of participants would also be large enough to prevent restrictive trading practices. Transaction costs arising with this approach should also prove to be comparatively low, on account of the small but adequate number of obligated parties, and should therefore be well below the efficiency benefits achievable through the emissions trading system.

4.5.3.4 Comparison of the advantages and disadvantages of individual parties

Table 12 surveys the parties that could be obliged to participate in an emissions trading system for international civil aviation.

Table 12: Comparison of possible obligated parties

	upstream	midstream	downstream
Obligated parties	fuel producers and importers	engine and aircraft manufacturers	Airline companies (passengers, airports)
Approach	fuel consumption	airplane, engine	flight
Number of traders	70-100[1)]	very small	150-200
Emission reduction is possible	CO_2, H_2O	CO_2, NO_x, H_2O	CO_2, NO_x, H_2O, contrails, partly cirrus clouds
Implied basis for assessment	CO_2 (and H_2O)	CO_2 (evtl. NO_x and H_2O)	all possible
Initial allocation	only auctioning[2)]	grandfathering, auctioning und Hybridsysteme	grandfathering, auctioning und hybrid systems
Compatibility with the Kyoto Protocol	possible	none	possible
Trading regime	open or closed	closed	open or closed
Disadvantages	auctioning needed	no incentive for operative measures of emission reduction	passenger: high transaction costs
Advantage	easy to administer, low transaction costs	Development of low-emission aircraft, technological progress	airline companies have a great influence on emissions, institutional structures exist

1) FCCC/SBSTA/1996/9/Add.2
2) Cames et al. 2001

Source: Öko-Institut

On the whole, the downstream approach, under which airline companies are obliged to hold emission allowances, proves to be the most appropriate for an emissions trading system for international civil aviation. It permits a comparatively large degree of freedom with regard to other design options (basis for assessment, initial allocation, trading regime, etc.), it demonstrates comparatively favourable market structures, so that restrictive trading practices are hardly to be expected and the liquidity of the market for emission rights should be assured at all times, and it gives rise to relatively low transaction costs.

In the European emissions trading system, emission rights relate to an installation, while the operator of that installation is obliged to hold emission rights. It is therefore proposed that a comparable structure be selected for an international system for civil aviation; namely, that emission rights relate to flight movements, and that flight operators – that is, the airline companies – be obliged to hold emission rights.

4.6 Initial allocation

Before trading in emission rights can commence, they have first to be brought into circulation; that is, they have to be distributed in some way to the parties participating in emissions trading. The total amount of emission rights to be distributed results from the quantitative target laid down in a political process before the instrument is established (Section 4.9). The question therefore arises, how the quantity of available emission rights should be divided among the different parties (allocation). To start with, two stages of allocation have to be distinguished: allocation of emission rights to the participating states (stage-one allocation), and allocation to individual legal entities (stage-two allocation).

Three exemplar allocation procedures can be differentiated for the allocation of emission rights:

- Auctioning: Emission rights are auctioned at the beginning of each commitment period, following which they can be freely traded.
- Grandfathering (Lyon 1986): Emission rights are allocated free of charge proportionate to past emissions.
- Benchmarking: Emission rights are allocated free of charge on the basis of a sector-specific benchmark (for example, CO_2 eq./km).

Mixed forms or combinations of these exemplar allocation procedures are, of course, also possible.

Certain aspects of both stages of allocation are discussed below. There follows an analysis of allocation procedures and their applicability to international civil aviation. A number of additional aspects, which are important so far as concerns initial allocation, are then discussed and assessed.

4.6.1 Stages of allocation

The states participating in an emissions trading system for international civil aviation having laid down the reduction target,[42] the total quantity of emission rights has then to be divided among the different states (stage-one allocation).[43] The option of having participating states bid for emission rights in an auction would be theoretically possible, but politically very unlikely. In this case, it would have to be decided for which purpose auction proceeds were to be used.

It is much more likely that emission rights will be allocated free of charge to participating states. The jointly agreed reduction and limitation target could also be applicable to individual participating states. If, for instance, emissions should be reduced by a total of 10% by the year 2010, compared to emissions in 1990, this would also apply to each of the participating states (principle of proportionality). It would also be possible to take additional factors into account, such as efficiency or reduction potential and marginal avoidance costs, and, in the course of political negotiations, to set reduction targets in absolute terms for each of the participating states.[44] Because the outcome of negotiated allocation is hardly predictable, the following comments are consistently based on a proportionate distribution of reduction and limitation targets between the participating states.

Once reduction and limitation targets have been decided in absolute terms for individual states, the emission rights available to each country have then to be allocated to the participating legal entities. A standardized procedure for stage-two allocation would be desirable to avoid distortions in competition, but it could meet with resistance on the part of individual states in negotiations on an international agreement, since it encroaches on their sovereignty. Since the adoption of international agreements requires consensus on the part of all participating states, recourse is frequently made in such situations to the principle of subsidiarity; according to which, superior political authorities should only take such decisions that subordinate authorities are unable to take. It must at least be doubted that initial allocation has inevitably to take place at a superior level, and not in participating states.

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42 A sequence of decisions on reduction targets and allocation procedures exists only in theory. Since both decisions are closely related, they are taken simultaneously. In other words: a country will only agree to a global target for the emissions trading system as a whole, if it regards the target, to which it is to be committed, as acceptable.

43 Where emissions trading in international civil aviation takes place without direct state involvement (Section 4.5.1), stage-one allocation can be dispensed with and stage-two allocation carried out.

44 Political negotiations – taking account of such factors as efficiency, avoidance potential and responsibility for problems – formed the basis for allocation under the Kyoto Protocol and within the framework of EU burden-sharing agreements of 1998. Apart from these special aspects, it is also of importance for stage-one allocations that certain states are won over to participation in a system in which less-ambitious targets are set. Accepted targets are therefore an indicator of how environmental goals are assessed in individual participating states.

A final appraisal of this debate is certainly not possible at this point, since this issue has also not been finally resolved within the scope of the debate on the European emissions trading system. The Draft Directive put forward by the European Commission (COM(2001)581) allows Member States a great deal of latitude so far as initial allocation is concerned, and provides only relatively general criteria for the design of so-called allocation plans (Annex III). This has met with criticism, for instance in the European Parliament, where the Committee on Legal Affairs and the Internal Market, for the Committee on the Environment, Public Health and Consumer Policy, has demanded that initial allocation be more strongly harmonized through the auctioning of at least 30% of emission rights (COM (2001) 581 – C5-0578/01 – 2001/0245(COD)). Stronzik/Cames (2002) also point out, that distortion to competition between Member States can arise on account of unresolved criteria, and that this could be prevented by a harmonized procedure for initial allocation. But even when harmonization of allocation procedures cannot be achieved before the conclusion of the protocol on emissions trading in international civil aviation, it should not necessarily be assumed that the allocation procedures of individual states would widely differ. For it is quite likely that during the course of establishing national allocation procedures the demand for harmonization will be recognized and, irrespective of the formal wording in the protocol, effective harmonization will occur at the practical level.

4.6.2 Initial allocation procedure

Irrespective of initial allocation, and assuming a competitive market in which strategic behaviour is precluded, emissions trading invariably leads to a more efficient use of resources (cf. Weimann 1991, p. 157ff; Feess 1997, p. 533ff). Emission rights are in every case utilized for those flights where the avoidance of emissions would be the most expensive alternative. Initial allocation therefore has no influence on the efficiency of the system. However, initial allocation always has distributive implications. From this point of view, the choice of procedure for initial allocation is a particularly sensitive issue; for the acceptance of the whole emissions trading system on the part of affected groups and, possibly, the general public ultimately depends on the distributive consequences.

4.6.2.1 Auctioning

With this procedure, emissions rights are auctioned off at the beginning of, or at various points of time during the respective commitment period. Companies covered by the emissions trading system acquire emission rights in accordance with their expectancies and marginal avoidance cost curve. Should it subsequently turn out that too many, or too few emissions rights have been acquired, emission rights can be purchased or sold at any time.

The decisive advantages of auctioning, in theory, are that it is in line with the polluter-pays principle and sets an early pricing signal for the costs of avoiding greenhouse gases in international aviation. Companies can at any time weigh up whether it is more advantageous to acquire emission rights or to avoid emissions. With auctioning, clear and strong incentives are therefore set for emission reduction. In addition, auctioning initially has no distributive implications for the group of parties covered by the emissions trading system.

This applies, however, only so long as the proceeds of the auction are ignored. For if these proceeds are used, for example, to reduce general budget deficits, an implicit redistribution takes place from those parties covered by the emissions trading system to all other parties. From the point of view of the obligated parties, emissions trading would have the effect of a tax and, due to the associated increase in costs, generally meet with insignificant acceptance, if not outright rejection.

This problem could be mitigated, if auction proceeds for the most part flow back to the obligated parties.[45] Here it is decisive that the flow-back is unrelated to the origin of such proceeds, since otherwise the efficiency of the system would be endangered. Redistribution could be implemented, for instance, on the basis of technical standards of efficiency, or in the form of a reduction in non-wage labour costs. The disadvantage of redistribution is, however, that distribution issues, which are not particularly easy to decide politically, must again be debated.

It has further to be considered, that the auctioning of emission rights for international civil aviation only appears to be acceptable when emission rights are also auctioned in emissions trading under the Kyoto Protocol. If emission rights are auctioned in international civil aviation, but issued free of charge in other sectors, this would amount to a distinct change for the worse for civil aviation in inter-sector competition.

4.6.2.2 Grandfathering

With grandfathering, emission rights are allocated free of charge to obligated parties proportionate to emissions in a past reference period. A pricing signal does not occur concurrent with allocation, but only when the quantity of allocated rights does not correspond with the current requirements of individual parties. Because, however, fewer emissions rights are allocated than are currently required, in order to achieve the reduction target, trading in emission rights will soon commence. Companies with favourable marginal avoidance costs will undertake reduction measures and offer surplus rights on the market. The volume of turnover in emission rights within a particular commitment period is considerably higher in the case of auctioning than with grandfathering. Auctioning ought therefore to provide the more reliable pricing signal.

Grandfathering is attractive from the point of view of the parties concerned, because it secures vested interests; and for this reason they generally demand this method of allocation. Grandfathering above all supports the vested interests of emitters and therefore fundamentally contradicts the polluter-pays principle.

[45] Proceeds can also be used to cover the costs of implementing and administering (transaction costs) the emissions trading system.

The group of obligated parties is agreed that emission rights should be allocated free of charge; the question of the distribution key to be employed is unresolved however. Emissions of one or several past periods are generally taken as a basis. Because the share of individual obligated parties in total emissions differs from year to year depending on the economic situation, market shares, early reduction measures etc.,[46] the determination of so-called base periods also implies a partial redistribution within this group of parties.

The influence of certain factors, such as the economic situation, can be minimized if, instead of a single base year, several successive years are selected as the base period. The extent to which early reduction measures – so-called early action – are taken into account also depends on the base period. Parties who reduced their emissions through early investment in climate-protecting technology or organizational measures, will insist on a base period that lies a long way back, since their endeavours will then be accounted for on a larger scale. Parties, on the other hand, who made no effort to reduce their emissions before the introduction of emissions trading, will demand a late base year, since they will then be allocated more emission rights.

The choice of base period cannot be decided, however, solely on the extent to which early action is taken into account. For the earlier the base year or period the less reliable the data that provides the basis for the calculation of the distribution key. In choosing the base period, the scale of early action must be weighed against data availability for the corresponding period.

With grandfathering, it also has to be decided how new entrants – that is, participants that did not exist at the time of the base period – are to be treated. Since they did not produce emissions during the base period, they will not be allocated emissions rights free of charge. Instead, they will have to purchase the emission rights they require on the market. This represents preferential treatment of existing companies and is a barrier to market entrance for future participants. It would be possible, for instance, to withhold 5% of available emission rights for issue to new entrants. In the case of an average 10% reduction target, new entrants would be allocated 90% of their forecast emission rights requirements free of charge, and would then have to purchase the remaining 10%.[47] With such a regulation, however, it is not necessarily guaranteed that new entrants will have an incentive to make use of new technology. Furthermore, this

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46 Isolated events, such as the terror attacks in the USA on 11. September 2001, can also have noticeable effects on emissions. The year 2001 would therefore be inappropriate as sole base year.

47 The setting up of subsidiaries should not be treated as the founding of a new company, since what is involved is often a matter of expansion or transfer strategies on the part of established companies. Gratis emission rights should, in principle, not be made available within the framework of an emissions trading system for such market strategies. In practice, however, it will be difficult to clearly differentiate between the founding of a new company and the setting up of a subsidiary.

approach also requires ex post control of whether forecast demand tallies with actual demand.

The treatment of insolvent companies and mergers has also to be clarified. In the case of bankruptcy, emission rights are part of the bankrupt company's assets and can be disposed of by the receiver. They therefore remain available on the market. Once bankruptcy proceedings have been initiated, however, no further emission rights should be allocated. Mergers and take-overs during the course of emissions trading are not a major problem, since the emission rights of both former companies are available to the merged company. Where the merger takes place, however, between the base period and the commencement of emissions trading, it has to be ensured that in the initial allocation the merged company receives the rights due to both former companies.

All in all, the debate on new entrants and on company insolvency and mergers confirms that although grandfathering at first appears to be comparatively simple and attractive, it is still fraught with considerable problems, which up to now have not been satisfactorily resolved.

4.6.2.3 Benchmarking

With benchmarking, emission rights are also allocated 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 particular sector.[48] Because there is a particularly homogeneous output factor in international civil aviation to which the benchmark can relate, namely kilometres flown, this option should also be seriously considered. To determine the benchmark, an average value is first calculated from the total emissions of all obligated parties and the total number of kilometres flown, which is then weighted with the relative reduction target. By multiplying this average value, or benchmark,[49] by the total of kilometres flown by the respective party, one arrives at the total amount of emission rights to be allocated to that party.

The advantage of benchmarking is that a number of problems associated with grandfathering can be avoided or minimized. Since new entrants are allocated emission rights irrespective of the efficiency of the aircraft they operate, they have an incentive – in contrast to grandfathering – to operate efficient aircraft and to sell surplus emission rights. With grandfathering, the use of efficient aircraft would have the result that new entrants are allocated comparatively few emission rights in the following period, and will therefore be at a disadvantage compared to existing parties. With grandfathering, it would be quite plausible for new entrants to operate old, less efficient aircraft, but not in the case of benchmarking.

48 Benchmarking is therefore occasionally described as a special form of grandfathering.

49 Besides the average of a base period, benchmarks could also be average emission values or emission values according to the state of the art, best practice or best available technology (CAEP 2001).

With the choice of a late base year or period, moreover, early action is largely accounted for, because the specific emissions of companies that have carried out early reduction measures are below average. They thus receive a greater-than-average initial allocation of emission rights, and need to purchase fewer emission rights, or, in the most favourable case, can even sell emission rights. Initial allocation can therefore be based on current data, and questions concerning the reliability and availability of data from the past and the scale of early action to be considered are no longer relevant.

Benchmarking can be applied, however, neither on a cross-sector basis nor in sectors with particularly inhomogeneous products, such as the chemical industry, since in this case a common denominator cannot be found for the determination of benchmarks. If the number of products of a sector is small, the problem can be solved by identifying and differentiating subsectors with homogeneous products and calculating individual benchmarks for these subsectors.

This problem does not arise, however, in the case of international civil aviation, whose output is sufficiently homogeneous. Flight kilometres are an obvious denominator for the calculation of a benchmark, which can be used for both freight and passenger transport, thereby integrating two market segments of international civil aviation with very similar output. All in all, benchmarking is a quite interesting approach, which can also be considered for emissions trading in international civil aviation.

4.6.2.4 Hybrid procedure

Since all the allocation procedures described above have specific advantages and disadvantages, through a practical combination their advantages could perhaps be exploited and their disadvantages mitigated. Were 80% of emission rights to be allocated according to the grandfathering procedure, for instance, and 20% auctioned (IPPR 2000), the high costs of an auction – that have been rejected by the affected parties – would be substantially reduced, and a reliable early pricing signal nonetheless created. The disadvantages of grandfathering (treatment of new entrants etc.) would also be mitigated, even if not completely removed with this combination.

A combination of several procedures is also worth considering for the allocation of emissions rights within the framework of an emissions trading system for international aviation. For on the one hand, costs associated with the auctioning of emission rights would lead to considerable avoidance activity on the part of users; and on the other hand, sufficiently reliable historic data is not available for all elements of the potential basis for assessment.

If CO_2 is chosen as the sole basis for assessment (Section 4.4.2.1), then in principle all previously described allocation procedures can be used. Sufficiently reliable data is available for grandfathering or the determination of a benchmark. In this case, emission rights could also be auctioned, in part or as a whole.

Were the more comprehensive basis for assessment (Section 4.4.2.3) to be chosen, however, two procedures would be conceivable:

- Sufficient flight-specific historic data is probably available on the share of carbon dioxide, water vapour and nitrogen oxide emissions for grandfathering to be used. In the case of contrails, however, only globally aggregated estimates are available, so that grandfathering cannot be used. The share of contrails in total greenhouse gas emissions from civil aviation should therefore be auctioned. This also appears to be justified, since greenhouse gas emissions caused by contrails can be avoided through an insignificant change in flight routes with negligible additional costs. By auctioning the share of greenhouse gas emissions caused by contrails, a considerable incentive would be provided to avoid these emissions. Just for this reason, the costs of auctioning would be much less than could be expected from the share of contrail-related emissions in total greenhouse gas emissions from international aviation.
- Alternatively, initial allocation could take place according to the benchmarking procedure on the basis of an average emission index. The advantage would be that emission rights could be issued entirely free of charge, and decisions on redistribution or other application of proceeds would no longer be necessary. In addition, the benchmark could be determined on the basis of relatively recent data. It would even be possible to set up a measuring period prior to commencement of emissions trading, during which data required for determining the basis for assessment could be measured and reported on.[50] On the basis of this data, the benchmark could then be determined that is later used for the initial allocation of emission rights.

Both procedures can be employed irrespective of whether open or closed emissions trading is introduced for international civil aviation.

