CLIMATE CHANGE

Netherlands Research Programme on Climate Change
Scientific Assessment and Policy Analysis

Climate impacts from international aviation and shipping

State-of-the-art on climatic impacts, allocation and mitigation policies

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This study has been performed in the framework of the Netherlands Research Programme on Climate Change (NRP-CC), subprogramme Scientific Assessment and Policy Analysis, project 'International policies to mitigate environmental impacts of aviation and shipping'

Wetenschappelijke Assessment en Beleidsanalyse (WAB)

WAB is een subprogramma van het Netherlands Research Programme on Climate Change (NRP-CC). Het doel van dit subprogramma is:

- Het bijeenbrengen en evalueren van relevante wetenschappelijke informatie ten behoeve van beleidsontwikkeling en besluitvorming op het terrein van klimaatverandering;
- Het analyseren van voornemens en besluiten in het kader van de internationale klimaatonderhandelingen op hun consequenties.

Het betreft analyse- en assessmentwerk dat beoogt een gebalanceerde beoordeling te geven van de stand van de kennis ten behoeve van de onderbouwing van beleidsmatige keuzes. Deze analyse- en assessmentactiviteiten hebben een looptijd van enkele maanden tot ca. een jaar, afhankelijk van de complexiteit en de urgentie van de beleidsvraag. Per onderwerp wordt een assessmentteam samengesteld bestaande uit de beste Nederlandse experts. Het gaat om incidenteel en additioneel gefinancierde werkzaamheden, te onderscheiden van de reguliere, structureel gefinancierde activiteiten van het consortium op het gebied van klimaatonderzoek. Er dient steeds te worden uitgegaan van de actuele stand der wetenschap. Klanten zijn met name de NMP-departementen, met VROM in een coördinerende rol, maar tevens maatschappelijke groeperingen die een belangrijke rol spelen bij de besluitvorming over en uitvoering van het klimaatbeleid.

De verantwoordelijkheid voor de uitvoering berust bij een consortium bestaande uit RIVM/MNP, KNMI, CCB Wageningen-UR, ECN, Vrije Universiteit/CCVUA, UM/ICIS en UU/Copernicus Instituut. Het RIVM/MNP is hoofdaannemer en draagt daarom de eindverantwoordelijkheid.

Scientific Assessment and Policy Analysis

The Scientific Assessment and Policy Analysis is a subprogramme of the Netherlands Research Programme on Climate Change (NRP-CC), with the following objectives:

- Collection and evaluation of relevant scientific information for policy development and decision–making in the field of climate change;
- Analysis of resolutions and decisions in the framework of international climate negotiations and their implications.

We are concerned here with analyses and assessments intended for a balanced evaluation of the state of the art for underpinning policy choices. These analyses and assessment activities are carried out in periods of several months to about a year, depending on the complexity and the urgency of the policy issue. Assessment teams organised to handle the various topics consist of the best Dutch experts in their fields. Teams work on incidental and additionally financed activities, as opposed to the regular, structurally financed activities of the climate research consortium. The work should reflect the current state of science on the relevant topic. The main commissioning bodies are the National Environmental Policy Plan departments, with the Ministry of Housing, Spatial Planning and the Environment assuming a coordinating role. Work is also commissioned by organisations in society playing an important role in the decision-making process concerned with and the implementation of the climate policy. A consortium consisting of the Netherlands Environmental Assessment Agency – RIVM, the Royal Dutch Meteorological Institute, the Climate Change and Biosphere Research Centre (CCB) of the Wageningen University and Research Centre (WUR), the Netherlands Energy Research Foundation (ECN), the Climate Centre of the Vrije Universiteit in Amsterdam (CCVUA), the International Centre for Integrative Studies of the University of Maastricht (UM/ICIS) and the Copernicus Institute of the Utrecht University (UU) is responsible for the implementation. The Netherlands Environmental Assessment Agency – RIVM as main contracting body assumes the final responsibility.

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Abstract

The international aviation and shipping sectors contribute significantly to climatic change and air pollution. Until now, however, Parties to the United Framework Convention on Climate Change (UNFCCC) have not been able to agree on a methodology to assign responsibility for greenhouse gas emissions from these sectors. In addition, the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) have not been able to agree on any action to ensure effective implementation of mitigation policies to reduce greenhouse gas emissions from international aviation and shipping. However, both ICAO and IMO are investigating several policy options. These options may have implications for monitoring and reporting requirements as well as for the allocation of responsibility for international climate emissions from both sectors. It is for this reason that the present report focuses broadly on all these issues.