4.7 Monitoring

The operability of an emissions trading system is dependent on clearly structured responsibilities and a strict monitoring system. Reliable data has to be available, which allows actual emissions to be compared with permissible emissions and compliance with reduction commitments to be checked. Besides the monitoring of emissions and relevant indicators, this involves regular and complete reporting as well as the verifica-

[50] The base period for grandfathering should be before a decision is taken on the introduction of an emissions trading system; otherwise obligated parties will attempt to improve their respective starting positions through strategic behaviour (for example, through the increased operation of particularly old aircraft). With grandfathering, such strategic behaviour does not make sense, since, although it pushes up the benchmark, it does not improve the starting position of an individual company compared to that of its competitors. It would be possible, however, for all obligated parties to pursue the intention – in the sense of a cartel agreement – of consciously raising the benchmark, in order to increase the allocation of emission rights to the sector as a whole. Even when the benchmark is somewhat distorted by such strategies, it is not to be expected that the emissions trading system as a whole will be reduced to absurdity, since the use of such strategies is at the same time limited by other factors, such as competition and fuel costs.

tion of reported data. In addition, registries have to be set up for the administration of emission rights.

If an open emissions trading system is established for civil aviation, it has to be ensured that conditions for monitoring, reporting and verification are compatible with the Kyoto Protocol (Tsai et al. 2000). Reporting should also be transparent. It would be conceivable, for instance, for essential data to be put at the immediate disposal of all participants in emissions trading on the Internet. IPPR (2000) recommends the setting up of a reporting system similar to that introduced in the USA by the Environmental Protection Agency for trading in SO_2 allowances. Traders, states and UNFCCC bodies should then have access to a daily-updated Website with information on traded emission quantities and prices. As far as possible, this data should also be made available to the general public, to improve transparency and thus trust in the system.

Emission rights should be issued, traded and held in electronic form. Electronic registries have to set up for the administration of emission rights, in which individual transactions (issue, transfer, use, cancellation etc.) are recorded and the current status of an emission right can be clearly established at any time. To facilitate international trade in emission rights, and to increase transparency, emission rights data should be harmonized (internationally unique serial numbers, year of issue etc.).

With an open emissions trading system, it is important that clear interfaces are established with the emissions trading register under the Kyoto Protocol. Emission rights and their respective status could also be recorded in the same registry – or with the same registry software – in which emission rights are recorded under the Kyoto Protocol.

Where reduction and limitation targets are initially agreed upon at state level, and legal entities are then authorized by these states to participate in emissions trading, participating states have to set up national registries for legal entities parallel to registries at a state level. As envisaged in the Kyoto Protocol, several states can make joint use of a registry.

It has also to be guaranteed, by means of international guidelines, that airline companies calculate their greenhouse gas emissions on a common basis. The form of emission reporting at the airline level should be elaborated with the help of experts from the ICAO. The ICAO is already involved in the licensing of engines, and it has developed flight efficiency indices that should provide the basis for a levy with a neutral effect on revenue (Section 2.2). Against this background, it is obvious that responsibility for technical questions within the scope of implementation of an emissions trading system for international civil aviation should be entrusted to the ICAO. Among the tasks that would then devolve to the ICAO would be the determination of developments in technology and best available technology, as well as the laying down of updated emission indices and detailed procedures for calculating the basis for assessment.

Irrespective of whether an open or a closed emissions trading system is established for international civil aviation, the question arises as to which institutional structures have to be set up at a national and international level for the control of the emissions trading system. Such an institution has to ensure that actual emissions do not exceed the total of emission rights in circulation; a task that could also be entrusted, in the case of a closed emissions trading system for international civil aviation, to the institution responsible for emissions trading under the Kyoto Protocol (IPPR 2000).

The parties affected – that is states, or other parties authorized by them – must prove compliance with obligations. Independent third parties, which have first to be accredited for this purpose by the respective states, must verify reports and inventories submitted for examination of compliance. It is not the supervising bodies that have to prove non-compliance on the part of obligated parties, but rather the parties themselves that have to prove beyond doubt that they have properly fulfilled their obligations. Because parties generally have immediate access to their data, the onus of proof, structured in this way, allows the costs of control as well as the size of supervisory authorities to be kept to a comparatively low level.

4.8 Sanctions

Sanctions should guarantee that the rules of the emissions trading system as well as imposed and accepted obligations are also complied with. They should therefore be "effective, reasonable and deterrent" (COM(2001)581), and represent an incentive for parties to comply with the obligations of the system. If the sanction, for instance, corresponds to the three-fold average market price of an emission right in the given commitment period, parties will make a serious effort to preclude sanctions.

Sanctions should take effect not only in the case of non-fulfilment of reduction or limitation commitments, but also for non-fulfilment of reporting, monitoring and control obligations. Because non-fulfilment of reduction or limitation commitments is of greater importance for the functionality of the system, sanctions should in this case be more severe. The catalogue of sanctions should therefore properly reflect the significance of the offence.

In the case of an emissions trading system where states initially enter into binding commitments and legal entities only participate in international emissions trading with the authorization of the respective state, sanctions must first be laid down at the level of the participating states. Because states themselves have a considerable interest in compliance with reduction or limitation commitments on the part of authorized legal entities, the imposition of sanctions on airline companies should theoretically be left to the respective states in accordance with the principle of subsidiarity. Nevertheless, harmonized lower limits for sanctions would be useful, so that distortions to competition can be prevented and administration of the trading system simplified.

There is absolutely no need for moderate sanctioning[51] in the case of an open emissions trading system, since both participating states and legal entities are always able to acquire emission rights on a very large and liquid market to comply with their reduction targets.

In order to ensure compatibility of emissions trading in international aviation with the Kyoto Protocol, one should consider structuring sanctions similar to the rules laid down in the Marrakesh Accords, which provide for the exclusion of states from the use of flexible instruments in the case of non-fulfilment of reduction targets or reporting, monitoring and control commitments. Non-fulfilment of quantitative reduction or limitation commitments is to be penalized with a deduction (in tonnes) from assigned emissions in the following commitment period equivalent to 1.3 times the amount (in tonnes) of excess emissions.

These sanctions could also be applied to legal entities authorized to participate directly in the emissions trading system. They could be excluded from emissions trading or, more precisely, from the sale of emission rights, until such time as they can prove compliance with their reduction targets. During this period of exclusion from trading in emission rights, legal entities would not be allowed to emit more than they were entitled to under their initial allocation, with a further reduction in respect of excess emissions in the preceding year.

This obligation to subsequently purchase rights can also be combined with a financial penalty. For every emitted CO_2 equivalent, which is not covered by emission rights, a fine would be levied. The size of the fine could follow the practice laid down in the American SO_2 Allowance Trading Programme, which lays down a penalty equivalent to three times the previously forecast market price. Alternatively, the penalty can amount to three times the achieved average price for emission rights. In the case of repeated infringement, states could impose a take-off and landing ban on the party concerned.

4.9 Cap

Before introduction of an emissions trading system, the quantitative emissions target – the so-called cap – has to be laid down. The starting point for determining the cap is provided by scientific and ecological knowledge of the environment's loading capacity

[51] One talks of moderate sanctions when the penalty for non-compliance with reduction or limitation commitments is only insignificantly higher than the expected market price. Where the market price for emission rights increases above the penalty level, because the reduction target is too ambitious and cannot be complied with by participants as a whole, it is more advantageous for individual participants not to fulfil their commitments, but rather to accept the sanction. The reduction target is then not achieved. From a legal point of view, however, what is involved in this case is not a sanction, but rather a so-called buy-out option. For, whereas the sanction falls due in the case of non-intended behaviour, the use of the buy-out option is intended to help avoid excessive prices for emission rights. It is therefore more relevant to the debate on mechanisms for market flexibilization (banking, borrowing etc.) than to that on sanctions.

in respect of certain emissions. This applies so long as the emissions trading system covers all polluters. Where the trading system covers only a subgroup of polluters, however, the share of emissions, for which this subgroup of polluters is responsible, must also be determined. In addition, the technical and organizational avoidance options have to be considered that are at the disposal of individual groups of polluters, and also whether subgroups of polluters can be equally obliged to avoid emissions, or whether reduction or limitation commitments, analogous to avoidance options, have to be variedly distributed. Apart from ecological criteria, technical, economic and political considerations also play a role in determining a cap. Ultimately, the determination of a quantitative reduction target is also a normative question, which cannot be exclusively decided on the basis of strict scientific criteria, but has also to take account of political realizability and acceptance.

Different caps can therefore be considered for emissions trading in international civil aviation. It would be possible, for instance, to apply those caps to international aviation that have been originally agreed in the Kyoto Protocol. Emissions would then have to be reduced by 5.2% in the period 2008 to 2012, compared to emissions in 1990.[52] Because international aviation is growing very strongly and its greenhouse gas avoidance costs are also comparatively high, this target can only be imposed with open emissions trading, by means of which the aviation sector purchases emission rights from other sectors. With a closed emissions trading system, emission reductions would have to be wholly achieved in the aviation sector, which would inevitably lead to a drastic restriction of international air transport.

Stabilization of emissions at the levels of 1990 would correspond to the current status of Kyoto commitments, which, as a result of the withdrawal of the USA from the Kyoto Protocol, will in fact hardly lead to emission reductions in absolute terms in Annex I states. But stabilization of emissions at 1990 levels would also represent a noticeable restriction of international aviation, which has grown substantially since 1990. This target would therefore presumably only be achievable with an open emissions trading system.

Stabilization at the current level of emissions, or at the level of the year 2000, could also be considered. But also in this case, in view of the enormous growth forecast for international aviation, with a closed system the result would be considerable restriction of growth, so that this cap could only be seriously considered with an open emissions trading system.

It was proposed within the framework of ICAO/CAEP considerations on the design of an emissions trading system for international aviation (ICAO/CAEP 2000), that growth

[52] Should emissions trading not be introduced in international aviation in the first, but only in the second commitment period of the Kyoto Protocol, the target agreed for the second period would have to be applied to international aviation.

in emissions be halved,[53] or reduced by 5% compared to the trend. These quantitative targets are considerably lower than those previously discussed, since they permit, in each case, further growth in aviation emissions. With a closed emissions trading system for international civil aviation, this “reduction commitment”[54] would be realized partly through increases in efficiency and partly through air traffic avoidance. These weaker targets could be agreed on for both a closed and an open emissions trading system. Table 13 provides an overall view of the caps described above.

Table 13: Possible caps for emissions trading in international civil aviation

Cap	Trading regime
-5,2 % compared with 1990	open
0 % compared to 1990	open
0 % compared to 2000	open
Halving of growth compared with trend	closed/open
-5% compared with trend	closed/open

Source: ICAO/CAEP 2000 (related to CO_2), Öko-Institut proposals

With the targets shown in Table 13, emission reductions decrease in absolute terms from top to bottom. The caps are also much more severe at the top than at the bottom. None of the caps can be classified a priori as better, or more suitable for emissions trading in international aviation. For such an assessment, further aspects of systems design have to be considered, as well as rough estimates of the economic effects of the different caps on international aviation. But even taking account of these aspects, the determination of an emissions target is in the end always a normative question that requires a political answer.

4.10 Overview

Different design options could theoretically be combined in a variety of ways. In practice, however, the decision for one of the options precludes the choice of others, because the options are partly dependent on each other. The different design options are therefore brought together in Table 14 in consistent approaches for an emissions trading system for international aviation that are currently regarded as most likely. This survey is, however, by no means conclusive. Besides the variations shown, further consistent variations could be developed.

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[53] The halving of growth compared to the trend is roughly equivalent to an annual increase of around 1.5% between 1990 and 2010. This growth corresponds to a cap of about 135% compared to the level of emission in 1990 (ICAO/CAEP 2000).

[54] There is no reduction in this case in absolute terms, but merely a limitation of emission growth.

With an open emissions trading system (options 1 & 2), the comprehensive basis for assessment should definitely be chosen, for there is otherwise the risk that greenhouse gas emissions from civil aviation will be underestimated. Depending on the basis for assessment, it then appears obvious to select airline companies as obligated parties and to assign emissions to the place of flight departure or destination. Design flexibility in this case is to be found above all with regard to the initial allocation procedure (benchmarking or a combined procedure) and to the cap.

Options 3 & 4 are based on the assumption of closed emissions trading in international aviation. Because there is no exchange with the Kyoto Protocol in this case, there is a greater freedom of choice regarding not only the basis for assessment, but also the participating states. With options 3 & 4, the basis for assessment is restricted to CO_2. Design flexibility arises with regard to the obligated player.

Table 14: Survey of design options

Potential options	1	2	3	4
Trading regime				
• open	x	x		
• closed			x	x
• half-open				
Basis for assessment				
• CO_2			x	x
• CO_2, H_2O				
• CO_2, H_2O, NO_x, contrails	x	x		
• CO_2, H_2O, NO_x, contrails, particulates				
Obligated parties				
• fuel producers and importers			x	
• engine and aircraft manufacturers				
• airline companies	x	x		x
• airports				
Assignment of emissions				
• according to the place of departure or destination of passengers or freight; alternatively, division between places of departure and				
• according to place of aircraft departure or destination; alternatively, division of emissions between places of departure and destination	x	x		
• according to the nationality or domicile of the airline company				
• according to countries selling bunker fuels			x	x
Obligated parties				
• Annex I countries	x	x		
• Others			x	x
Initial allocation				
• Auctioning			x	
• Grandfathering based on past emissions		x		x
• Grandfathering/benchmarking				
• Combination grandfathering/benchmarking und auctioning	x			
Cap				
• -5,2 % compared with 1990				
• 0 % compared to 1990				
• 0 % compared to 2000				
• Halving of growth compared with trend				
• -5% compared with trend				

Source: Öko-Institut

Where fuel importers are obliged to hold emission rights, these should be auctioned (Section 4.5.3.1). If, on the other hand, airline companies are to be subject to the emission allowances obligation, initial allocation could be based on grandfathering.

5. Aviation perspectives

Of decisive importance for the acceptance and realization of emissions trading in aviation are issues concerning the economic effects brought about by the system and the relation of these economic effects to the extent of emissions reduction. A rough estimate of the economic and ecological effects of an emissions trading system can be made with the aid of model calculations based on scenarios.

On the basis of selected parameters, scenarios describe conditions in the future and are therefore hypothetical. As a rule, scenarios vary widely, depending on the assumptions made, and ought therefore to indicate the range of possible developments. In order to quantify the effects of an emissions trading system for aviation, a so-called reference or base scenario must first be produced, which describes developments without implementation of an emissions trading system. This scenario is generally compared with several scenarios based on policies and measures, in which different design options for emissions trading are described. The respective variable parameters should be selected in such a way as to enable the effects of an emissions trading system on individual businesses and the overall economy, on the one hand, and ecological benefits on the other hand, to be described and compared.

Figure 11: Main variables of the AERO Model

Macroeconomic and demographic development

- Macroeconomic growth
- Autonomous aviation demand growth
- Population development

Technological growth

- Development of aircraft technology (fuel, emissions)
- Average age of aircraft fleet / age of aircraft when scrapped
- Aircraft maintenance requirements
- Availability of new large aircraft
- Emission factors of land transport

Market development

- Operating costs
- Availability of high-speed trains
- Performance-related costs
- Fleet growth

Source: MTPWW 2002

In the past, different forecasts and scenarios have been developed regarding the greenhouse impact of aviation, with very different time horizons. Differentiated estimates and model calculations of the economic and ecological effects of an emissions trading system for aviation are available to only a very limited extent at both a national and international level. The AERO modelling System (AERO-MS) is one of the first extensive models able to provide a quantitative estimate, covering, inter alia, the effects of an open emissions trading system according to individual design options.

The informative value of scenarios depends, on the one hand, on the quality of the database, and on the other hand, on the assumptions upon which they are based. The specification of assumptions involves a number of uncertainties. To enable assessment of the scenario analysis presented below, the main factors influencing aviation emissions are therefore first explained:

- *Development in demand* is influenced to a great degree by macroeconomic and demographic factors. Although aviation has grown in the past at a considerably greater rate than the world economy, economic theories and empirical research point to the close correlation of both growth rates (IPCC 1999). As a result, most forecasts of aviation demand are based on the assumption that demand is influenced above all by economic developments. Econometric analyses show that around two-thirds of the increase in demand is attributable to growth in GNP (IPCC 1999). Growth in aviation beyond that is attributed by Vedantham/Oppenheimer (1998) to population growth and a change in the distribution of incomes. Meskill (2002) and Nielsen (2001) regard the increase in trade and globalization as well as the change in the pattern of travel and the availability of time and money as further factors affecting demand.
- *Technological development* – in particular with regard to fuel efficiency and emission reduction – is influenced above all by developments in the cost-effectiveness of innovations. Fuel efficiency has increased continually in the past. Since the introduction of the first jets, fuel consumption has decreased by 70%, 40% from the improvement in engines and 30% due to improved aircraft design (IPCC 1999). Engine improvement has to do, above all, with the development and application of modern high-bypass engine technology, as well as to combustion at high pressure and high temperatures to improve efficiency. This development has lead to a drastic reduction in CO_2 emissions and emissions of unburned hydrocarbons, whereas, in past decades, NO_x emissions tended to increase.
- *General conditions on the aviation market* have a decisive influence on developments in the scenarios. These include assumptions regarding the provision of necessary infrastructure and the shortage of capacity (airports, air traffic control etc.), assumptions concerning fuel supply as well as assumptions regarding the type of market and competition (liberalization of the aviation market etc.) These factors are strongly influenced by political decisions and can therefore be forecast only with great difficulty. For this reason, these assumptions vary in different scenario, through which the effects on development as a whole can be described.

In Figure 11 (page 97), some of the main variables are presented, which have been considered within the scope of AERO modelling.

In the following sections, different scenario analyses are first described and then compared. Following that, extensive and relatively recent simulation calculations of the AERO model are described in greater detail, on the basis of which, among other things, the introduction of an emissions trading system for aviation is considered.

5.1 NASA, ANCAT and DLR

In the IPCC report entitled “Aviation and the Global Atmophere” (IPCC (1999), emission scenarios from NASA, ANCAT (ECAC Working Group on Abatement of Nuisances Caused by Air Transport) and DLR (German Aerospace Center) are presented. The data of these scenarios comes from three-dimensional climate models (latitude, longitude, altitude) and is based, in addition, on assumptions concerning the development of international aviation, such as fleet structure, airports for takeoff and landing, flight frequencies and profiles (IPCC 1999).

NASA, ANCAT and DLR models are basically similar, but they vary with regard to simulation method. Furthermore, they make use of databases of varying detail. Databases differ greatly, in particular with regard to statistics on military flights. With all methods, all flights were simulated at a typical altitude and along the usual flight corridors for the estimation of fuel consumption. Combinations of different engines and aircraft were also considered, as well as emission factors varying according to flight altitude. As Table 15 shows, in the scenarios examined, fuel consumption and CO_2 emissions of civil aviation in the base year of 1992 were very close. NO_X emissions, however, were at least 10% higher with ANCAT and DLR than with NASA.

Table 15: Simulation results from NASA, ANCAT and DLR

		1992			2015		
		NASA	ANCAT	DLR	NASA	ANCAT	DLR
Fuel consumption							
Civil aviation	million t	114	114	112	288	272	271
Total global aviation	million t	139	131	129	309	288	285
CO_2 emissions							
Civil aviation	million t	359	360	354	908	859	853
Total global aviation	million t	440	414	408	973	905	899
NO_x emissions							
Civil aviation	million t	1.4	1.6	1.6	4.0	3.4	3.4
Total global aviation	million t	1.7	1.8	1.8	4.1	3.5	3.6
NO_x emission index							
Civil aviation	g/kg fuel	12.6	14.0	14.2	13.7	12.4	12.6
Total global aviation	g/kg fuel	12.0	13.8	13.9	13.4	12.3	12.5

Source: IPCC 1999

On account of different assumptions regarding the development of demand and technology, considerable differences arise for the year 2015 between NASA, on the one hand, and ANCAT and DLR on the other hand. ANCAT and DLR forecast an increase of approximately 140% in fuel consumption and CO_2 emissions between 1992 and 2015. In the NASA scenario, the values increase by 150%. In the case of NO_X emissions the difference is even more pronounced. Whereas ANCAT and DLR forecast growth of 110%, NASA expects growth of 170%. According to projections made by ANCAT and DLR, fuel consumption and CO_2 emissions of civil aviation increase by an average of 3.9% per year. NASA expects an annual increase of 4.1%. In the case of NO_X emissions, differences in growth rates are even greater. ANCAT and DLR ascertain an average annual increase of 3.3%, whereas NASA assumes an annual growth rate of 4.5%. With all scenarios, irrespective of differences in detail, annual growth is clearly above 3%, so that aviation and aviation emissions grow much more strongly than average global economic growth.

5.2 ICAO

The Forecasting and Economic Support Group (FESG) of the CAEP has developed long-tern emission scenarios for aviation. Assumptions of economic development are based on IPCC's so-called IS92 scenarios (IS92a – base, IS92c – low, IS92e – high). The scenarios are also based on the following assumptions:

- The global aviation market is the sum of regional sub-markets at different stages of development.
- Private and business trips can be combined in one model.
- Growth in the aviation sector is primarily driven by global economic growth. With increasing market development, growth in aviation gradually matches the development in GDP.
- Fuel is available at all times, while fuel prices do not grow disproportionate to other costs.
- Technical and regulatory changes have no significant effect on flight prices and service.
- Infrastructure is available in line with demand.
- Developments in other sectors (high-speed trains, telecommunications etc.) have no significant effect on aviation demand.

With regard to technological progress, two alternative development options are outlined:

- Technology-Option 1: As in the past, in the development of new aircraft, fuel efficiency and NO_x reduction are further developed. The average fuel efficiency of new aircraft will be improved in the period to 2050 by approximately 40 - 50% compared to 1997. At the same time, however, the average NO_X emission index increases to 15.3 - 15.5 g/kg fuel.

- Technology-Option 2: The reduction of NO_x emissions is more vigorously pursued, with the effect that a minor improvement in fuel efficiency is achieved. The average fuel efficiency of new aircraft will therefore be increased in the period to 2050 by approximately 30 - 40% compared to 1997. The average NO_X emissions index for the aircraft fleet could still be reduced by about 11.5 g/kg fuel.

Out of three different scenarios for aviation demand and two technological options a total of six FESG scenarios emerge (Table 16): Fa1 and Fa2 for the so-called base case, Fc1 and Fc2 in the case of relatively low growth in global GDP and Fe1 and Fe2 in the case of relatively strong growth in GDP.

Table 16: Results of FESG scenarios for 2050

		NASA 1992	NASA 2015	Fa1 2050	Fa2 2050	Fc1 2050	Fc2 2050	Fe1 2050	Fe2 2050
Fuel consumption									
Civil aviation	million t	114	288	457	473	254	263	730	758
Total global aviation	million t	139	309	471	488	268	277	744	772
CO_2 emissions									
Civil aviation	million t	359	908	1,440	1,492	800	829	2,302	2,389
Total global aviation	million t	440	973	1,485	1,538	846	874	2,347	2,435
NO_x emissions									
Civil aviation	million t	1.4	4.0	7.0	5.4	3.9	3.0	11.3	8.7
Total global aviation	million t	1.7	4.1	7.2	5.5	4.0	3.1	11.4	8.8
NO_x emission index									
Civil aviation	g/kg fuel	12.6	13.7	15.3	11.4	15.4	11.4	15.5	11.5
Total global aviation	g/kg fuel	12.0	13.3	15.3	11.3	14.9	11.2	15.3	11.4

Source: IPCC 1999

In the base case, fuel consumption and CO_2 emissions of civil aviation increase by at least 300% by the year 2050. This is equivalent to average growth of 2.4 - 2.5% per year. In the case of lower global economic growth, fuel consumption and CO_2 emissions would merely double (1.4 - 1.5% per year), while, in the case of a more dynamic development of the global economy, growth of around 650% could be expected (3.3% per year).

Since the reduction in the NO_X emission index in scenarios of the second technology option is lower than growth in demand, NO_X emissions increase in absolute terms in all scenarios. However, NO_X emissions in scenarios of the second technology option are about 23% lower than in scenarios of the first technology option. In return, CO_2 emissions some 3% higher have to be reckoned with in these scenarios.

5.3 EDF

Whereas in previously presented scenarios, a maximum time horizon up to 2050 has been considered, the Environmental Defence Fund (EDF) has developed a long-term scenario up to the year 2100 (Vedantham/Oppenheimer 1998). The estimation of the long-term development of aviation emissions involves considerable uncertainties, since the probability of unforeseen changes in key influencing factors clearly grows with the increasing time horizon. Nevertheless, there are various arguments in favour of long-term views. For, on the one hand, the introduction of an emissions trading system is to be expected in the medium to long term. On the other hand, the development of a new aircraft itself takes about a decade. With an average service life of 25 to 30 years (Anker 2000), present-day technological decisions on engine and aircraft design determine the greenhouse impact of aviation emissions up to the year 2040. Long-term scenarios are therefore an essential basis for technical, economic and political discussions on the future development of aviation.

The basis of EDF aviation scenarios is, on the other hand, the IS92 scenarios of the IPCC, whose assumptions on population development and growth in GDP are particularly considered (Table 17).

Table 17: Population and economic development in the IS92 scenarios of the IPCC

	World population (billions)		Growth rate of GNP (%/a)	
	2025	2100	1990 - 2025	1990 - 2100
IS92a, IS92b	8.4	11.3	2.9	2.3
IS92c	7.6	6.4	2.0	1.2
IS92d	7.6	6.4	2.7	2.0
IS92e	8.4	11.3	2.5	3.0
IS92f	9.4	17.6	2.9	2.3

Source: Leggett et al. 1992*, p.78*

In the model on which scenario analyses are based, business and private travel are differentiated, but also five different regions of the world. Furthermore, two different variants for the development in aviation demand are defined for individual regions. The variants differ with respect to assumptions concerning social factors, travel trends, penetration rates of modern communications technology and the development of competitive transport systems for different regions of the world. On the basis of these assumptions, development of demand on the aviation market can be deduced, which can be marked by the commencement of the market expansion phase and the commencement of the saturation phase (Table 18, page 103).

The main results of these scenarios are presented in Table 19 (page 103). Because, with the great variety of scenarios, track can easily be lost of the overall view, from the total of 10 scenarios (5 different IS92 and 2 demand variants) only the base case (IS92) in both demand variants as well as the scenario with the lowest growth in demand (IS92c, base damand) and the scenario with the greatest growth in demand (IS92e, high demand) are documented.

Table 18: Assumptions on the development of demand

	Demand - pkm/capita -	Commencement of expansion	Saturation	
			Base-demand	High-demand
Industrial economies	178	commenced	2010	2010
Newly-industrialized economies	52	commenced	2050	2030
Rapidly-developing economies	4	2000	2070	2050
Slowly-developing economies	20	2010	2080	2060
Post-communist economies	66	2010	2060	2040

Source: Vedantham/Oppenheimer 1998

Table 19: Main results of EDF scenarios

		1990	2000	2015	2025	2050	2100
Demand							
Base-demand level							
IS92a	billion tkm	332	555	935	1,428	3,556	7,336
IS92c	billion tkm	332	527	816	1,193	2,563	3,169
High-demand level							
IS92a	billion tkm	332	887	1,522	2,803	6,329	11,568
IS92e	billion tkm	332	912	1,659	3,089	7,089	17,389
CO_2							
Base-demand level							
IS92a	million t	550	807	1,210	1,723	3,630	4,693
IS92c	million t	550	770	1,027	1,430	2,640	2,090
High-demand level							
IS92a	million t	550	1,247	1,943	3,557	6,600	7,517
IS92e	million t	550	1,283	2,127	3,960	7,260	10,963
Percent of Global CO_2							
Base-demand level							
IS92a	%	2.1%	2.6%		3.8%	6.8%	6.3%
IS92e	%	2.1%	2.5%		3.5%	5.6%	5.4%
High-demand level							
IS92a	%	2.1%	4.1%		7.9%	12.4%	10.1%
IS92c	%	2.1%	4.3%		9.4%	17.6%	20.2%
NO_x above 9 km							
Base-demand level							
IS92a	million t	1.15	1.51	2.03	2.73	4.87	4.90
IS92c	million t	1.15	1.42	1.50	2.29	7.56	2.18
High-demand level							
IS92a	million t	1.15	2.30	3.30	5.63	8.89	7.86
IS92e	million t	1.15	2.38	3.61	6.19	9.78	11.48

Source: Vedantham/Oppenheimer 1998

Demand grows in the base scenarios, according to demand variant, between 1990 and 2015 by 180 to 360%. This is equivalent to demand growth of 4.3 and 6.2% per year, respectively. Annual demand growth ranges from 3.7% (IS92b, base demand) to 6.6% (IS92e, high demand). Growth in CO_2 emissions is somewhat lower (2.6% to 5.6%), due to technical and operative improvements. In the case of NO_X emissions this trend is even stronger, growth rates varying, according to scenario, between 1.1and 4.7%.

In the long term – that is, up to the year 2100 – aviation demand increases in the base case (IS92), depending on the demand variant, by a factor of 22 and 35, respectively. Even in the scenario with the lowest growth expectancy (IS92b, base demand) demand grows by 3.4% per year and increases almost ten-fold. In the most dynamic scenario (IS92e, high demand), aviation demand increases annually by 5.3%, leading to an increase in aviation demand by a factor of 52.

As a result of improvement in operations and technology, emissions do not grow as strongly as demand. In the end, however, long-term achievable improvements are insufficient even to stabilize aviation emissions in absolute terms. In the long term, therefore, the share of aviation in global CO_2 emissions could increase from the present level of 4% in the base case to 6 or 10%. Only in the case of very slow growth in GDP and in the demand for aviation services, could the share of aviation in global CO_2 emissions remain at around the present level. In the case of very dynamic growth (IS92e, high demand), however, the share of aviation could increase to more than 20%.

In view of the prospects, Vedantham/Oppenheimer (1998*, p. 693f*) recommend the reduction of risks for the global environment through early limitation of aviation emissions. In addition, these risks could also be decreased through the development of “green aircraft” in combination with increased technology transfer to regions of the world with particularly strong growth in aviation.

5.4 AERO Modelling System

The AREO Modelling System (AERO-MS) (MTPWW 2002) was developed on behalf of the FESG. It is one of the first extensive model with which the ecological and economic effects of political measures affecting international aviation can be described. Besides regulatory measures, such as traffic restrictions for older aircraft and aircraft with older technology, and operative measures, such as the limitation of flight altitude or speed, economic measures and a combination of different measures were also analysed. So far as concerns economic measures, apart from the impact of different types of taxes and levies, the effects of global emissions trading with different design options was also investigated.

The AERO-MS base year is 1992, being the most recent year for which a complete data set exists. Comparison with the base data of NASA, ANCAT and DLR scenarios (Section 1.1) shows that fuel consumption and CO_2 emissions in the AREO Model are about 17 to 20% higher in the base year, due to a more extensive database (Table 20, page 105).[55] Because 1997 is the latest year for which a full set of empirical data is available for the development of the model, calibration of computational results was carried out on the basis of data for the year 1997.

[55] Other databases show similarly high values (US DOE 1999, Balashov/Smith 1992, Shell 1993).

Table 20: Fuel consumption and emissions in civil aviation, 1992

		NASA	ANCAT	DLR	AERO-MS
Fuel consumption	million t	114	114	112	134
CO_2 emissions	million t	359	360	354	423
NO_x emissions	million t	1.4	1.6	1.6	1.7
NO_x emission index	g/kg fuel	12.6	14.0	14.2	12.6

Source: MTPWW 2002*, S. 168 table 13.5*

On the basis of this data, and taking into account ICAO forecasts on the development of demand in passenger traffic as well as Boeing forecasts on the development of demand in freight traffic, the AERO-M scenario was defined for development up to 2010 and 2020, which serves as reference for the assessment of different policy measures.[56] Besides assumptions on the development of demand, the reference scenario is based on the following premises:

- The NO_X emission index will not significantly improve up to 2010. Since, in the past, an improvement in fuel efficiency has generally resulted in deterioration in NO_X emission values, concurrent improvement in fuel efficiency and NO_X emission index is likely to be too optimistic.
- The average scrap-age of aircraft is assumed to increase over time. For the year 2010 a scrap-age of 28 years is assumed for aircraft with less than 180 seats and of 31 years in the case of aircraft with more than 180 seats.
- Time expended on repair and maintenance is proportionate to flight hours and does not change over the period of investigation.
- The price of fuel, in real terms, remains constant at the level of 1992.
- Landing and en-route charges increase by 2% per year in real terms.
- Capital costs for new aircraft as well as costs of flight personnel increase by 1% per year in real terms.
- Fleet growth is consistent with growth in the volume of traffic. .
- Additional restrictions due to weather or air traffic control are not expected. Possible restrictions on account of growing traffic volume can be compensated by improvements in air traffic management.
- In future, more high-speed trains will be operated in Europe.

[56] For the conduct of sensitivity analyses, which are not further considered at this point, four further scenarios were defined. Whereas in AERO-M, average demand growth of 5.5% per year is assumed, in AERO-LD (low demand) the value is 3.4% and in AERO-HD (high demand) it is 7.5% per year. In addition, two further scenarios (AERO-L, AERO-H) were defined with minimum and maximum growth in emissions, respectively. In these two scenarios, the assumptions on the development of fuel efficiency and demand differ from the assumptions made in the AERO-M scenario.

- Depending on price elasticity, airline companies will pass on the costs of political reduction measures to passengers, in order to achieve the same level of profit per unit of capacity.

On the basis of these assumptions, the AERO-M scenario is first developed, which serves as reference for the assessment of different policy measures. Of the different scenarios in which the effect of these policy measures is analysed, the scenario in which an open emissions trading system for aviation is modelled is of particular interest.

As we also recommend, a downstream system is examined within the scope of analyses with the AERO Model, in which airline companies are the obligated parties. In contrast to our recommendation, however, the model encompasses only CO_2 emissions, therefore encompassing only part of the total greenhouse effect of aviation. Apart from these assumptions, modelling of emissions trading was also based on the following considerations:

- Because aviation is responsible for only a small share of global CO_2 emissions, the industry is a so-called price-taker. The price emission allowances is therefore determined solely by the supply of and demand for emission rights on the global market, and not – or hardly – influenced by the design of the emissions trading system for aviation. In the modelling of emissions trading in aviation, different price levels for emission (16, 32 and 63 US$/t CO_2)[57] are specified extraneously, in order to analyse the effects of aviation.
- A reduction in CO_2 emissions of 5% compared with the level of 1990 – as in the Kyoto Protocol – is assumed as the reduction target.[58]
- Where emission rights are issued free of charge, their allocation takes account of the reduction target corresponding to CO_2 emissions in the year 1990 (grandfathering).
- Where emission rights are auctioned, airline companies can acquire emission rights from a global trading authority within the limits of the reduction target. Additionally required allowances have to be purchased from other sectors. On the assumption of an unregulated market, the price at auctioning and the price on the global market for emission allowances are identical.

In different model runs, not only were the effects of auctioning emission rights at different price levels investigated, but also the effects of different behaviour on the part of airline companies in the case of the free issue of emission rights (grandfathering). In addition, the combination of the free issue of emission rights with a voluntary commitment for the early retirement of old aircraft was considered.

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57 This is equivalent to a tax of 0.05, 0.10 and 020 US$/kg fuel, respectively.

58 In addition, however, sensitivity analyses are carried out with less ambitious targets, with which a reduction in the growth of emissions between 1992 and 2010 of 50 and 25%, respectively, is assumed. These variants are not considered further at this point.

With the free issue of emission rights, airline companies receive windfall profits to the extent of the value of these emission rights, deduced from the volume of allocated emission rights multiplied by the price of allowances (32 US$/t CO_2). There are three options open to airline companies concerning the treatment of these windfall profits:

- Option A: They can retain windfalls in full, thus increasing their profit. This would lead, however, to an increase in the price of flight tickets to the same extent as if emission rights had been auctioned.
- Option B: They can pass on their windfalls in full to their customers and thereby ensure that ticket prices increase, on average, only to the extent that costs arise for emission rights that have to be additionally acquired.
- Option C: They can retain windfalls in part and pass on the rest to their customers.