Against this background, the Netherlands Research Programme on Climate Change (NRP-CC) asked CE Delft and its partners to provide an assessment of the latest policy developments and scientific findings on the following issues:

- Development of greenhouse gas emissions from international aviation and shipping.
- Impacts on climate; for aviation an update of scientific findings since the 1999 IPCC Special Report on Aviation and the Global Atmosphere.
- Allocation options.
- Development of mitigation policies at global and EU levels for aviation and shipping.
- Data availability and data requirements.

The primary aim of this report is to inform representatives of Ministries of Transport and Environment of the EU-25 and other stakeholders on the latest scientific findings and policy developments with regard to the aforementioned issues. This may facilitate further policy discussions in the UNFCCC, within ICAO, IMO and the EU with respect to monitoring and allocation of greenhouse gas (GHG) emissions from international aviation and shipping and possible policies to mitigate those emissions.

Summary and conclusions

Why this report?

The international aviation and shipping sectors contribute significantly to climatic change and air pollution. Until now, however, Parties to the United Framework Convention on Climate Change (UNFCCC) have not been able to agree on a methodology to assign responsibility for greenhouse gas emissions from these sectors. In addition, the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) have not been able to agree on any action to ensure effective implementation of mitigation policies to reduce greenhouse gas emissions from international aviation and shipping, other than agreeing on best practice in terms of air traffic management operations, in the case of ICAO. However, both ICAO and IMO are investigating several policy options. These options may have implications for monitoring and reporting requirements as well as for the allocation of responsibility for international climate emissions from both sectors. For example, ICAO is currently investigating the possibilities of an open emissions trading system for aviation. Such a system requires a highly accurate and sound monitoring and reporting system based on bottom-up data. This may involve a need for airlines to report their actual fuel consumption and possibly (in the future) other flight parameters providing information on climatic impacts not directly correlated with fuel burn. Implementing an open emissions trading system may also involve allocation of greenhouse gas emissions from international aviation to Parties and/or to entities such as airlines. Consequently, discussions on data availability and the definition of data requirements are tightly bound up with the feasibility and ultimate choice of particular mitigation policies and allocation options. It is for this reason that the present report focuses broadly on all these issues.

Against this background, the Netherlands Research Programme on Climate Change (NRP-CC) asked CE Delft to provide an assessment of the latest policy developments and scientific findings on the following issues:

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- Allocation options (chapter 4).
- Development of mitigation policies at global and EU levels for aviation (chapter 5) and shipping (chapter 6).
- Data availability and data requirements (chapter 7).
- Regional and local air pollution from aviation and shipping (chapter 8).

The focus of this report is on the climate impacts and policies of aviation and shipping. However, at the request of the Netherlands Research Programme on Global Change (NRP-CC) this report also briefly examines, in chapter 8, the impacts of aviation and shipping on regional and local air pollution. The first motive for adding this chapter is policy-makers' fairly limited knowledge of the contribution of shipping and aviation to regional and local air pollution, in particular above land. A second reason is the need for a better understanding of the potential interactions between climate policies and policies addressing other environmental themes within these two sectors.

Aim of this report

The primary aim of this report is to inform representatives of Ministries of Transport and Environment of the EU-25 and other stakeholders on the latest scientific findings and policy developments with regard to the aforementioned issues. This may facilitate further policy discussions in the UNFCCC, within ICAO, IMO and the EU with respect to monitoring and allocation of greenhouse gas (GHG) emissions from international aviation and shipping and possible policies to mitigate those emissions.

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

Emissions aviation and shipping

CO_2 emissions

This study provides an overview of the development of CO_2 emissions of international aviation and marine shipping, based on sales of bunker fuels according to statistics of the International Energy Agency (IEA). Based on these statistics the following observations can be made:

- The share of international aviation and shipping in the national total CO_2 emissions of the EU-25 was, respectively, 2.8% and 3.8% in 2002.
- Global total CO_2 emissions by aviation and shipping increased by 24% and 28%, respectively, in the period 1990-2002. For international aviation this trend was clearly negatively influenced by the decline in the early '90s of the Economies-In-Transition, notably in Russia, and the global decline in air traffic after 9/11 in 2001. However, the situation is now rapidly normalizing and expectations are that the industry will return to growth rates in the order of 4% annually in the decades to come.
- EU-25 total CO_2 emissions by aviation and shipping increased by 60% and 32%, respectively, in the period 1990-2002, with the CO_2 aviation emissions of Poland, Ireland, Spain and the Netherlands showing more than a doubling in that period.
- The CO_2 emissions of non-Annex I countries increased by about 40% and 60%, respectively, for aviation and shipping in the period 1990-2002, with the international CO_2 aviation emissions of Hong Kong, Thailand, Singapore, Mexico and the mainland of the People's Republic of China doubling or tripling in this period.
- After 9/11 and SARS in ASIA, growth of aviation passenger demand is in 2004 beginning to return back to the level of 2000. Global passenger air travel is projected to grow by about 4-5% per year. Based on these demand growth levels, CO_2 emissions from civil aviation are projected to increase by 110% in the period 2002 – 2025.

Contribution of aviation emissions to local air pollution

Growing air traffic and NO_x emissions could contribute to breaches of NO_2 limit values under European regulations designed to maintain local air quality, in particular around major airports. Until recently it was assumed that non-LTO (non-Landing-Take Off Cycle) emissions held little significance for local and regional air quality. Recent studies have shown that aircraft emissions of nitrogen oxides above 3,000 feet over Europe make a small but significant contribution to nitrogen deposition (2-3%) and mean surface ozone (about 1%). Their contribution to exceedance of European air quality standards, such as AOT40 (5-10%) and AOT60 (about 30%) is more significant. In the future, when background tropospheric ozone levels are expected to rise and surface emissions have been reduced, their importance may grow further.

Impacts: recent scientific results

Impacts of aviation emissions

The effects of aviation emissions on radiative forcing were estimated in the IPCC Special Report on Aviation and the Global Atmosphere [IPCC, 1999]. Recent research results indicate that some of the forcing estimates provided by IPCC [1999] need to be revised:

- The CO_2 forcing due to aviation has increased as a result of increased fuel usage between 1992 and 2000.
- The radiative forcing of contrails is presently thought to be a factor of 3-5 less than the figure given in IPCC [1999].
- Radiative forcing from enhanced cirrus cloud cover is thought to be the potentially largest single effect of aviation on climate. New studies since the IPCC Special Report indicate that the effect of aviation on cirrus clouds appears to be at the high end of the range estimated by IPCC [1999], or greater. This would imply that the forcing impact of enhanced cirrus could be up to 2 times that of the CO_2 emitted by aviation.
- Recent model calculations suggest that the impact of aviation emissions of nitrogen oxides (NO_x) on methane (CH_4) concentrations is about a factor of 2 lower than estimated in IPCC [1999]. The ozone (O_3) forcing is similar to that estimated in IPCC 1999.
- In spite of the suggested revisions for the individual gases, the best estimate for the overall radiative forcing by aviation for 2000 remains close to the value given by IPCC [1999]. This overall estimate does not include enhanced cirrus cloud cover because – although knowledge has improved considerably since 1999 – scientific understanding of this effect is still ‘very poor’ and no best estimate is available, only a range (as was the case for the IPCC report).
- According to a central estimate in that IPCC Special Report, the full radiative forcing impact of aviation is about 2 to 4 times greater than that of its CO_2 emissions alone.

Effects on climate of shipping emissions

The contribution of CO_2 emissions from shipping and their effect on radiative forcing are of the same order of magnitude as those of aviation. According to the only model study performed to date, the radiative forcing caused by the increase in ozone and the reduction in methane due to nitrogen oxide emissions by ships, although more uncertain, is also of the same order of magnitude as that due to aviation. The effect on radiative forcing of particle emissions by ships (notably black carbon) and the resulting changes in cloud properties remain to be quantified.

Responsibility for international emissions: Allocation

Allocation is defined in this study as the inclusion of international aviation and maritime transportation emissions in the overall greenhouse gas inventories of nations that are Parties to the UNFCCC. This means that these Parties are *responsible* for these emissions (and thus says nothing about a cap).