Option A is largely identical with the auctioning of emission rights, but with the difference that the proceeds of auctioning accrue not to individual states but rather to the companies. In theory, it can hardly be determined, which of these three options will become reality, since they are influenced by different factors. For instance, the possibility of airline companies increasing prices depends on how their competitive position changes with regard to alternative means of transport, such as high-speed trains (substitution elasticity), and how the demand for flights reacts to price changes (demand elasticity). For this reason, the potential effects of all three options were considered within the scope of investigations with AERO-MS.

Beyond that, a further Option D was considered, with which a grandfathering option (Option C) is combined with a voluntary commitment on the part of airline companies for the early retirement of aircraft that have been in operation for longer than 25 years.

Simulation results of the auctioning of emission rights at different price levels for allowance are presented in Table 21.

Table 21: Effects of different allowance prices with the auctioning of emission rights

		1992	1997	2010			
				AERO-M	16 US$	32 US$	63 US$
Aircraft operation	billion RTK		415	828	813	799	774
Change in aircarft operation	%				-1.8%	-3.5%	-6.6%
Aircraft older than 12 year	Units		9,206	17,657	17,021	16,509	15,468
Aircraft younger than 12 years	Units		10,947	15,350	15,258	15,504	15,058
Fuel consumption	million t	134	155	242	236	231	221
Specific fuel consumption	kg/km		5.16	4.60	4.58	4.54	4.49
CO_2 emissions	million t	423	489	763	746	729	698
CO_2 emissions	1992 = 100	100	115	180	176	172	165
Share of the reduction in aviation	%				5%	10%	18%

Source: MTPWW 2002

With the auctioning of emission rights, the demand for air transport services, compared with the reference development (AERO-M) and depending on the price of allowances, decreases by 2010 by about 1.8 to 6.6%. Fuel consumption decreases by 2.3 to 8.5%, attributable to technical improvements in aircraft, but above all to structural changes in aircraft fleets. For whereas, in the reference case, only 46.5% of aircraft are less than 12 years old, this share increases in the scenarios to values of 47.3 and 49.3%. Even with very high emission allowance prices, CO_2 emissions from aviation increase further, lying in the measure scenarios between 4 and 15 percentage points lower than in the reference development. On account of high reduction costs for CO_2 in aviation, only a small proportion of emission reductions will be achieved through measures in aviation itself (5 to 18%). Remaining reduction commitments will be fulfilled through the purchase of allowances from other sectors.

Table 22 displays the effects of different patterns of behaviour with the free issue of emission rights on the basis of the level of emission in the year 1990 (grandfathering), assuming an allowance price 32 US$/t CO_2.

Table 22: Effects of different allocation options, 2010

			Grandfathering			
		AERO-M	A	B	C	D
Aircraft operation	billion RTK	828	799	814	812	808
Change in aircarft operation	%		-3.5%	-1.8%	-2.0%	-2.4%
Aircraft older than 12 year	Units	17,657	16,509	17,110	15,891	15,150
Aircraft younger than 12 years	Units	15,350	15,504	15,289	16,363	16,685
Fuel consumption	million t	242	231	236	233	226
Specific fuel consumption	kg/km	4.60	4.54	4.57	4.50	4.41
CO_2 emissions	million t	763	729	746	734	714
CO_2 emissions	1992 = 100	180	172	176	173	169
Share of the reduction in aviation	%		10%	5%	8%	14%

Source: MTPWW 2002

When airline companies fully retain windfall profits from the free issue of emission rights (Option A), the result, as expected, is the strongest decline in demand (-3.5% compared to the reference development). The decline in demand is at its lowest when windfall profits are passed on in full to customers (Option b). Although the reduction in demand in Option D is comparatively low, fuel consumption and CO_2 emissions here show the greatest decline (-6.4%), while, in this case, structural change in the aircraft fleet is greatest. Whereas in other options, the share of new aircraft increases from 46.5% to between 47.2 and 50.7%, it increases in Option D, due to the voluntary commitment to scrap older aircraft early, to 52.4%. By means of this combined measure, CO_2 emissions could be reduced by 4 percentage points more than with a strategy (Option C) based exclusively on emissions trading. The lion's share of the reduction commitment (86%) will nevertheless be fulfilled, also in this variant, through the purchase of emission rights from other sectors.

All in all, the simulations show that the demand for air transport services declines all the more the higher the price of emission allowances. With the free issue of emission rights on the basis of the level of emissions in the year 1990, however, the decline in demand could be smaller, according to the assumption that is made on the passing on of windfall profits to customers. Irrespective of these assumptions, however, only a small share of emission reductions will be realized in the aviation sector itself. This has to do with the fact that, in this case, CO_2 has been chosen as the sole basis for assessment, and that avoidance costs for aviation-related CO_2 are relatively high. Other measures for the reduction of the greenhouse impact of aviation are not addressed by such an emissions trading system. This can ultimately lead to the situation that the greenhouse impact of aviation actually turns out to be lower than assumed, or even increases, since the greenhouse impact of other substances that affect the climate, such as NO_X, contrails and cirrus clouds, increase many times with optimization directed exclusively at CO_2. Such trade-offs are not covered by the emissions trading system under consideration. In the emissions trading system we recommend, with a basis for assessment that encompasses the overall greenhouse impact of aviation, the results of these simulations can therefore be applied, at best, only to a limited extent.

6. Options for reducing the climatic impact of aviation

In an emissions trading system, each participating party is faced with the decision to avoid emissions itself at a reasonable price, or, if it is more efficient, to acquire emission rights from other parties. The question then arises as to the options available for reducing the climatic impact of aviation; and here, technical measures affecting aircraft and avoidance options in the operation of aircraft can be differentiated.

Technical options include the climatic optimization of jet engines and improvement in the aerodynamic efficiency of aircraft. Avoidance options in the operation of aircraft include improved maintenance, optimization of air traffic management (ATM) and the optimization of air routes from the climate point of view.

In order to be able to assess the effects of an emissions trading system, an analysis of specific avoidance costs appears to be essential, on which a number of design issues depend including the laying down of reduction targets for aviation and the decision on the choice of an open or closed trading system.

6.1 Flight route optimization from the climate point of view

The formation of contrails and cirrus clouds can generally be avoided by not flying through ice-saturated and humid air masses.[59] Flight route optimization from the climate point of view is a matter of avoiding such air layers by changing flight altitude or route, or by adapting flight operation to climatic circumstances.[60] Up to now, flight routes have been optimized on the basis of weather conditions and safety factors, but above all, from an economic point of view, in terms of flight duration and fuel consumption.[61]

At low altitudes, the aerodynamics of aircraft deteriorate due to denser air masses, which can result in increased fuel consumption and longer flight duration. For on the one hand, at lower altitude, time and thus also fuel consumption during the climb and descent phases are reduced. On the other hand, fuel consumption increases during cruising, not only through a longer cruise phase but also through the loss in aerody-

59 The contribution of cirrus clouds to the climatic impact of aviation has not yet been conclusively resolved scientifically. There are clear indications, however, that cirrus clouds develop partly through the ageing of persistent contrails. Through flight route optimization, through which the development of contrails is avoided, the formation of cirrus clouds could also be avoided. Lee (2003) estimates that this way up to 44.5% of contrails could be avoided. In estimating the specific avoidance costs of flight route optimization, the possible contribution of cirrus clouds is therefore considered within the scope of sensitivity calculations.

60 Daytime flights instead of night flights could be beneficial from a climate point of view, since the climatic impact of persistent contrails following aviation emissions is greater at night than during the day. (Mannstein 2003).

61 Such flight route optimization is itself not new, having been practised with military flights for a long time. For safety reasons, altitudes with a high probability of contrail formation are determined in advance and avoided during flights (Sausen 2002).

namic efficiency of the aircraft. The net effect depends on the magnitude of both effects (Williams et al. 2002b), and it can vary considerably for short- and long-haul flights.[62]

With a reduction in flight altitude, CO_2, H_2O and NO_x emissions initially increase as a result of deterioration in aerodynamic efficiency. While the climatic impact increases through the greater emission of CO_2 and H_2O, NO_X emissions result in less significant formation of ozone, despite increased emission quantities, since they are emitted at lower altitude. As a result, their climatic impact is less. Furthermore, through a reduction in flight altitude the formation of contrails and, under particular circumstances, cirrus clouds can be avoided, so that the net effect with regard to climatic impact is clearly positive.

Besides the loss in aerodynamic efficiency, the assessment of flight route optimization must also take particular account of the restriction of airspace. For in European airspace, in particular, capacity on certain routes is greatly overburdened. Heavy congestion could result from a restriction of airspace. From the climate point of view, the systematic realization of flight-route optimization is thus linked to realization of the so-called “free flight concept”,[63] by means of which airspace capacities could once more be considerably expanded.

Different research projects, in which the potentials of flight route optimization for the avoidance of contrails have been analysed, are described below.

6.1.1 Results of current research

The evaluation of existing literature and research provides different estimates and results regarding the potential of contrail avoidance through flight route optimization. This has to do, above all, with basically different investigative approaches.

Williams et al. (2002a and 2002b) and AvioPlan (1999) investigated, for instance, the *complete* avoidance of contrails on one and two flight routes, respectively, within a given base year. In the TRADEOFF Project (Fichter 2003), on the other hand, the total greenhouse gas reduction potential from the avoidance of contrails has been estimated, in the course of which only those potentials were considered where the distance remains unchanged, so that potentials can be realized at *comparatively low* cost.

[62] In comparison to a fuel-optimized flight, the net effect is always negative. With long-haul flights the net effect tends to be greater than with short-haul flights, because the relation between avoided fuel consumption in the climb phase and additional fuel consumption in the cruising phase is lower in the case of long-haul flights.

[63] With the free flight concept, pilots are able to select flight route, altitude and speed in real time. Whereas pilots at present exclusively follow the instructions of air traffic control, and have to adhere to a strict flight plan, according to the free flight concept further real time information channels (on-board instruments, communication with pilots of other aircraft etc.) are incorporated into flight planning. As a result, flight safety could be guaranteed without compliance with a strict flight plan, and airspace capacity also considerable enlarged.

6.1.1.1 Reduction of the climatic impact of aviation through the restriction of cruise altitude

Williams et al. (2002a, 2002b)[64] investigated, by means of simulation models, the effects on flight duration and fuel consumption of climatic optimization of flight routes. They also investigated the consequences that were to be expected for air traffic control. The first investigation relates to *European airspace*, for the most part with short-haul flights (2002a). In the second investigation, *North American and North-Atlantic airspace* is considered, predominantly with long-haul flights of up to 6,000 nautical miles (2002b).

The starting point for assessment is in each case a reference flight (simulation model) with a fuel-optimized route. For climatically optimized flight routes it is assumed that the cruise altitude of the whole flight is reduced for reliable and complete avoidance of contrails.[65] The most important results of the investigation for European airspace regarding fuel consumption and flight duration are displayed in Table 23.

Table 23: Change in fuel consumption and flight duration with the restriction of flight altitude in European airspace

Maximum flight altitude	Months	Increase in fuel consumption in comparison with the reference flight	Proportion of flights with duration		
			increased	unchanged	reduced
- ft -		- % -		- % -	
24,000	Feb.	7.2	45	35	20
25,000	Jan., March, Nov., Dec.	5.8	32.5	36	33.5
26,000	April	5.3	27	37	36
29,000	May, Oct.	2.7	12	48	40
31,000	June, July, August, Sept.	1.6	4	60	36
Average	Over the year	3.9	20.2	46	34.5

Source: Williams et al. 2002a

According to Williams et al. (2002a), a restriction of flight altitude to between 31,000 and 24,000 feet is necessary, according to the time of year, for the complete avoidance of contrails in *European airspace*. The effects of this restriction on flight duration and fuel consumption depend not only on the type of aircraft, but also on flight distance. According to the time of year and the necessary change in flight altitude, additional consumption varies between 1.6 and 7.2 per cent. On average, additional consumption is 3.9%. CO_2 emissions increase – on account of the linear connection – to the same extent. The increase in NO_x emissions, on the other hand, depends heavily on the technology used.

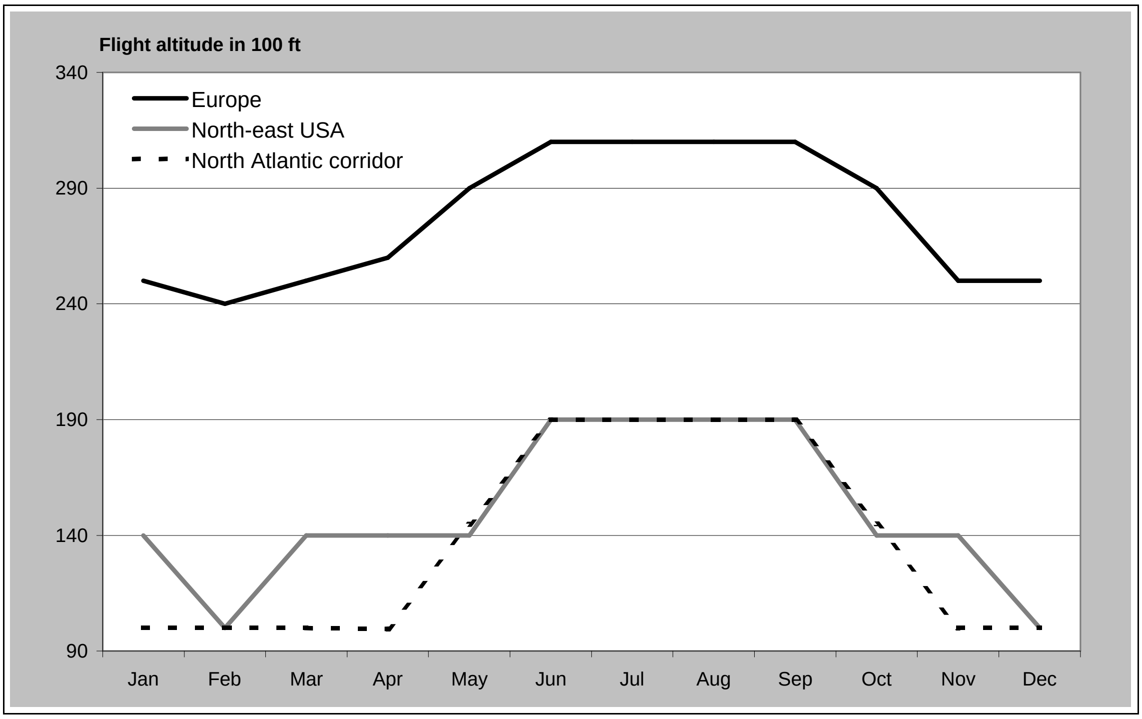
[64] The studies are entitled: "Reducing the climate impact of aviation by restricting cruise altitudes" and "Air Transport Cruise Altitude Restrictions to Minimize Contrail Formation".

[65] Because contrails often only arise on sections of flight routes, however, the effects and costs of the avoidance of contrails is clearly over-estimated with this approach.

For the assessment of flight route optimization with regard to airspace restrictions, Williams et al. (2002a) investigated the number of flight movements affected. With a restriction of flight altitude to 24,000 feet, two-thirds of European flights would be affected, while with restriction to 31,000 feet, only 40% of flights within Europe would be affected.

Flight duration can both decrease and increase as a result of a change in flight altitude. In around one-third of flight movements, flight duration remained unchanged or was somewhat shorter. In one-fifth of flight movements, however, flight duration would increase by up to 17 minutes. The influence on flight duration therefore lies at around the level of daily variability. Williams et al. (2002a) come to the conclusion that change of flight duration ought not to be an obstacle to the introduction of flight altitude restrictions for the avoidance of contrails.

Figure 12: Annual cycle of permissible flight levels with complete avoidance of contrails



Source: Williams et al. 2002b

The results also evidence a strong dependence on the type of aircraft. While the restrictions led to reductions in flight duration in the case of certain aircraft manufactured by McDonnell Douglas, it was above all Boeing 757 and 777 aircraft as well as Airbus A310, A320 and A340 aircraft that were affected by an extension of flight duration.[66]

Quite different results were provided by comparable simulations for the *North-Atlantic flight corridor* and *USA airspace* (Williams et al. 2002b). In the case of long-haul flights, correspondingly greater effects are to be expected on fuel consumption and flight duration. For the complete avoidance of contrails, flight altitudes would have to be restricted, according to the time of year, to between 9,000 and 19,000 feet (Figure 12, page 113). These results have only limited general applicability, however, since they are based on the evaluation of data for just one year. Williams et al. (2002b) therefore draw attention to the fact that the formation of contrails can fluctuate greatly from year to year depending on prevailing temperature.

For a flight over a distance of 3,000 nautical miles, fuel consumption increases on average by 10%. With a restriction in flight altitude to 19,000 feet, flight duration can be prolonged by between 40 and 120 minutes, depending on the type of aircraft investigated. In contrast to the extension of flight duration determined in respect of European airspace, these changes exceed the order of magnitude for daily variability. As a result, apart from additional fuel costs, further costs can arise due to increased working hours of flight crews, for example, or due to a reduced number of return flights per aircraft. In addition, a general restriction of flight altitude would result in greater airspace congestion and possibly, due to stricter air traffic control regulations, to further restrictions (Williams et al. 2002b).[67]

6.1.1.2 TRADEOFF Project

Within the framework of the TRADEOFF Project (CAEP WG3 2003, WG3 WP5-3, Aircraft Emissions: Contribution of different climate components to changes in radiative forcing – tradeoff to reduce atmospheric impact), the effects on climatic impact of a change in flight altitude were also investigated. The main aims of the EU TRADEOFF Project are a) to calculate future changes in climatic influences in the atmosphere as well as the contribution to climate change of aircraft emissions of a rapidly growing aircraft fleet, b) to reduce the large uncertainties in current calculations of the impact from future air traffic and c) to provide industry and decision-makers with options to reduce the future climatic impact of aircraft emissions.

With the TRADEOFF Project, not only are contrails and CO_2 emissions weighed up against each other; the effects of nitrogen oxide emissions are also considered. Early results show that with a reduction in flight altitude of 6,000 feet, about 5.2% more CO_2 and NO_x emissions would arise. Annual fuel consumption would grow from 111.5 mil-

[66] The reasons for this are differences in the optimum cruise altitude of different types of aircraft and in engines. In the case of aircraft with a high optimum cruise altitude, a restriction of cruise altitude to 31,000 or 24,000 feet leads to a greater extension of flight duration than in the case of aircraft with lower optimum cruise altitudes.