Non-allocation (i.e. a commitment structure under which legal entities are directly accountable to an international body such as IMO or ICAO) is theoretically conceivable, but of limited practical relevance, as it would require considerable legal changes to the UNFCCC and establishment of institutional capacity to administer the emissions, i.e. distribution, monitoring and verification procedures, enforcement and sanctions, etc., at a supranational level. To perform this function, the legal position of ICAO and IMO in relation to the UNFCCC would need to be resolved, moreover.

Based on an assessment of policy documents and the literature, we conclude that there are practical, legal and political grounds for supporting allocation among countries. However, a decision on allocation to countries should only be taken after or in combination with decisions on coordination and type of mitigation policies. First, because all allocation options will lead to allocation of emissions to a given country of emissions caused by airline or shipping companies from other countries over which the country has limited regulatory control. Second, unilateral regulatory mitigation policies will often lead to a deterioration of the competitive position of the country's own airlines or economy. An agreement on international cooperation with regard to implementation of a regulatory scheme under ICAO or at least EU guidance appears to be a basic condition for allocation of international emissions between countries.

The UNFCCC selected 5 allocation options for further investigation out of a potential 8 candidate methods. Based on a review of the literature and an assessment based on criteria of 'data availability', the 'Polluter pays principle' (PPP) and 'evasion', we conclude that only option 5 (destination/arrival) is feasible for aviation. Option 4 (nationality of airline) might only be feasible under a global scheme.

With regard to shipping, there is currently no feasible allocation option. Option 3 (country where bunker fuel is sold) appears to be the most practical option from the point of view of data availability, but does not meet the other two criteria ('PPP' and 'evasion') considered in this study and is thus not feasible. The other allocation options are not currently viable, owing to a lack of accurate monitoring methodologies and data sources. Following up on this conclusion would imply that research activities should be instigated to arrive at accepted and robust bottom-up methodologies for calculating CO_2 emissions from ships.

Mitigation policies

Aviation

Up until now the International Civil Aviation Organization has not been able to agree on any action to ensure effective implementation of mitigation policies aiming at reducing greenhouse gas emissions from international aviation However, ICAO continues to study policy options to limit or reduce the environmental impact of aircraft engine emissions and develop concrete proposals and will provide advice as soon as possible to the Conference of the Parties of the UNFCCC, placing special emphasis on the use of technical solutions while continuing its consideration of market-based measures. At its 35th Session in October 2004, the ICAO Assembly adopted, with regard to market-based measures to address aircraft engine emissions, among other decisions, the following substantive revisions that supersede the previous Resolution A33-7:

1. **Voluntary measures**: States are encouraged to limit international aviation emissions, in particular through voluntary measures and by making use of guidelines provided by ICAO.
2. **Emission-related levies**: States are urged to refrain from unilateral implementation of greenhouse gas emission charges [prior to] the next regular session of the Assembly in 2007. In addition, studies on such charges should continue, with the aim of completion by the next regular session of the Assembly in 2007.
3. **Emissions trading**: Further development of an open emissions trading system[1] for international aviation should be continued. This work should focus on two approaches:
    a. ICAO would support the development of a voluntary trading system that interested Contracting States and international organizations might propose.
    b. ICAO would provide guidance for use by Contracting States, as appropriate, to incorporate emissions from international aviation into Contracting States' emissions trading schemes consistent with the UNFCCC process.

With regard to emissions trading, the EU supports approach b related to the UNFCCC process as the only effective solution consistent with the EU emissions trading scheme coming into effect on 1 January, 2005. In this option ICAO would provide guidance for use by States, as appropriate, to incorporate emissions from international aviation into States' emissions trading schemes consistent with the UNFCCC process. As part of an ongoing process, the European Commission intends to launch a study to investigate the feasibility of including aviation in the EU emissions trading system.

Studies show that introducing a tax on aviation fuel at the European level would give rise to considerable distortions in competition and may need amendment of bilateral air service agreements. En-route emission charges are also under consideration, *inter alia* on the basis of a study finalized in 2002. The intended

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[1] 'Open' emissions trading means that participants in an international aviation trading scheme must be able to buy and/or sell emission allowances and so on outside the aviation sector.

emissions trading study would complete the existing knowledge base of the European Commission.

What is the current position of the EU, though?
The EU has repeatedly announced it intention to implement measures of its own should consensus not be reached within ICAO. The EU is not currently focusing on any specific measures, but keeping all options open.