[67] Through realization of the free flight concept, however, airspace capacities could be considerably expanded (cf. footnote 63, page 111).

lion tonnes to 117.33 million tonnes (Fichtner 2003), and CO_2 emissions from 351.7 million t/a to 370.1 million t/a. At the same time, however, 44.5% less visible contrails arise. The decline in radiative forcing amounts to around 47.5% (Sausen/Lee 2003), since at lower flight altitudes more NO_x is emitted, but less ozone is formed.

Grewe et al. (2002) have investigated, within the framework of the TRADEOFF Project, the climatic impact of aircraft emissions of nitrogen oxide depending on flight altitude. With a reduction in flight level of around 3,300 feet, the results of simulations coupled with Chemistry-Climate Model E39/C (Grewe et al. 1999) show, despite increased fuel consumption, a 10% decrease in ozone formation, because nitrogen oxides are converted at low altitudes to HNO_3 and washed out, and therefore, due to the shorter lifespan, there is a lower concentration of NO_x emissions (Grewe et al. 2002).

Sausen (2002) assumes that consideration of ecological criteria in flight route optimization is quite possible. Lower flight altitudes for climate-policy reasons and current air traffic control regulations can result in airspace congestion, which, however, could be compensated through realization of the free flight concept (cf. Footnote 63, page 111).

6.1.1.3 Determination of environmentally-optimized flight routes

Further advice on the assessment of the climatic impact of flight routes is provided by the system for the determination of environmentally optimized flight routes that was developed by AvioPlan (1999). Besides climatic impact, economic criteria such as fuel consumption and flight duration were also examined. *North Atlantic airspace* was investigated, and, because of the seasonal variation of contrail formation, a distinction was made between summer and winter. In establishing climatic impact, not only were contrails and CO_2 emissions considered, but also the chemical reaction products of ozone formation.

With optimization conducted solely on the basis of ecological criteria, contrails could be almost completely avoided. In comparison to optimization based purely on economic criteria, climatic impact could be reduced by 20 - 30 per cent, although costs increased by 2%. The maximum attainable reduction of climatic impact amounted to 44%, according to calculations with the model. Flight duration would increase by 8% and fuel consumption by 13%. The results of exemplary calculations by AvioPlan are displayed in Table 24.

Table 24: Effects of flight route optimization based on the example of selected flight routes and profiles

	Flight duration		Fuel		Chemical effect		Contrails		Climate impact	
	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer
	- h:mm -		- t -		-		- nm -		-	
North route										
just costs	3:18	3:33	39	41	60	132	280	340	62	94
additional costs	3:19	3:37	39	42	54	116	120	-	49	68
proportional	3:26	3:37	43	42	41	113	-	-	39	56
more environment	3:33	3:39	44	44	31	105	-	-	35	65
just environment	3:55	3:40	45	45	30	104	-	-	35	65
South route										
just costs	3:32	3:20	41	39	74	188	390	-	75	95
additional costs	3:32	3:21	42	39	71	173	-	-	50	89
proportional	3:32	3:22	42	40	69	164	-	-	49	86
more environment	3:33	3:23	43	41	67	115	-	-	48	83
just environment	3:34	3:25	44	44	64	147	-	-	48	81
	- % -									
North route										
just costs	-	-	-	-	-	-	-	-	-	-
additional costs	1%	2%	1%	1%	10%	12%	-57%	-	-21%	-28%
proportional	4%	2%	10%	2%	32%	14%	-	-	-37%	-29%
more environment	7%	3%	12%	7%	48%	20%	-	-	-44%	-31%
just environment	8%	4%	13%	8%	50%	21%	-	-	-44%	-31%
South route										
just costs	-	-	-	-	-	-	-	-	-	-
additional costs	-	-	2%	1%	4%	8%	-	-	-33%	-6%
proportional	-	1%	3%	2%	7%	13%	-	-	-35%	-9%
more environment	-	1%	4%	6%	9%	18%	-	-	-36%	-13%
just environment	1%	1%	6%	12%	14%	22%	-	-	-36%	-15%

Note: In the exemplary calculation "only costs", only the economic optimization criteria "flight duration (20%) and "fuel" (80%) are considered, whereas in the exemplary calculation "only environment", the optimization criteria "fuel" (27%), "chemical effect" (40%) and "climatic impact" (27%) are considered. In the case of calculations between these extreme examples, optimization criteria are considered in graded weightings.

Source: AvioPlan 1999

6.1.1.4 Effects of a restriction on flight altitude

Within the framework of investigations with the AERO Modelling System (Section 5.4), global reduction measures, such as a restriction on flight altitude for the avoidance of contrails and the reduction of the climatic impact of NO_X, were modelled and analysed. Assuming a restriction of cruise altitude to 27,000 feet and 30,000 feet, respectively, the effects on demand, fuel consumption and emissions were investigated. The effects on the total climatic impact of aviation were not however considered. The main assumptions and results of this analysis are displayed in Table 25 (page 117).

Restriction-related deviation from fuel-optimized cruise altitude results in an average increase in fuel demand and fuel costs of 4 to 8 per cent. Increased fuel costs are passed on to consumers and result in a minor reduction in demand of 0.4 to 0.6 per cent. In addition, the rise in fuel consumption increases the incentive for airline companies to operate new, fuel-efficient aircraft and to modernize their fleets.

An interesting aspect of these results is that, despite a reduction of flight altitude compared to fuel-optimized cruise altitude of up to one-quarter, additional fuel consumption does not exceed 8%. Since it is sufficient for the avoidance of contrails to fly just a few flight levels lower, additional fuel requirements for the avoidance of contrails ought generally to be much lower.

Table 25: Effect of the restriction of cruise altitude, 2010

			Limit	
		AERO-M	27.000 ft	30.000 ft
Aircraft operation	billion RTK	828	823	825
Change in aircarft operation	%		-0,6%	-0,4%
Aircraft older than 12 year	Units	17.657	17.092	17.304
Aircraft younger than 12 years	Units	15.350	15.335	15.381
Fuel consumption	million t	258	278	269
Change in fuel consumption	%		7,9%	4,2%
CO_2 emissions	million t	814	878	848
NO_x emissions	million t	3,49	3,66	3,56
NO_x emission index	g/kg fuel	13,52	13,16	13,24

Source: MTPWW 2002

6.1.1.5 Assessment

Research shows that there is significant potential for the avoidance of contrails and for the reduction of the climatic impact of aviation through flight route optimization, and that this potential can for the most part be realized at a reasonable cost. It becomes clear, however, that the potential for flight route optimization greatly varies according to the time of the year and the flight route. Furthermore, airspace restriction plays a major role in the assessment of flight route optimization. The results of research do not provide a uniform picture, however, of the extent to which this potential flight route optimization is limited by current air traffic control regulations. The extent to which air traffic control regulations can be adapted to flight route optimization on the basis of ecological and economic criteria should be investigated, as well as the potentials that can be exploited through harmonization of airspace and the realization of the free flight concept.

6.1.2 Estimation of specific avoidance costs for contrails and cirrus clouds

With the reduction of the climatic impact of aviation through flight route optimization, costs arise in particular through an increase in fuel consumption. On the basis of the specific avoidance costs (US$/t CO_2 eq.) that arise, it can be estimated whether, and to what extent aviation emerges in an open system as a purchaser of emission rights, or which costs would arise for airline companies with the introduction of a closed emissions trading system.

A prerequisite for estimation of specific avoidance costs is an assessment of the climatic impact of contrails and aviation-related cirrus clouds. Because of the current status of scientific knowledge, such assessments are still fraught with uncertainties. Through the description of possible bandwidths, the scale of specific avoidance costs can nevertheless be estimated.

For the estimation of specific avoidance costs, typical flight relations for a medium-haul and a long-haul flight were analysed in detail. Although the results for other aircraft types and other flight routes can differ from these estimations, the order of magnitude should be clearly recognizable on the basis of these model flights.

6.1.2.1 Database and main assumptions

6.1.2.1.1 Investigated flight routes and standard aircraft

The specific data of standard relations and standard Airbus aircraft for these relations, on which the estimation is based, is presented in Table 26. Further consideration of the short-haul flight (Frankfurt to Rome) is dispensed with, since with such a flight, as a rule, a cruise altitude is not reached at which contrails develop.

Table 26: Specific data for standard aircraft and routes

		Airbus 320-200	Airbus 330-200	Airbus 340-600
Exemplary flights				
Relation		Frankfurt - Rome	London - New York	Frankfurt - Los Angeles
Route distance	nm	500	3,000	5,000
Route distance	km	926	5,556	9,260
Standard jet engines		V2500-A1	CF&-80E1A3	Trent 556
Number of seats	PAX	150	293	380
Weight				
MTOW	kg	73,500	230,000	365,000
MZFW	kg	61,000	168,000	256,000
OWE	kg	42,390	119,527	177,705
Number of flights per year		2,006	641	463
Flight kilometres per year	1.000 km	1,003	1,923	2,315

Source: Airbus 2003, Öko-Institut presentation

6.1.2.1.2 Change of flight level

For medium- and long-haul aircraft, an average fuel-optimized cruise altitude of 41,000 feet is assumed.[68] On the basis of this average value it is further assumed that for the avoidance of contrails and cirrus clouds, flight altitude is reduced by three flight levels, namely, by 6,000 feet. For according to the results of the TRADEOFF Project (cf. Section 1.1.1.2), through such a reduction the formation of contrails could be considerably reduced, without an inevitable increase in the number of kilometres flown. Also investi-

68 Aircraft such as the Airbus 330 and 340 fly, according to weather conditions and fuel reserves, at an altitude of between 37,000 and 43,000 feet (Airbus 2003).

gated, within the scope of sensitivity analyses, is the effect of the reduction of cruise altitude by four or five levels (-8.000 ft, -10.000 ft) on the climatic impact of flight movements and the burden of costs on airline companies. It can be assumed that the avoidance potential with such a reduction in flight level is greater, although higher costs arise and the distance flown does not remain unchanged, but rather increases.

6.1.2.1.3 Additional fuel consumption

The basis for the determination of additional fuel consumption is provided by the respective fuel-consumption and emission profile, according to AEIG (2001b).[69] Basically, additional fuel consumption and CO_2 emissions, in the case of a reduction in cruise altitude, depend on the type of aircraft and engine. However, average values can be applied for a rough estimation of specific avoidance costs. In Table 27, relative additional fuel consumption – on which estimates are based – is shown in relation to a reduction in cruise altitude.[70]

Table 27: Additional fuel consumption in relation to a reduction in cruise altitude

Cruise altitude		Reduction in altitude	Additional fuel consumption
ft	m	m	%
41,000	12,500	0	0.0
39,000	11,890	-610	0.3
37,000	11,280	-1,220	2.3
35,000	10,670	-1,830	5.6
33,000	10,060	-2,440	9.8
31,000	9,450	-3,050	12.2

Source: Airbus 2003

Additional fuel consumption brought about by a reduction in cruise altitude is generally not proportional to the distance flown. In the case of short distances, additional fuel consumption per kilometre is greater than with longer distances, since climbing to the original altitude contributes disproportionately to fuel consumption. With the following estimates, for the purpose of simplification, proportionality is nevertheless assumed between distance and additional fuel consumption (*proportional approach*).

69 Fuel consumption and NOx emission profile on the basis of AEIG (2001 b) are shown, by way of example, for the A 310 aircraft in Table 4 in Section 4.4.3.2.

70 The value used here in respect of the lowering of cruise altitude by 1,830 metres is somewhat higher than the value of 5.2% that is used in the TRADEOFF Project (section 1.1.1.2). According to information provided by Lufthansa, the fuel consumption of a flight from Frankfurt to San Francisco increases with a reduction in average cruise altitude of 890 metres by 5.1%, and with a reduction of 1,260 metres by 5.9%.

The dependence of additional fuel consumption on flight route is nevertheless considered within the scope of further sensitivity analysis, with which it is assumed that the whole flight is made at the lower flight level (*across-the-board approach*). This approach provides information on the maximum additional fuel consumption to be expected. It is based on the assumption that aircraft cannot simply change flight levels and have therefore to fly greater distances than necessary with reduced aerodynamic efficiency. Over-estimation of additional fuel consumption is therefore inevitable.

With a lowering of cruise altitude, fuel consumption increases for cruising but remains constant for the LTO cycle. Here, however, percentage additional fuel consumption is established generally for the flight as a whole, that is, for the LTO cycle and cruising. This way, additional fuel consumption tends to be over-estimated, especially when the lowering of flight level only occurs during parts of the flight.

6.1.2.1.4 Assessment of increased emission of NO_X

With reduced flight altitude, higher NO_X emissions also occur on account of increased fuel consumption. Due to another chemical compound in the atmosphere, however, the specific climatic impact of these emissions is lower (see Section 1.1.1.2)

In a conservative estimate of avoidance costs for contrails it is assumed for the purpose of simplification that at low flight altitude both the level of emissions and the climatic impact of NO_X emissions remain constant. With this approach, the level of NO_X emissions is in fact underestimated, their climatic impact, however, overestimated.

6.1.2.1.5 Extent of contrail avoidance

Meteorologists can nowadays quite accurately predict the occurrence of contrails for individual flights. There is, however, no well-founded knowledge to be discovered in specialist publications concerning the flights and the distances during which contrails actually occur.

It is conceivable that a large number of flight movements give rise to contrail formation, but only on certain sections of routes. Since contrail formation is heavily dependent on ambient temperature, this could be the case, for instance, with flights from the north to the south in northerly latitudes. With transatlantic flights during the winter, on the other hand, contrails can develop throughout cruising. For the estimation of the specific avoidance costs of flight route optimization these cases are therefore differentiated; it being assumed that contrails arise over 20%, 50% and 90%[71] of the flight distance. Data on the frequency of these cases is not available. CE (2002a) merely assumes, across the board, that contrails arise during about 10% of the distance flown worldwide.

[71] 90% is virtually equivalent to the formation of contrails over the entire cruise distance, since during the LTO cycle altitudes are not reached at which contrails can occur.

6.1.2.1.6 Assessment of climatic impact

The climatic impact of contrails and cirrus clouds has already been dealt with in Section 3.2. The development mechanisms of CO_2, NO_X and contrails are now sufficiently understood and are determinable. The development mechanisms of cirrus clouds and the role of aviation, however, have not yet been conclusively established. The effect of cirrus clouds is therefore based on large bandwidths, ranging from 0 to 0.075 W/m².[72] Since cirrus clouds also develop from contrails, it is assumed, within the scope of the following sensitivity analyses, that through a reduction of cruise altitude and the avoidance of contrails the development of cirrus clouds could also be prevented. The avoidance costs that would arise, when the possible effect of cirrus clouds is included in calculations, are also examined. For the purpose of a conservative estimate, however, only half of the maximum possible effect is considered (0.375 W/m^2), since not all contrails might develop into cirrus clouds, and cirrus clouds do not exclusively develop from contrails. Table 28 displays the values for the climatic impact of a flown kilometre, which form the basis of different sensitivity analyses.

Table 28: Climatic impact of one flown kilometre with contrails and cirrus clouds

				Contrails	**IPCC average**	**Contrails and cirrus clouds**
		Average flight with contrails during 10 % of the flight duration	Situation **without contrails and cirrus clouds** (90 % of flight duration)	Situation **with contrails** (10 % of flight duration)	Situation **with contrails and cirrus clouds** (10 % of flight duration)	Situation **with contrails and cirrus clouds** (10 % of flight duration)
Flown kilomertes (1992)	billion km	20.70	18.63	2.07	2.07	2.07
Radiative Forcing	**W/m²**	**+0.0325**	**+0.0261**	**+0.0064**	**+0.0229**	**+0.0439**
CO_2	W/m²	+0.0180	+0.0162	+0.0018	+0.0018	+0.0018
O_3 (through NO_x)	W/m²	+0.0230	+0.0207	+0.0023	+0.0023	+0.0023
CH_4 (through NO_x)	W/m²	-0.0140	-0.0126	-0.0014	-0.0014	-0.0014
H_2O	W/m²	+0.0020	+0.0018	+0.0002	+0.0002	+0.0002
Contrails	W/m²	+0.0035		+0.0035	+0.0035	+0.0035
Cirrus clouds	W/m²				+0.0165	+0.0375
SO_2	W/m²	-0.0030	-0.0027	-0.0003	-0.0003	-0.0003
Soot	W/m²	+0.0030	+0.0027	+0.0003	+0.0003	+0.0003
Specific radiative forcing	**pico W/m²/km**	**+1.6**	**+1.4**	**+3.1**	**+11.1**	**+21.2**
Cirrus clouds, contrails	pico W/m²/km	+0.2		+1.7	+9.7	+19.8
Consideration of cirrus clouds	%				22%	50%
Specific greenhouse impact of contrails and cirrus clouds	**t CO_2 eq./km**			**0.04**	**0.24**	**0.50**

Source: Öko-Institut calculations

Investigations are based on the values for global radiative forcing of aviation according to IPCC (1999). However, the values for contrails and cirrus clouds have been adjusted

[72] Radiative forcing of 0.075 W/m² for cirrus clouds arises on the assumption that cirrus clouds have the same optical depth as contrails.

to take account of more recent knowledge (Marquart et al. 2003, CAEP 2003). If one divides total radiative forcing of aviation by flown kilometres, the result is specific radiative forcing. For conversion into CO_2 equivalents, the specific radiative forcing of contrails and cirrus clouds has been divided by the specific radiative forcing of CO_2, according to the method employed by CE (2002a). By multiplying this quotient with the average emissions factor of CO_2 (22 kg/km, IPCC 1999*, S. 302*), the specific greenhouse gas impact of contrails and cirrus clouds can be determined (see Sections 4.4.3.3 and 4.4.3.4).

The following assumptions have been made for sensitivity analyses. With the sensitivity object “contrails”, only the lower, updated greenhouse gas impact has been considered, according to Marquart et al. (2003). This way, in estimating specific avoidance costs the upper limit is established, and in estimating the avoidance potential the lower limit is established. The upper limit of avoidance potential and the lower limit of specific avoidance costs are again determined, when cirrus clouds are considered with 50% of their maximum possible effect (0-0375 W/m^2) (sensitivity object “contrails and cirrus clouds”).

The third sensitivity object, “IPCC average”, lies between these values. Here it is assumed, in line with most recent scientific knowledge, that the impact of contrails is lower than that assumed by IPCC, but that the probability of a substantial contribution from cirrus clouds has increased. Were the maximum possible radiative forcing of cirrus clouds (0.075 W/m^2) to be considered only to the extent of 22% (0.0165 W/m^2), a greenhouse gas impact for one flown kilometre would arise that corresponds with the average values of IPCC (1999).

Greenhouse gas impacts of between 0.04 and 0.5 t CO_2 eq./km have therefore been assumed for these different sensitivity objects in the following estimations (Table 28).

6.1.2.1.7 Consideration of costs

Comprehensive flight route optimization in terms of the climate can only be carried out when air traffic management and air traffic control systems are reorganized. With the introduction of new systems, costs arise that are only partly attributable to emissions trading, because reorganization of the systems is in any case necessary on other grounds. Apart from the costs that arise with the introduction of emissions trading, additional costs arise for the monitoring and control of the emissions trading system. Neither of these cost categories can be reliably estimated at present, and they are therefore disregarded in the determination of specific avoidance costs.

So far as airline companies are concerned, optimization of flight routes from the climate point of view can result, on the one hand, in an increase in flight duration, and on the other hand, in higher fuel consumption. Because extension of flight duration is in certain cases substantial, but lies, on average, within the normal variability of flight duration, it is initially ignored in the determination of additional costs. The estimation of the specific avoidance costs for contrails and cirrus clouds resulting from flight route optimization is primarily based on additional costs for increased fuel consumption. For this purpose an average fuel price of 0.28 US$/kg is assumed.

In estimating additional costs per passenger, an average load level of 70% is applied.

6.1.2.2 Evaluation of sensitivity analyses

On the basis of previously presented data and assumptions, the specific avoidance costs for contrails and cirrus clouds can be estimated. Table 29 displays, by way of example, the main initial data and assumptions as well as the results of estimation for a flight from Frankfurt to Los Angeles with an Airbus 340-600.

In the left-hand column, reference flight data is displayed, which assumes that contrails and cirrus clouds occur over more than 50% of the total flight distance. In the right-hand column, it is assumed – based on the same flight – that for that part of the flight for which contrail formation has been forecast, flight altitude is reduced by 1,830 metres to avoid the formation of contrails (and cirrus clouds). According to the assumption made for the climatic impact of contrails and cirrus clouds, flying lower could in this case result in a saving of between 190 and 2,310 t CO_2 eq.;[73] with higher costs, in particular for fuel, of the order of 530 US$. As a result, specific avoidance costs of between 0.23 and 2.77 US$ per t CO_2 eq. arise. Already at this point it becomes clear, that specific avoidance costs – even when only the impact of contrails is considered – of 2.77 US$/t CO_2 eq. are still relatively low, and below the price that is currently paid for cheap greenhouse gas credits from CDM projects (3-5 US$/t CO_2 eq.).

[73] Here it was assumed, that the radiative forcing of the greenhouse gas impact of aviation corresponding to considerations put forward in Sections 3.3.1 and 4.4.3.4 can be transformed into CO_2 equivalents.

Table 29: Avoidance costs for contrails and cirrus cloud with a flight from Frankfurt to Los Angeles

Route		Frankfurt - Los Angeles	
Flight altitude	m	12,500	10,670
Reduction of flight altitude by	m	0	1,830
Emissions			
Fuel consumption	t	68	70
Cruisung	t	66	68
LTO cycle	t	2	2
Carbon dioxide emissins	t	213	219
Water vapour emissions (cruising)	t	81	84
Nitrogen oxide emissions (cruising)	kg	1,093	1,093
Nitrogen oxide emission index (cruising)	g/kg fuel	17	0
Proportion of the route with contrails	%	50	0
Distance with contrails	km	4,630	0
Total greenhouse impact: contrails	**t CO_2 eq.**	**586**	**395**
Total greenhouse impact: IPPC average	**t CO_2 eq.**	**1,520**	**395**
Total greenhouse impact: contrails & cirrus clouds	**t CO_2 eq.**	**2,708**	**395**
Carbon dioxide	t CO_2 eq.	213	219
Water vapour	t CO_2 eq.	26	26
Nitrogen oxide	t CO_2 eq.	149	149
Contrails	t CO_2 eq.	198	0
IPPC average	t CO_2 eq.	1,132	0
Contrails & cirrus clouds	t CO_2 eq.	2,320	0
Savings potential per flight			
Contrails	t CO_2 eq.		191
IPPC average	t CO_2 eq.		1,125
Contrails & cirrus clouds	t CO_2 eq.		2,313
Change in fuel consumption			
Additional consumption	t		1.89
Additional cost	US$		530.52
Additions cost per passenger	US$		1.99
Specific avoidance costs			
Contrails	US$/t CO_2 eq.		2.77
IPPC average	US$/t CO_2 eq.		0.47
Contrails & cirrus clouds	US$/t CO_2 eq.		0.23

Source: Öko-Institut calculations

On the basis of this model of one example, the influence of different parameters on specific avoidance costs is analysed in the following sections.

6.1.2.2.1 Influence of flight level on specific avoidance costs

Table 30 displays the specific avoidance costs of contrails and cirrus clouds depending on the number of flight levels by which cruise altitude is reduced. The proportional approach provides the basis; that is, it has been assumed that flight level is reduced only over the distance for which meteorological conditions favour the formation of contrails and cirrus clouds.[74]

Table 30: Influence of flight level on specific avoidance costs (proportional approach)

Flight		Frankfurt - Los Angeles			London - New York		
Reduction of cruise altitude	m	1,830	2,440	3,050	1,830	2,440	3,050
Additional fuel consumption	%	5.6%	9.8%	12.2%	5.6%	9.8%	12.2%
Specific avoidance costs							
Contrails	US$/t CO_2 eq.	2.69	4.83	6.10	2.44	4.36	5.51
IPCC average	US$/t CO_2 eq.	0.46	0.80	1.00	0.42	0.73	0.91
Contrails & cirrus clouds	US$/t CO_2 eq.	0.22	0.39	0.49	0.20	0.35	0.44

Source: Öko-Institut calculations

Depending on the extent to which the climatic impact of cirrus clouds is considered with this approach, estimates for both exemplary flights, with a reduction of cruise altitude by 3 flight levels, indicate specific avoidance costs of between 0.20 and 2.69 US$/t CO_2 eq.

As a rule, reduction of cruise altitude by 3 flight levels should be sufficient to avoid the formation of contrails (and cirrus clouds). In many cases, a marginal reduction of just 1 level should even be sufficient to avoid the formation of contrails (Brockhagen/Lienemeyer 1999). In the case where cruise altitude must nevertheless be reduced by 4 or 5 flight levels (2,440 and 3,050 metres, respectively) to avoid the formation of contrails (and cirrus clouds), higher specific avoidance costs also arise due to increased fuel consumption. With a reduction of cruise altitude by 5 flight levels they amount to between 0.44 and 6.10 US$/t CO_2 eq., according to the assumed greenhouse gas impact of cirrus clouds.

These sensitivity analyses show that the greater the required reduction of flight level to avoid the formation of contrails the higher specific avoidance costs. But they also show, that when only the avoidance of contrails is considered, and at the same time a relatively drastic reduction in cruise altitude by 4 flight levels is assumed, specific avoidance costs, at a maximum of 4.83 US$/t CO_2 eq., are still of the same magnitude that is expected for CDM projects.

6.1.2.2.2 Influence of flight distance with contrails on specific avoidance costs

As a rule, the latest meteorological methods enable a quite accurate forecast to be made of the flight distance over which contrails can occur. A reduction in flight level is

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[74] Because with this approach, not only the avoided climatic impact but also the additional fuel costs are proportionate to the distance at reduced flight level, specific avoidance costs ultimately depend on the distance over which contrails and cirrus clouds can occur.

therefore only necessary over those sections of the route where contrails can arise. Within the scope of further sensitivity analysis it has nevertheless been assumed, that the whole flight is conducted at a lower flight level to completely avoid the development of contrails (and cirrus clouds) (across-the-board approach). It has also been assumed, that cruise altitude is reduced by 1,830 metres (3 levels) and that fuel consumption increases as a result by a total of 5.6%.

Table 31: Specific avoidance costs by flight distance with contrails (across-the-board approach)

Flug		Frankfurt - Los Angeles			London - New York		
Distance with contrails	%	20%	50%	90%	20%	50%	90%
Specific avoidance costs							
Contrails	US$/t CO_2 eq.	15.55	5.56	3.00	13.89	5.03	2.72
IPCC average	US$/t CO_2 eq.	2.34	0.92	0.51	2.12	0.84	0.46
Contrails & cirrus clouds	US$/t CO_2 eq.	1.12	0.45	0.25	1.02	0.41	0.22

Source: Öko-Institut calculations

Table 31 displays the results of this sensitivity analysis. When only the greenhouse gas impact of contrails is considered, specific avoidance costs of between 2.72 and 15.55 US$/t CO_2 eq. arise. In the case where contrails occur only over 20% of the flight route, but cruise altitude for the whole flight is nevertheless reduced by 1,830 metres compared to the fuel-optimized flight level, specific avoidance costs then arise above the expected price for emission allowances in the European emissions trading system (5 to 10 euros/t CO_2 eq.). In this case, it should be more attractive for airline companies to acquire emission credits from CDM projects or from international emissions trading than to reduce the greenhouse gas impact through a climate-optimized choice of flight route.

However, this case is based on assumptions that can hardly be regarded as realistic and clearly overestimate specific avoidance costs. For although contrails only occur over 20% or 50% of the flight route, for example, the whole flight is made at a lower flight level. Where contrails occur over virtually the whole flight route, the across-the-board approach corresponds roughly with the proportional approach. In this case, specific avoidance costs range between 2.70 and 3.00 US$/t CO_2 eq., when only the greenhouse gas impact of contrails is considered. Moreover, if one takes account of the climatic impact of cirrus clouds with 50% of the maximum possible contribution (0.0375 W/m²), the established specific avoidance costs lie well below 1.50 US$/t CO_2 eq.

Sensitivity analysis shows, that generally flying lower for the avoidance of contrails could reduce the greenhouse impact, but, in those cases where contrails only occur over part of the flight route (=50%), it would not be efficient. Only when the impact of cirrus clouds would be accounted for with a contribution to the greenhouse effect at the upper limit of the current range of uncertainty, would such an across-the-board strategy be efficient. Ultimately, efficiency could also be increased in this case, if cruise altitude is only reduced over parts of the flight route where contrails could occur.

It is therefore important for the establishment of all measures for the limitation and reduction of the greenhouse gas impact of contrails (and cirrus clouds), that appropriate instruments for the timely forecast of the occurrence of contrails are available.[75] Where this is not the case, a general reduction in cruise altitude could noticeably reduce the greenhouse impact of aviation, but it could not be ensured that these measures would be more efficient for every flight than measures applied in other sectors of the economy.

6.1.2.2.3 Effects on fuel costs

Related to a single flight from Frankfurt to New York additional costs of between 100 and 1,200 US $ arise through the reduction in cruise altitude. These additional costs vary depending on the assumptions made concerning the proportion of flight distance with contrails and the reduction of flight altitude, and dependent also on the method of calculation (Table 32).

Table 32: Additional fuel costs

		Proportional approach									Across-the-board approach		
Reduction of the flight altitude by	m		1,830			2,440			3,050		1,830	2,440	3,050
Additional fuel consumption	%		5.6%			9.8%			12.2%		5.6%	9.8%	12.2%
Parts of routes with reduced flight altitude	%	20%	50%	90%	20%	50%	90%	20%	50%	90%		100%	
Frankfurt - New York, 5,560 km													
Distance with reduced flight altitudes	km	1,111	2,778	5,000	1,111	2,778	5,000	1,111	2,778	5,000		5,556	
Change in fuel consuption													
Fuel consumption	t	38.4	39.0	39.8	38.7	39.8	41.2	38.9	40.2	42.0	40.0	41.6	42.4
Additional consumption	t	0.4	1.0	1.8	0.7	1.8	3.2	0.9	2.2	3.9	2.0	3.5	4.4
Additional costs	US$	112	281	505	197	491	884	245	612	1101	562	983	1223
Frankfurt - Los Angeles, 9,260 km													
Distance with reduced flight level	km	1,852	4,630	8,334	1,852	4,630	8,334	1,852	4,630	8,334		9,260	
Additional Fuel Consumption													
Fuel consumption	t	68.4	69.5	71.0	69.0	70.9	73.5	69.3	71.7	74.9	71.3	74.1	75.7
Additional fuel consumption	t	0.7	1.8	3.3	1.3	3.2	5.8	1.6	4.0	7.2	3.7	6.4	8.0
costs	US$	206	515	926	360	901	1621	449	1121	2018	1029	1801	2243

Source: Öko-Institut calculations

For a flight from Frankfurt to Los Angeles, the additional costs vary accordingly between 200 and 2,250 US $. Additional costs per flown kilometre thus amount to between 0.02 and 0.24 US $. Even with very restrictive assumptions, additional costs are, on balance, quite moderate.

75 Since such forecasts have been carried out for military flights for some time, the provision of such instruments should not be a problem (Sausen 2002).

6.1.2.2.4 Effects on ticket prices

With the introduction of an emissions trading system, airline companies will attempt to pass on any additional costs to their customers. The question therefore arises as to the particular costs they will have to pass on in the case of climate-optimized flight routes. In addressing this question, it is assumed that the additional costs of flight route optimization can be wholly passed on, and that flights, on average, have a 70% capacity utilization.[76]

Table 33: Additional costs per passenger (proportional approach)

Flight		Frankfurt - Los Angeles			London - New York		
Reduction in cruise altitude	m	1.830	2.440	3.050	1.830	2.440	3.050
Additional fuel consumption	%	5,6%	9,8%	12,2%	5,6%	9,8%	12,2%
Specific avoidance costs with contrail formation over ... of the route							
20%	US$/Ticket	0,77	1,35	1,69	0,55	0,96	1,19
50%	US$/Ticket	1,93	3,39	4,22	1,37	2,40	2,98
90%	US$/Ticket	3,48	6,10	7,59	2,46	4,31	5,37

Source: Öko-Institut calculations

The results of this investigation are displayed in Table 33. They confirm that possible additional costs are very moderate, lying on the whole well below 10 US$. Related to ticket prices, additional costs amount to a maximum of 1 to 2%, in most cases well below 1%.

6.1.3 Avoidance potential for contrails and cirrus clouds

Besides specific avoidance costs, avoidance potential is also particularly relevant for the assessment of a reduction option; for when the reduction potential of an option is limited, the reduction contribution can also only be limited, even in the case of very low specific avoidance costs.

The main data and results of estimation of avoidance of contrail and cirrus clouds through climate-orientated flight-route optimization are presented for the year 1992 in Table 34. The assumptions discussed in Section 6.1.2.1 and the results of the TRADEOFF Project (Section 6.1.1.2) provide the basis.

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[76] Additional costs of flight route optimization for a single flight, in absolute terms, are independent of the contribution to reduction. It has therefore not been necessary in this examination to differentiate between different possible reduction contributions of flight route optimization.

Table 34: Determination of reduction potentials for contrails and cirrus clouds

		Contrails	IPCC average	Contrails & cirrus clouds
Specific climate impact				
Contrails & cirrus clouds (C & CS)	t CO_2 eq./km	0.04	0.24	0.50
CO_2- and H_2O (3 flight levels lower)	t CO_2 eq./km	0.0014	0.0014	0.0014
Aggregated greenhouse gas impact				
Contrails & cirrus clouds	million t CO_2 eq.	89	506	1,037
Reduction C & CS (3 flight levels lower)	%	44.5%	44.5%	44.5%
CO_2- and H_2O (3 flight levels lower)	million t CO_2 eq.	3	3	3
Avoidance potential	million t CO_2 eq.	37	222	459

Source: Öko-Institut calculations

The departure point for estimation is the specific climatic impact of contrails and cirrus clouds (Table 28). The aggregate greenhouse gas impact can be determined on the basis of the assumption that contrails (CE 2002a) and cirrus clouds develop during only 10% of worldwide flown kilometres (2.07 billion km). According to the results of the TRADEOFF Project, 44.5% of the greenhouse gas impact can be avoided through a reduction in cruise altitude by three flight levels (see Section 1.1.1.2). At the same time, additional greenhouse gas emissions of the order of 3 million t CO_2 eq.[77] occur due to increased fuel consumption. Depending on the assumed greenhouse impact of cirrus clouds, the worldwide avoidance potential in respect of contrails and cirrus clouds ranges from almost 35 million t CO_2 eq. to roughly 460 Million t CO_2 eq. On the basis of realistic but cautious assumptions, the avoidance potential amounts to at least 200 Million t CO_2 eq. (IPCC average).

Alternatively, avoidance potential can be determined on the basis of radiative forcing (Table 35). The conversion of radiative forcing of mW/m^2 into CO_2 eq. occurs with the help of radiative forcing of CO_2 emissions for aviation as a whole.

As a result of flight route optimization, as outlined in the TRADEOFF Project, the climatic impact of aviation increases by up to 0.0001 W/m^2 and 3.1 million t CO_2, eq., respectively (related to the values for 1992), due to increased fuel consumption. This way, however, 44.5% of the climatic impact of contrails (and cirrus clouds) could be avoided. The total avoidance potential amounts to 0.0014 W/m^2 for contrails and up to 0.018 W/m^2 for cirrus clouds. This is equivalent to an avoidance potential of around 41 million t CO_2 eq. for contrails and up to 470 million t CO_2 eq. for cirrus clouds; that is, a total avoidance potential of between 40 and 510 million t CO_2 eq.

[77] On the assumption of an average emissions factor of 22 kg CO_2/ km and additional fuel consumption of 5.6% with a reduction in cruise altitude of 3 flight levels.