Full climate impact of aviation
One major difficulty in developing a mitigation policy for aviation is how to cover the non-CO_2 impacts from aviation. IPCC [1999] estimates these effects to be about 2 to 4 times greater than that of CO_2 alone. This means the environmental integrity of any mitigation policy depends on the extent to which these effects are also taken into account.

Shipping
In the past few years, the International Maritime Organization (IMO) has started research and discussions on the mitigation of greenhouse gas emissions by the shipping industry. The potential of technical and operational measures was explore and several mitigation policies were presented and outlined. To support this work, IMO has adopted a strategy on the issue, focusing mainly on further development of a CO_2 emission indexing scheme for ships[2] and further evaluation of technical, operational and market-based solutions. However, even though there has been progress on further investigation of these issues, discussions within IMO have currently come to a stand-still because of a difference of opinion between several members. One major obstacle is that there are different views about whether or not GHG policies within IMO should differentiate between Annex I and non-Annex I countries.

In parallel to the IMO initiatives, the EU is also working on development of policies for emission reductions in shipping, including CO_2 emissions. A strategy was agreed on, in which, among other things, Member States are encouraged to support the IMO in its work to limit GHG emissions in shipping. Furthermore, it was stated that the Commission will consider taking action at EU level if the IMO has not adopted a concrete, ambitious strategy on GHG reduction by 2003. At the end of 2003, the Council of the European Union also supported the development of a strategy by IMO and urged EU Member States to submit concrete proposals to IMO vis-à-vis such a strategy. Furthermore, the need was recognized to investigate specific EU actions with respect to GHG emission reduction in shipping.
In 2003, a research study was commissioned by the EU to investigate the possible effects and feasibility of various market-based instruments in shipping. Although this study focused mainly on the reduction of NO_x and SO_2, a follow-up study that is expected to be commissioned in the near future will explicitly look at CO_2 emissions as well.

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[2] The basic principle of a CO_2 emission index is that it describes the CO_2 efficiency of a ship, i.e. the CO_2 emission per tonne cargo or passenger per nautical mile.

Data needs and availability

Based on an assessment of required and available data, the following conclusions can be drawn:

- Both ‘allocation’ of the responsibility of international climate emissions to Parties and establishing an adequate monitoring and enforcement system for polic implemented require *accurate* data on current flight or navigation operations.
- Flight movement data are already available in the aviation sector, but need to be reported. The most attractive option for arriving at accepted and specific emission figures for individual aircraft would be to base the CO_2 emission on the trip fuel consumed, which most airlines are currently obliged to register in their weight and balance documentation. In the United States actual fuel consumption data are already available as all airlines of a certain size are required by law to report their operating statistics to the Department of Transportation (the so-called ‘Form 41 arrangement’).
- We recommend that other relevant authorities establish reporting requirements similar to those applied in the US; to be similar, these would need to be enforceable regulatory measures. The oft-heard objection concerning confidentiality of airline fuel consumption data can be addressed in the same way as in the case of fuel data reported for stationary sources in National GHG Inventories, i.e. airline companies report disaggregated data to the monitoring authorities, with these authorities reporting only aggregated data to the public domain.
- In the shipping sector, the system of bunker delivery notes that is to be introduced next year can be expected to provide comprehensive and reliable data on the total amount of bunker fuels tanked and consumed, for all vessels larger than 400 GT. However, even though bunker delivery notes may provide very valuable data on *total* bunker fuels tanked and consumed, they cannot be used to specify the fuel used on specific voyages or in specific regions or time periods, since it is common shipping practice for various voyages to be made between bunkering stops.
- Data on ship movements of commercial vessels > 100 GT (which covers the great majority of vessels engaged in international shipping), including their daily position, are registered by Lloyds Marine Intelligence Unit and are commercially available. However, this database does not cover ferry movements, nor does it record actual fuel consumption or parameters relevant to fuel efficiency such as speed and energy produced by auxiliary engines.
- Statistics on bunker fuel sales cannot form an adequate database for monitoring protocols for policy instruments like emission trading or charges that are indexed directly to aircraft or ship emissions. The main reason is that the amount of bunker fuel sold is not necessarily equal to the fuel consumed on the trip in question. Secondly, even if the bunker fuel statistics of individual states were improved and harmonized, it remains doubtful whether these could serve as a sufficiently accurate basis for emission-based instruments. Thirdly, bunker fuel statistics are inappropriate if a basis for assessment is adopted that goes beyond carbon dioxide and water vapor, as emissions that are not necessarily proportional to the amount of fuel consumed but depend

on specific trip conditions – aircraft or vessel type, turbine engine, route, weather etc. – cannot be registered. Bunker fuel statistics might be used, however, to verify quantified emissions based on operational (bottom-up) data, but are nonetheless insufficiently accurate for detailed emission reporting.