Table 35: Determination of avoidance potential on the basis of radiative forcing

	Radiative forcing W/m²			CO_2 equivalents million t CO_2 eq.		
Climate impact						
CO_2 emissions (total)			0,0180			506
CO_2 emissions (10 % of flight route)			0,0018			51
H_2O emissions (total)			0,0015			42
H_2O-Emissionen (10 % of flight route)			0,0002			4
Increased emissions through flight route optimization			0,0001			3
Contrails			0,0035			98
Cirrus clouds	0,0000	to	0,0375			1.054
Aviation as a whole	0,0320	to	0,1070	899		3.007
Avoidance potential	**0,0014**	to	**0,0181**	**41**	to	**510**
Contrails			0,0014			41
Cirrus clouds	0,0000	to	0,0167	0	to	469

Source: Öko-Institut calculations

On the assumption that aviation does not give rise to cirrus clouds, or alternatively, that these have no impact on the climate, the avoidance potential for contrails is equivalent to about 4.5% of the climatic impact of aviation. If, however, cirrus clouds are to be accounted for in the climatic impact of aviation, and half of their climatic impact – as in the case of contrails – can be prevented to the extent of 44.5% through flight route optimization, then this way the climatic impact of aviation can be reduced by up to 17%.

The results of both of these calculation methods are of the same order: The avoidance potential for contrails amounted to between 35 and 40 million t CO_2 eq. in the year 1992. This potential can be realized through a reduction in cruise altitude by 3 flight levels without an increase in the number of kilometres flown. If, with this strategy, the climatic impact of cirrus clouds can be reduced by 44.5%, and these have an optical depth comparable to that of contrails, then this way an additional – in certain circumstances much greater – potential of up to 470 million t CO_2 eq. can be exploited.

The avoidance potential could even be much greater, if the climatic impact of aviation could be still further reduced through a drop in cruise altitude by 4 or 5 flight levels. Specific avoidance costs would then be somewhat higher, since additional fuel consumption would be noticeably greater; but they should nevertheless be lower than the specific avoidance costs of many other measures for the reduction of greenhouse gas emissions in aviation.

The future avoidance potential for contrails and cirrus clouds can be forecast according to both of the methods described above (Table 36). It is assumed that in future contrails arise over 10% of flown kilometres.

Table 36: Avoidance potential for contrails and cirrus clouds

		1992			2010			2020		
		min.		max.	min.		max.	min.		max.
Avoidance potential on the basis of aircraft operation										
Aircraft operation	billion km		20.7			44.5			65.0	
Avoidance potential	million t CO_2 eq.	37	-	459	89	-	1,205	142	-	1,974
Avoidance potential on the basis of radiative forcing										
Contrails	W/m^2	0.001		0.001	0.003		0.003	0.004		0.004
Cirrus clouds	W/m^2	0.000	-	0.017	0.000	-	0.038	0.000	-	0.050
Avoidance potential	million t CO_2 eq.	41	-	510	79	-	1,107	94	-	1,352
Contrails	million t CO_2 eq.	41		41	79		79	94		94
Cirrus clouds	million t CO_2 eq.	0	-	469	0	-	1,028	0	-	1,258

Source: Öko-Institut calculations

The estimates show that the avoidance potential for contrails and cirrus clouds will be greater in future: In the year 2010, the greenhouse gas impact of aviation could be reduced through the avoidance of contrails by about 80 million t CO_2 eq., and in 2020 by at least 90 million t CO_2 eq. Taking account of cirrus clouds, however, with 50% of their potential effect, the potential is many times higher, amounting in the year 2010 to at least 1,100 million t CO_2 eq., and in 2020 to at least 1,350 million t CO_2 eq. Investigation shows, that through flight route optimization a considerable potential for greenhouse gas reductions in aviation can be exploited in the short and medium term.

6.2 Communications, navigation and surveillance systems

Through the introduction of new communications, navigation and surveillance systems as well as air traffic management systems (CNS/ATM), flight routing could be optimized – particularly with regard to flight altitude and speed – and delays and congestion reduced (ICAO 2002). According to the CAEP, fuel consumption in the USA and Europe could be reduced by 5% by the year 2015, compared with reference developments, through planned changes in CNS/ATM systems, new digital technology, greater automation and the expansion of satellite navigation. IPCC (1999) quantifies the fuel savings potential in this area at 6 to 12%; it assumes, however, that this potential can only be exploited over a prolonged period.

These estimates have been based on the assumption that fuel consumption can be reduced through the introduction of new CNS/ATM systems. If, however, for reasons of fuel optimization, a flight altitude is selected that allows the formation of contrails (and cirrus clouds), this can then have the result that the climatic impact of such flights increases, rather than decreases. In future, it is therefore important to set incentives for these new CNS/ATM systems through the introduction of emissions trading or other instruments in such a way, that flights are optimized not in terms of fuel requirements but rather from the climate point of view. New CNS/ATM systems should basically be applied in such a way that routes could also be optimized on the basis of such objectives.

Within the scope of analyses with the AERO Modelling System (AERO 2002), a model was made of the reduction of delays and congestion in airspace through an improved ATM system. On the assumption that the improved management system could be introduced without airline companies incurring additional costs, up to 9.5% of fuel could be saved in 2010. From that, an avoidance potential of 30 to 130 million t CO_2 eq. can be deduced.

6.3 Flight Management

Under the concept of flight management, Stratus Consulting (2002) collect together a number of different strategies that contribute to a reduction in emissions. These include measures such as the reduction of aircraft weight – for example, through reduced passenger air service (fewer crew, reduced catering etc.) – or limited fuelling and the reduction of flight speed.[78]

Stratus Consulting (2002) estimates that through broadly-based flight management fuel consumption can be reduced by 5%, leading to a 5% reduction in CO_2 emissions and a reduction in NO_x emissions of about 9.5%. As a result, an avoidance potential of about 30-50 million t CO_2 eq. can be deduced for the year 2010.

6.4 Improved capacity utilization

Basically, the higher aircraft capacity utilization the lower emission per passenger kilometre. From that point of view, greenhouse gas emissions from aviation could also be reduced through an increase in capacity utilization. Through the design of the pricing system it would be possible for demand to be directed from flights with low capacity utilization to flights with a high capacity utilization but with spare passenger capacity. In effect, substantial emission reductions could only be realized when flights with low capacity utilization are cancelled.

Such a strategy on the part of airline companies would result in restrictions on the comfort of passengers, however, who would enjoy less flexibility in their travel planning due to streamlined flight scheduling, and also because a flight with a heavy passenger load tends to be less comfortable than one with a normal passenger load. In addition, the optimization of flight schedules must already be one of the key control instruments of airline companies, through which not only the services on offer but also costs are considerably influenced. The contribution of such a strategy to the avoidance of greenhouse gas emissions could well be negligible.

[78] According to CE (2002c), CO_2 emissions are 15 to 25% lower with emission-optimized aircraft speed than at the speed with the highest emissions.

6.5 Maintenance

Because of the risk of accident, aircraft must be among the best-maintained machines. But the standard of maintenance could be optimized from the ecological point of view, according to the ICAO (2002). This concerns not only the maintenance of aircraft, but also the maintenance of engines. If aircraft doors are not 100% aligned, for instance, so that they protrude by a few millimetres, the result can be considerable turbulence, which increases fuel consumption. Through realignment, which takes about one hour, around 500 litres of fuel could be saved per year (ICAO 2002).

In the case of engines, the increase in specific fuel consumption is primarily a result of erosion-related deformation of blades and impairment of surface quality. An increase of 1% in specific fuel consumption leads, on average, to an increase in fuel costs of 10 US$ per operating hour (ICAO 2002). In addition, engine performance is determined, above all, by gas flow; and time and again, dirt and deposits result in deteriorating performance, which could be avoided by simple washing operations without having to remove engines.

With thorough maintenance, an increase in fuel consumption can therefore be avoided; and with limited expenditure of time, considerable fuel savings can often be realized. (ICAO 2002).

6.6 Engine optimization from the climate point of view

The climate optimization of engines aims not only at the minimization of fuel consumption, and thus CO_2 emissions, but also at the reduction of nitrogen oxide emissions.

Improvement in fuel efficiency has been achieved in the past through the development and use of modern engines that operate at high temperatures and pressure. These circumstances favour, however, the formation of nitrogen oxide. The stabilization or reduction of nitrogen oxide emission is therefore only attainable by means of alternative combustion chambers that lower NO_x emissions (Rand Europe 2002).

On account of the overriding significance of fuel consumption for the efficiency of engines, with the current operating cost structure of aircraft there is little incentive to promote NO_x-reducing technologies. Against the backdrop of the trade-off between CO_2 and NO_X, Rand Europe (2002) developed a concept for emission limit values, with which the climatic impact of CO_2 and NO_X is jointly considered. The prerequisite for this concept – which can only be realized in the long term – is that all parties involved mutually agree the climatic impact of CO_2 and NO_X.

Rand Europe (2002) has also prepared two short-term, technology-related strategies for NO_x emission limit values. The conservative approach comprises a tightening-up of the CAEP/4 limit value by 9 to 28%; the progressive approach a tightening-up of 30 to 45%. Through the exploitation of technological reduction potentials, NO_X emissions of international civil aviation could be 17% below forecast reference emissions in the year 2020. Because aviation growth is considerably higher, however, even with the exploitation of these potentials there will still be an increase in NO_X emissions in absolute terms (Rand Europe 2002).

The effect on the level of emissions of an annual reduction of the NO_X emission index and an annual increase in fuel efficiency of, in each case, 1% was investigated by means of simulations with the AERO Modelling System (AERO 2002). From the model results, depending on the cost of these measures for airline companies, a savings potential for engine optimization can be deduced amounting to 3 to 20 million t CO_2 eq. in the year 2010 and 35 to 130 Million t CO_2 eq. for the year 2020.

The *replacement of old with new, more efficient engines* (re-engining) is an avoidance option especially for aircraft that are less than 20 years old. For at a discount rate of 7%, the installation of a new engine is amortized only after about 20 years. Annual CO_2 savings depend on the age of the aircraft and the replaced engine. Stratus Consulting (2002) estimate that, on average, around 0.5% of CO_2 emissions can be saved for each year of operation of the replaced engine. Related to a twenty year-old engine, CO_2 savings amount to around 10%.

The replacement of engines, however, has an effect not only on CO_2 emissions, but also on NO_X emissions. Stratus Consulting (2002) assume that through engine replacement around 0.725% more NO_X is emitted per year of operation of the replaced engine. Related to a twenty year-old engine, this amounts to an increase in nitrogen oxide emissions of 14.5%.

CE (2002a) investigated the avoidance option of re-engining on the basis of two case studies. It came to the conclusion that the contribution of aviation to the climate problem could be reduced, however, only at a very high cost. To what extent re-engining is economic greatly depends on general conditions. Whereas in the 1980s and 1990s, for instance, re-engining represented a frequently considered avoidance option, due to high fuel costs and increasing demands on noise limit values, at the present time it is generally not economic.

6.7 Improvement in aerodynamics

Through improved aerodynamics of aircraft, fuel consumption as well as CO_2 and NO_X emissions can be reduced. The aerodynamics of aircraft can presently be optimized through the use of so-called winglets and riblets.

6.7.1 Winglets

Optimum wing design is one of the greatest challenges in the development of new aircraft. The aerodynamic qualities of wings can be improved, on the one hand, by enlarging wing spread, and on the other hand, by mounting wing-tip devices, so-called winglets, at the end of the aircraft wing.[79] Winglets can generally only be installed on older aircraft, because, in the case of more recent aircraft types wing design is already optimized.

Emission reductions achieved through the use of winglets range, according to CE calculations (CE 2002a), from 2% of CO_2 emissions and 3% of NO_X emissions over short distances to up to 6% of CO_2 emissions and 11% of NO_x emissions over long distances. Because the reduction of fuel consumption through the use of winglets on medium- and long-haul flights is greater than on short-haul flights, the installation is especially attractive for aircraft with a maximum design zero fuel weight (MZFW) above 70 tonnes.

Table 37: CO_2 and NO_x savings through the installation of winglets

Flight distance - nautical miles -	CO_2 savings - % -	NO_x savings - % -
< 500	1.0	1.90
< 1,000	1.5	2.85
< 1,500	2.0	3.80
< 2,500	2.5	4.75
< 3,500	3.0	5.70
< 4,500	3.5	6.65
> 4,500	4.0	7.60

Source: Stratus Consulting 2002

Stratus Consulting (2002) assumes that the capital cost of installing winglets is amortized over 15 years. Achievable CO_2 savings vary, according to the length of flight, between 1 and 4% (Table 37). Concurrent NO_X savings result from reduced throttle settings needed to achieve the same flight speed. They exceed achievable CO_2 savings by a factor of 1.9.

6.7.2 Riblets

The aerodynamics of aircraft can also be improved through the application of so-called riblets, ribbed plastic coating with a thickness of less than 1 mm, which is applied instead of paint to the external surface of aircraft. Despite the increased weight from the

79 Traditional winglets available on Boeing and Airbus aircraft are mounted on the end of the wing and go up at a steep angle. New blended winglets, which curve gently upward at the end of the wing, have been developed by Boeing and Aviation Partners (Stratus Consulting 2002).

applied material,[80] the aircraft's reduced drag coefficient enables noticeable emission reductions to be achieved. The effect of riblet deterioration, through the build up of dirt and grime in the grooves, is to reduce CO_2 savings and thus the effectiveness of this avoidance option.

Stratus Consulting (2002) assumes a maximum aircraft age of 30 years for application of this technology. The capital cost is amortized over five years. CO_2 emissions can be reduced from 1 to 2% and NO_X emissions by 2 to 4% (Table 38). The restriction of CO_2 savings through riblet deterioration, however, is not taken into account.

Table 38: CO_2 and NO_x savings through the application of riblets

Flight distance - nautical miles -	CO_2 savings - % -	NO_x savings - % -
< 500	1.0	1.90
< 1.500	1.5	2.85
> 1.500	2.0	3.80

Source: Stratus Consulting 2002

According to information from CE (2002c), through the application of riblets, and depending on flight distance, between 0.5 and 1.5 per cent of fuel consumption can be saved. Capital costs – depending on aircraft size – are between 30,000 and 250,000 US$. According to CE calculations, the application of riblets is nowadays only economic in the case of aircraft with a MZFW in excess of 70 tonnes. The economic efficiency of riblets would increase considerably, however, with the introduction of emission-related levies or emissions trading.

6.7.3 Potential

Both techniques for the improvement of the aerodynamic efficiency of aircraft demonstrate reduction potential that should not be ignored. However, the installation of winglets is an improvement measure that is only useful for a proportion of older aircraft. New aircraft are already supplied with aerodynamically optimized wing design, so that improvement is unnecessary. Winglet potential is therefore limited in time.

With riblets, on the other hand, reduction potential is not subject to time limitation. On account of the problem with dirt and grime, however, they have not been established on the market (CE 2002c, Airbus 2003). The combined reduction potential of both techniques is currently estimated at a maximum of 10 million t CO_2 eq. per year.

80 The increase in aircraft weight amounts to about 150 to 800 kg, according to the size and surface area of the aircraft, and according to whether riblets are applied over paint or instead of paint. (CE 2002c).

6.8 Early retirement of aircraft

New aircraft are more efficient than old aircraft. They require less fuel and emit fewer greenhouse gases. Through the replacement of old aircraft with new, more efficient models (early retirement) both fuel consumption and greenhouse gas emissions can be reduced.

Stratus Consulting (2002) estimates that, with regard to the avoidance of CO_2, 60% of increased aircraft efficiency is attributable to engine improvements, with the rest due to improvements in aircraft themselves and in their operation. Average improvement in fuel efficiency is assumed to be 1% per year. For example, if a 30 year-old aircraft is retired and replaced by a new aircraft three years earlier than planned, 30% of fuel consumption, and thus 30% of CO_2 emissions are saved in each of those three years. Savings in NO_X emissions are lower, since the energy efficiency of new engines can mostly only be increased at the cost of the emission index for NO_X. According to estimates of Stratus Consulting (2002), NO_X emissions could be reduced by 0.02% per year of operation of the retired aircraft; that is, in the case of early retirement of a 30 year-old aircraft, a 0.6% reduction in NO_X emissions is assumed.

A number of factors are involved in the highly-complex decision concerning the early retirement of aircraft, such as expected fuel prices, market perspective, liquidity of airline companies and expected return on investment. Ecological criteria have not been considered up to now. CE (2002c) estimates that with the introduction of a fuel tax or of emissions trading with an allowance price of the order of 10 to 50 €/t CO_2 eq., the replacement of old aircraft will be brought forward by up to two years.

The effects of early retirement of aircraft have also been simulated with the AERO Modelling MS (AERO 2002, Section 5.4). Retirement after 20, 25 and 30 years was considered, and was also differentiated according to whether the costs of early retirement are borne by individual states or by airline companies. According to the assumption made, there arises an avoidance potential of 45 to160 million t CO_2 eq. in the year 2010 and of 50 to 200 million t CO_2 eq. in 2020. Realization of this avoidance potential is coupled, however, with relatively high costs.

6.9 Result

Analysis of the different options for the reduction of the greenhouse gas impact of aviation has shown that there are a number of measures with which this climatic impact can be reduced. The options differ, however, not only with regard to potential and specific costs, but also with respect to the timing of their realization. Certain measures can be realized in the short to medium term; others require a longer realization period. Table 39 reviews different aspects of individual reduction options.

Table 39: Review of avoidance potentials

Avoidance options	Reduction of the climate impact of	Realization	Potential in million t		Specific avoidace cost/ comments
			CO_2 eq.	CO_2	
Flight route optimization	C & CS, NO_x	1992	37- 470		< 3 US$/t CO_2 eq.
		2010	80 - 1,100		< 3 US$/t CO_2 eq.
		2020	90 - 1,350		< 3 US$/t CO_2 eq.
CNS/ATM	CO_2, NO_x, H_2O	2010	30 - 130	20 - 80	
Flight management	CO_2, NO_x, H_2O	2010	30 - 50	30 - 40	
Improved capacity utilization	all		low	low	Trade-off with comfort & Service
Maintance	CO_2, NO_x, H_2O		low - medium	low - medium	Low-cost
Engine optimization					
Increased NO_x reduction	CO_2, NO_x, H_2O	2010	3 - 20	0 - 11	Trade-off between NO_x and CO_2
		2020	35 - 150	0 - 80	Trade-off between NO_x and CO_2
Re-engining	CO_2, NO_x, H_2O	Medium - long term	medium - large		High-cost
Improvement of aerodynamics	CO_2, NO_x, H_2O	Short term	< 10	< 10	
Early retirement	CO_2, NO_x, H_2O	2010	45 - 160	30 - 95	High-cost
		2020	50 - 200	30 - 115	High-cost
C: Contrails, CS: Cirrus cloueds					

Source: Öko-Institut calculations

As a result of measures taken in aviation, by 2010 between 200 and 1,470 million t CO_2 eq. could be saved, and by 2020 between 390 and 1,900 million t CO_2 eq. The respective upper limits involve uncertainties, however, since around two-thirds are to be explained by the avoidance of contrails and cirrus clouds. The reduction potential for CO_2 emissions is only 90 to 235 million tonnes in 2010 and 325 million tonnes in 2020.