1 Introduction

1.1 Background and objectives

The international aviation and shipping sectors contribute significantly to climatic change and air pollution. Up until now, Parties to the United Framework Convention on Climate Change (UNFCCC) have not been able to agree upon a methodology to assign responsibility for greenhouse gas emissions from international aviation and shipping.
In addition, the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO) have not been able to agree upon any action to ensure effective implementation of mitigation policies to reduce greenhouse gas emissions from international aviation and shipping, other than agreeing on best practice in terms of air traffic management operations, in the case of ICAO.
The slow pace of developments on these issues at the global level is due to several factors, including: (i) the complexity of trans boundary economic activities of transport, (ii) different interests and views of Parties to the UNFCCC, (iii) the sector-specific perspective prevailing in ICAO and IMO, and (iv) data availability and difficulties in finding accurate methods for quantifying greenhouse gas emissions from aviation and shipping.

Against this background, the Netherlands Research Programme on Climate Change (NRP-CC) asked CE Delft to provide an assessment of the latest policy developments and scientific findings on the following issues:

- Development of greenhouse gas emissions from international aviation and shipping (chapter 2).
- Impacts on climate; for aviation an update of scientific findings since the 1999 IPCC Special Report on Aviation and the Global Atmosphere (chapter 3).
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1.2 Aim of this report

The primary aim of this report is to inform representatives of Ministries of Transport and Environment of the EU-25 and other stakeholders on the latest scientific findings and policy developments with regard to the aforementioned issues. This may facilitate further policy discussions in the UNFCCC, within ICAO, IMO and the EU with respect to monitoring and allocation of greenhouse gas (GHG) emissions from international aviation and shipping and possible policies to mitigate those emissions.

1.3 Organization of the study

CE Delft and its partners were commissioned to carry out this study by the Netherlands Research Programme on Climate Change (NRP-CC). Analysis of the climate impacts of aviation was carried out by the Royal Netherlands Meteorological Institute (KNMI) together with David Lee of the Manchester Metropolitan University (chapter 3 and Annex A to this report). KNMI also analyzed the climate impacts of shipping. Mr. Jos Olivier of the Netherlands Institute for Public Health and the Environment (RIVM) provided valuable technical contributions to chapter 2 (emissions data) and chapter 7 (data availability).

Notwithstanding the cited support and (technical) contributions, the contents of this report are the sole responsibility of CE Delft and do not necessary reflect the view of the EU, the Netherlands or any other country.

1.4 Political and institutional context

This section briefly discusses the role of the main institutions working on the topic of this study. Specific policy developments, i.e. actions, decisions or statements by these institutions, are discussed in the following chapters.

At the international level, work on concepts for reducing the climatic impact of aviation and shipping has proceeded at the United Nations through the Framework Convention on Climate Change (UNFCCC) and at the International Civil Aviation Organization (ICAO)[3] and the International Maritime Organization (IMO)[4].
The environmental activities of these two specialized UN agencies, ICAO and IMO, are undertaken largely by the Committee on Aviation Environmental Protection (CAEP) and the Marine Environment Protection Committee (MEPC), respectively.

At the Third Conference of Parties to the Framework Convention on Climate Change in 1997, at which the Kyoto Protocol was drawn up, agreement could not be reached on how emissions from international aviation and shipping should be allocated among countries. The national inventories of annual national greenhouse gas emissions reported by Parties to the UNFCCC include only emissions from *domestic* air and marine transport. Emissions associated with fuel used for international transport activities are to be reported separately. As a result, emissions from international aviation and shipping are not included in the emission targets for the period 2008-2012 set under the Kyoto Protocol.

The Subsidiary Body for Scientific and Technical Advice (SBSTA) of the UNFCCC is working on methods to improve reporting on bunker fuel emissions, as well as on concepts for incorporating these emissions in national inventories of greenhouse gases. SBSTA, ICAO and IMO cooperate, through joint participation in expert meetings, on methodological issues relating to improved reporting and the exchange of information on their activities concerning international aviation and shipping emissions.

Besides the work of SBSTA, article 2.2 of the Kyoto Protocol states that '*Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from international aviation and marine bunker fuels, working through the International Civil Aviation Organization (ICAO) and the International Maritime Organization (IMO)*

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[3] The ICAO is a specialized agency of the United Nations 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.

[4] The IMO is a specialized agency of the United Nations responsible for measures to improve the safety and security of international shipping and to prevent marine pollution from ships. It was established by means of a Convention adopted under the auspices of the United Nations in Geneva in 1948. IMO's governing body is the Assembly, which is made up of all 164 Member States and normally meets once every two years. It adopts the budget for the next biennium together with technical resolutions and recommendations prepared by subsidiary bodies during the previous two years. The *Council* acts as governing body in between Assembly sessions. It prepares the budget and work programme for the Assembly. The main technical work with regard to mitigation of climatic impacts from international shipping is carried out by the Marine Environment Protection Committee (MEPC).

respectively' [UNFCCC, 1997]. As yet, neither the ICAO nor the IMO Assembly have been able to agree on any action to ensure effective implementation of mitigation policies aimed at reducing greenhouse gas emissions from international aviation and shipping. However, both ICAO and IMO are investigating several policy options. These options may have implications for monitoring and reporting requirements as well as for the allocation of responsibility for international climate emissions from both sectors. For example, ICAO is currently investigating the possibilities of an open emissions trading system for aviation. Such a system requires a highly accurate and sound monitoring and reporting system based on bottom-up data. This may involve a need for airlines to report their actual fuel consumption and possibly (in the future) other flight parameters providing information on climatic impacts not directly correlated with fuel burn. Implementing an open emissions trading system may also involve allocation of greenhouse gas emissions from international aviation to Parties and/or to entities such as airlines. Consequently, discussions on data availability and the definition of data requirements are tightly bound up with the feasibility and ultimate choice of particular mitigation policies and allocation options. It is for this reason that the present report focuses broadly on all these issues.

2 Emissions

2.1 Introduction

This chapter discusses trends in fuel consumption and CO_2 emissions from global international marine and air transport and the contribution of individual countries and regional groupings according to the Kyoto Protocol (e.g. Annex I countries, essentially the industrialized countries (OECD and Economies-In-Transition, EIT, i.e. former USSR and Eastern European Countries)), for which purpose IEA statistics have been used. To interpret the quality of the data, however, it is essential to know whether and how a distinction has been made between domestic and international transport, as many OECD countries do not appear to comply with internationally used definitions, in particular for aviation. This issue of consistency and comparability will be discussed separately in chapter 7. Shipping and aviation emissions of the other *direct* greenhouse gases methane (CH_4) and nitrous oxide (N_2O) are not discussed here, being negligible compared with the CO_2 emissions of these sectors [see EDGAR 3.2 data, documented in Olivier and Berdowski, 2001; Olivier *et al.*, 2002].

The UNFCCC and Kyoto Protocol employ the IPCC definitions of domestic and international transport [IPCC, 1997], which are explained in more detail in the IPCC Good Practice Guidance [IPCC, 2000; see tables 2.8 and 2.9 for the distinction between domestic and international marine transport and aviation]. Elements discussed in these guidelines are: 1) destination of trips, 2) allocation of fisheries, and 3) allocation of military transport.

The definition used by energy statistical offices such as the IEA and the IPCC/UNFCCC for reporting emissions from ships and aircraft engaged in international transport, i.e. departing from a domestic location and having as their destination a location in another country and irrespective of where the ship or airline is registered, seems straightforward. Moreover, the UNFCCC/IPCC/IEA reporting guidelines request countries to report *fishing activities*, be they inland, coastal or ocean, under the *domestic* category ‘agriculture’. UNFCCC/IPPC guidelines report all military emissions under the domestic subcategory ‘other’ (CRF 1.A.5), whereas IEA statistics report *military shipping* activities under *international* maritime bunker fuels and *military aircraft* activities under *domestic* air transport. (All other military fuel use, i.e. for stationary sources, is to be reported domestically under ‘non-specified other sector’, as do the UNFCCC/IPCC guidelines). In addition, the UNFCCC/IPCC guidelines require military ‘multilateral operation’ activities to be reported as a separate ‘Memo item’, i.e. under neither domestic activities nor international bunkers.