A good third of CO_2 reduction potential could be realized through the early retirement of aircraft. This measure is, however, comparatively costly. It is basically only attractive when prices for emission rights lie between 10 and 50 US$/t CO_2 eq.

If, however, the entire climatic impact of aviation is covered, between at least one-third and two-thirds of reduction potential could be exploited through the avoidance of contrails and cirrus clouds. In contrast to the early retirement of aircraft, with this measure the costs are relatively low. Even on the basis of unfavourable assumptions, costs for the avoidance of contrails should hardly exceed 3 US $/t CO_2 eq.; that is, below the prices that are currently expected for reduction credits from CDM projects (3-5 US §/t CO_2 eq.).

However, in estimating avoidance costs for contrails, a number of simplifying assumptions have been made. For instance, an extension of flight duration and, where appropriate, the resultant costs have been ignored. This appears to be justified, however, since model analysis (Section 1.1.1.1) has shown that with a reduction in cruise altitude flight duration is extended only for a proportion of flights, and that with some flights, flight duration is even shortened. Furthermore, contrails do not, as a rule, arise over the entire flight route, so that possible extensions of flight duration could be limited by reducing flight altitude only for those sections of flight routes where contrails occur. Ultimately, it cannot be ruled out, that in the case of some flights considerable extensions of flight duration will occur. On average, the effect on flight duration is actually small and can therefore be disregarded. The prerequisite for this, however, is that flight altitudes are optimized from a climate point of view within the scope of a free flight concept and can be selected in a flexible manner.

Furthermore, it has been assumed that the greenhouse gas impact of aviation can be converted into CO_2 equivalents. This is indispensable within the framework of open emissions trading; for otherwise, aviation emission rights would not be comparable with emission rights and reduction credits under the Kyoto Protocol and therefore not tradable between systems. The conversion of the greenhouse impact of aviation was initially based on the radiative forcing of individual substances that have an impact on the greenhouse effect. By means of the so-called radiative forcing index, the radiative forcing of contrails can be compared with the radiative forcing of CO_2, for example. Radiative forcing, however, does not yet take into account the differing residing times of climate-impacting substances in the atmosphere. Analyses by the IPCC (1999) for 1992, 2015 and 2050 have shown that the radiative forcing of contrails was greater than that of CO_2 at each of these points in time; although with contrails, on account of their short residing time, only the radiative forcing of each of these years was considered, whereas in the case of CO_2, the radiative forcing of emissions accumulated since 1950 were considered (Section 3.1.1). Despite their short residing time, contrails and cirrus clouds can be converted with this method into CO_2 equivalents.

Transaction costs for the monitoring and control of requirements for the avoidance of contrails (and cirrus clouds) by air traffic control have also been disregarded, since no relevant data is available. In the end, however, these costs should be comparatively low, since data required for monitoring and control is to a large extent already gathered and recorded on a continuing basis. New methods for evaluating such data would be necessary, which promptly inform not only pilots, but also air traffic control, whether requirements are being complied with.

Despite necessary simplification due to the limited availability of data, the specific costs of avoiding contrails of up to 3 US $/t CO_2 eq. should represent the upper limit of avoidance costs. In this connection, it has been assumed that either cruise altitude has to be reduced by 4 flight levels, although in certain cases contrails can be avoided by the reduction of cruise altitude by just one flight level, or the whole flight has to be conducted 3 flight levels lower, although contrails only arise along half of the flight route. If one assumes, more realistically, that flight altitude has to be reduced by only 3 levels, and that flight altitude is reduced only for that section of the flight route where contrails arise, then one arrives at specific avoidance costs of the order of 2.70 US $/t CO_2 eq.[81]

At the same time, the impact of cirrus clouds is not considered at all, due to current scientific uncertainties concerning their effect. If one assumes, however, that through

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[81] Additionally, through the reduction of cruise altitude – as it were, as a positive side effect of this avoidance strategy – the cosmic burden of radiation for crew and passengers will be cut. This should be of interest, above all, to crews, since the radiation accumulated in the course of their working lives could be considerably reduced.

the avoidance of contrails cirrus clouds can also be avoided, and that their impact is only 22% of that, which is regarded as their maximum impact, then one arrives at specific avoidance costs of the order of 0.50 US $/t CO_2 eq.

All in all, these considerations show that the avoidance of contrails, and possibly also cirrus clouds, according to the present – doubtless still limited – state of research, represents a very low-cost avoidance option for aviation, which can well compete with the prices of CDM reduction credits. Contrary to the widespread opinion, that within the framework of an open emissions trading system aviation will presumably emerge only as a purchaser of emissions rights and reduction credits, these considerations show that low-cost reduction potentials can also be exploited in the aviation industry itself – at least in so far as the entire climatic impact of aviation is considered.

If, however, CO_2 is selected as the sole basis for assessment for an emissions trading system for aviation, the avoidance potentials in aviation will be not only relatively limited, but also, for the most part, of a very high cost. In this case, aviation should emerge predominantly as a purchaser of emission rights and itself contribute to emission reductions to only a relatively insignificant extent.

7. Conclusions

According to IPCC estimates, international aviation contributes about 3.5% to global warming. If the growth in aviation continues to grow at 4% per year, as in the 1990s, the share of international aviation in the greenhouse effect will be higher in 2010 than Germany's share in global warming. Nevertheless, the greenhouse impact of aviation is not yet covered by the Kyoto Protocol, although the ICAO is required under Article 2.2 of the Kyoto Protocol to limit and reduce greenhouse gas emissions from bunker fuels. Against this background, the introduction of emissions trading for international aviation is currently being discussed in the environmental committee of the International Civil Aviation Organization ICAO (Committee on Aviation Environmental Protection CAEP).

In this study, the possibilities and design options for an emissions trading system for international aviation have been investigated in detail. To begin with, the climatic impact of aviation, which is considerably more complex than the climatic impact of ground-level emissions from stationary or mobile sources, has been closely examined. In aviation, apart from carbon dioxide (CO_2), the greenhouse impacts of water vapour, of the reaction products of nitrogen oxide (ozone and methane), of contrails and cirrus clouds and, at a subsidiary level, of soot and sulphate aerosols have all to be considered. The development mechanisms and effects of these different greenhouse-impacting substances have not yet been conclusively explained scientifically.

It has already been agreed at a scientific level, however, that the total greenhouse impact of aviation is caused only partially by CO_2 emissions. Depending on the extent of climatic impact that is attributed to cirrus clouds, the share of CO_2 in the climatic impact of aviation in 1992 was between 21 and 58 per cent. Therefore, even when aviation-related cirrus clouds are completely disregarded, two-fifths of the total climatic impact is brought about by other substances.

With regard to the design of an emissions trading system, it is especially important that trade-offs take place between individual greenhouse-impacting substances. When engines are optimized solely in respect of CO_2, for instance, this can lead to an increase in engine emissions of NO_x and, as a result, to increased formation of ozone. Moreover, fuel consumption and CO_2 emissions could be reduced through a further increase in flight level, as a result of which additional contrails and cirrus clouds could develop. The greenhouse impact of aviation will only be reduced, however, when these trade-offs are taken into consideration and the net effect is clearly negative. If CO_2 is selected as the sole basis for assessment for the emissions trading system, the end result could be an increase in climatic impact. An emissions trading system based solely on CO_2 must therefore be accompanied by other measures, such as sufficiently-restrictive limit values for NO_x emissions, or the restriction of cruise altitude during sections of flight routes where contrails and cirrus clouds could develop.

By contrast, with a basis for assessment that covers the greenhouse impact of aviation as a whole, incentives for reducing the greenhouse impact would be properly applied, so that there would be no need for accompanying measures. Even when transaction costs in this case are higher than with an emissions trading system based purely on CO_2, additional costs as a whole should be relatively low, since much of the required data is already recorded and documented. From that point of view, the development of an emissions trading system founded on a comprehensive basis for assessment is both feasible and advisable.

The question arises, apart from that concerning the basis for assessment, whether the emissions trading system should be introduced solely for aviation (closed system), or whether trading with other sectors should be permitted (open system).

An open trading system for aviation must be designed in such a way, that the tradability of emission rights from the aviation system with emission rights traded under the Kyoto Protocol is guaranteed, since Kyoto trading is the only suitable market place.

A closed system is easier to administer, but it has the disadvantage that only reduction potentials in aviation can be exploited. Once low-cost reduction potentials have been exhausted, further reductions can only be achieved through a reduction in aircraft operation. In such a system, reduction targets cannot be set at such an ambitious level as in an open emissions trading system.

With open emissions trading, however, it has to be ensured that emission rights are comparable. Were CO_2 to be selected as the sole basis for assessment, this comparability would exist, though only at a formal level. But when one tonne of CO_2 is emitted in aviation, this involves a much higher climatic impact than, for example, when one tonne of CO_2 is emitted from a stationary road traffic source. Therefore, direct comparability of emission rights does also not exist in an emissions trading system based solely on CO_2. Against this background, in such a system a basis for assessment should therefore be selected that covers the total climatic impact of aviation, although it would be more difficult to administer and require the development of a gateway mechanism, with which all climate-impacting substances from aviation can be compared with the climatic impact of CO_2.

In designing such a system, the question also arises as to the parties that should be obliged to participate in trading. Although, basically, a number of different parties can be considered (fuel traders, airports, manufacturers etc.), analysis shows that airline companies are the most suitable choice as obligated parties, since their number is small enough to ensure that the cost of control remains within limits, but also large enough to ensure competition on the market for emission allowances and to prevent the development of market power and restrictive practices. Moreover, airline companies have a direct influence on technical and operative reduction options and can therefore react directly to incentive mechanisms newly established by emissions trading.

In principle, an emissions trading system in aviation could be designed in the form of a “cap-and-trade” or a “baseline-and-credit” system. With a cap-and-trade system, the quantity of emission rights is limited in absolute terms, and the contribution of aviation to the reduction of the greenhouse effect is then also clearly defined. With increased aircraft operation, the reduction or stabilization target for aviation – in particular in the case of a closed emissions trading system – would be automatically more ambitious. Prices for emission allowances would also increase. With a baseline-and-credit system, this is not the case. It would be conceivable, that a specific emission factor per passenger kilometre could be laid down. Airlines, whose average emission factor was lower than the baseline, could sell a corresponding number of reduction credits, whereas airlines with a higher emission factor would have to acquire such credits. Because the reduction target is proportionate to aircraft operation, it remains constant – in relative terms – not only with increasing, but also with decreasing aircraft operation. The problem with such a system from an ecological point of view is, however, that the contribution of aviation to the reduction of the greenhouse effect cannot be exactly determined.

As experience with the British emissions trading system has shown, the linking of a cap-and-trade system with a baseline-and-credit system is very difficult to administer. Because emissions trading under the Kyoto Protocol is designed as a cap-and-trade system, the setting up of a baseline-and-credit system for aviation is therefore only possible with a closed emissions trading system. Moreover, with an open emissions trading system there is always the possibility to purchase favourably-priced emission rights from other sectors. Even in the case of increasing demand in aviation, prices for emission allowances would therefore not exceed the level of prices for emission rights traded under the Kyoto Protocol. With an open emissions trading system there is no justification for setting up a baseline-and-credit system.

It has to be assumed with emissions trading in aviation – as is the case with the Kyoto Protocol – that not all states will participate from the beginning in an emissions trading system. It would be possible for emissions trading in aviation to be introduced in those states that have ratified the Kyoto Protocol. Basically, it would not be a problem, if the group of states participating in an emissions trading system for international aviation was not absolutely congruent with the group of states participating in Kyoto trading.

Within the framework of climate negotiations, different options have been identified for the assignment of emissions from international aviation to individual states. The advantages and disadvantages of the different options have been discussed in depth. Analysis has shown that the assignment of emissions on the basis of flight departure and destination is the most appropriate for an emissions trading system, since it is most comparable with the territoriality principle of the Kyoto Protocol and, moreover, limits unwelcome evasion strategies.

In every restricted emissions trading system the question constantly arises of how activities should be treated that extend beyond the limits of the system, or that compete with activities outside the system. It is undisputed that flights between two participating states should be covered in full, in so much as both states are assigned half of the emissions. Flights between two non-participating states would not be covered. For flights between a participating and a non-participating state, at least 50% of greenhouse gas emissions should be assigned to the participating state.

In this connection, the registration of a flight relation should be regardless of whether an airline has its domicile in a participating or in a non-participating state. For example, where a flight is operated between two participating states by an airline that has its domicile in a non-participating state, this flight is covered in full. In the case of the free issue of emission rights, this airline would also have to be allocated emission rights. Within the framework of an emissions trading system, the state of domicile of an airline is therefore irrelevant. Were this not the case, an airline domiciled in a participating state would be at a huge competitive disadvantage, and would have a strong incentive to switch its domicile to a non-participating state. In this way, airlines could evade their commitments at short notice, without the climatic impact of their operations being reduced.

Apart from aspects of efficiency, practicability and compatibility with other regulations, the question of the reduction options that can be exploited is important for the design of an emissions trading system. Here, not only are the potentials important, but also the specific avoidance costs of individual measures.

Basically, aviation-related greenhouse impacts can be reduced by means of technical measures concerning aircraft, through air traffic control measures as well as through operative measures on the part of airline companies.

Technical measures generally involve higher specific avoidance costs, and they mostly require a longer realization period. Besides climate-optimization of engines, which have previously only been optimized in terms of fuel efficiency, technical measures also include the replacement of old engines and the early retirement of aircraft. In addition, the aerodynamics of aircraft in operation can also be improved through the mounting of winglets and the application of riblets, and, as a consequence, fuel consumption and climatic impact can be reduced.

Further reduction options can be exploited through the introduction of new communications, navigation and surveillance systems (CNS) and air traffic management systems (ATM). Through appropriate modifications of CNS/ATM systems (new digital technologies, greater automation, expansion of satellite navigation etc.), routine operations – in particular with regard to flight altitude and speed – could be optimized and delays and congestion in airspace reduced.

Airline companies can also lessen the greenhouse impact of aviation through operative measures, such as improvement in capacity utilization and the reduction of flight weight (for instance, through changed fuel strategies), So long as a basis for assessment is selected that covers the total greenhouse impact of aviation there is also the option of preventing the formation of contrails and cirrus clouds through flight-route optimization to reduce the climatic impact of aviation. For this, it is generally sufficient when cruise altitude is reduced by a few flight levels over sections of routes where cirrus clouds could develop.

This last-mentioned option is of particular importance on account of lower avoidance costs and greater potential. Depending on the assumed impact of cirrus clouds, avoidance costs range from 0.20 to 3 US$/t CO_2 eq. and are therefore below the price that is currently expected for reduction credits from CDM projects. Under very unfavourable circumstances, avoidance costs could reach 10 or 15 US$/t CO_2; but if cirrus clouds are only accounted for with a share of about one-quarter of their currently estimated maximum contribution to the aviation-related climatic impact, then even under very unfavourable circumstances avoidance costs still lie under 2.50 US$/t CO_2. The potential of flight-route optimization from the climate point of view is also dependent on the extent to which cirrus clouds have a climatic impact and their formation can be avoided through flying at lower altitudes. Should cirrus clouds have be considered with their maximum impact, the greenhouse impact of aviation in the year 2010 could be reduced by up 1,100 t CO_2 eq.

Apart from flight-route optimization, a substantial reduction potential could be exploited, above all, through the early retirement of aircraft. In contrast to flight-route optimization, the avoidance costs in this case are considerably higher, at between 10 and 50 US$/t CO_2 eq.

In summary, this study shows that the setting up of an emissions trading system for aviation is basically possible, and represents an option for the fulfilment of commitments under Article 2.2 of the Kyoto Protocol on the limitation and reduction of aviation-related greenhouse gas emissions. It is clear, however, that considerable latitude exists regarding the design of such an emissions trading system. If CO_2 is selected as the sole basis for assessment, the climatic impact of aviation will not be wholly covered and an increase in climatic impact could well be the outcome. In addition, an emissions trading system based solely on CO_2 could itself rule out low-cost reduction potentials exploitable through flight-route optimization. Airline companies would then largely emerge – at least in an open system – as purchasers of emission rights and themselves contribute very little to a reduction in climatic impact. The danger exists, from an environmental point of view, of a grave misdirection of control.

In the medium term, at least, the aim should be to cover the total greenhouse impact of aviation, so that through the emissions trading system comprehensive incentives can be set for the efficient reduction of the greenhouse impact of aviation as a whole.

It is important for the establishment of an emissions trading system with a comprehensive basis for assessment that the state of knowledge is improved concerning the development and causal connections of individual, aviation-related substances that aggravate the greenhouse effect. Knowledge of contrails and cirrus clouds, in particular, should be improved, since in this area substantial, low-cost avoidance potentials can probably be exploited. The aim of such efforts should be to develop practicable and generally recognized methods, with which the greenhouse impact of these substances can be reliably measured and compared.

This must be in the interest not only of governments but also of airline companies. For in the medium term, they must also make a contribution to the reduction of the greenhouse gas effect. Low-cost potentials should not be rejected at the outset, but rather realized as soon as possible.

If, however, an emissions trading system is introduced that is solely based on CO_2, it should be accompanied by measures limiting other greenhouse impacts of aviation; otherwise, the result could be misdirected control and an unintended increase in the climatic impact of aviation. The increase in NO_X emissions should be restricted through appropriate emission-limit values for engines; and the formation of contrails and cirrus clouds should be prevented through a restriction on flight altitude in those regions where contrails and cirrus clouds could in all probability develop.

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