These definitions are mainly based on the definitions used by the IEA for a long time for their international energy statistics surveys of OECD countries, which also specify where to report military transport activities [IEA, 2004a]. However, according to international statistics agencies such as the IEA, it is often the case that different definitions are used by individual countries. In addition, ICAO uses a somewhat different definition. In the IEA statistics on the international and domestic aviation of non-OECD countries, no distinction is made between domestic and international flights.

2.2 Aviation

Below we describe trends in aviation emissions, compiled from the following data sources:

1 IEA Bunker fuel statistics (Section 2.2.1).
2 Emission inventory models (Section 2.2.2).

2.2.1 Emissions based on bunker fuel sales

The bulk of fuel sold for international transport is concentrated in a limited number of countries. For both shipping and aviation 50% of the global total is sold by the top-5 countries. Aviation bunker sales, as recorded by the IEA, are somewhat more concentrated than marine bunkers:

- 2/3 of the global total is accounted for by the top-10 and the top-15 countries, respectively;
- The top-25 countries account for about 90% and 80%, respectively.

During the period 1990-2002, global total CO_2 emissions from international bunkers increased by 24% and 28%, respectively, for aviation and marine. For international aviation, however, this trend is clearly negatively influenced by the decline in the early '90s in the Economies-In-Transition, notably in Russia, and the global decline in air traffic after 9/11 in 2001. It should also be noted that the USA reported large changes in 1990, owing to a change in data collection and reporting methodologies [IEA, 2004a]. With regard to the trend in the preceding two decades, i.e. the period 1970-1990, we observe a 11% increase in international marine bunker emissions and an increase of about 75% in international aviation emissions (figures 1 and 2). The share of the EU-25 in 2002 international bunker emissions is about 30% for both shipping and aviation.

table 1 Trends in CO_2 emissions from bunker fuels sold to international aviation, 1990 to 2002, worldwide, in Annex I, Annex B and non-Annex I countries and in the EU-25

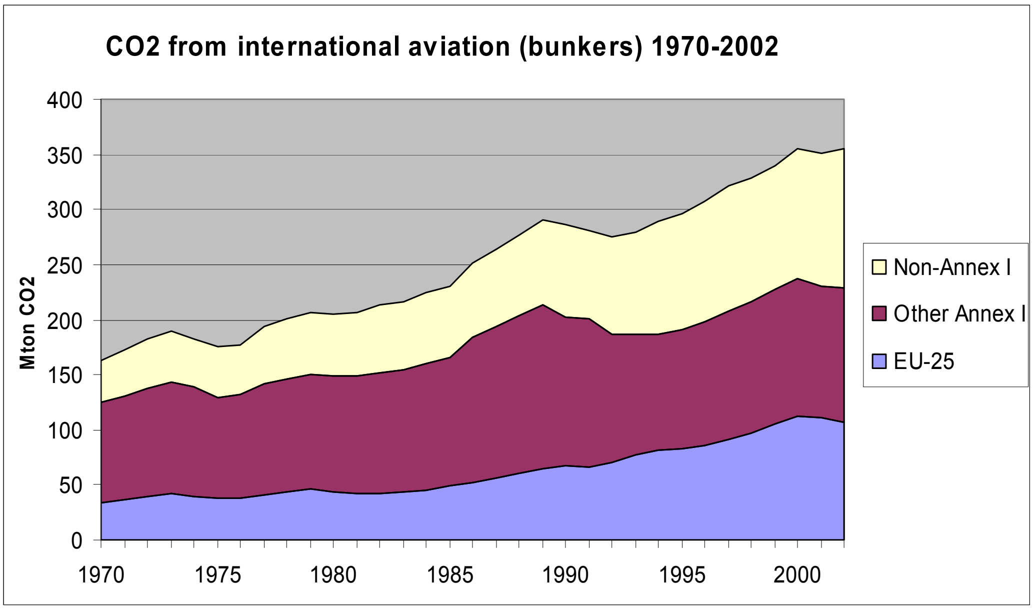
Country	1990	2002	Diff 02/90	Share in international aviation
	[Mt]	[Mt]	[%]	[%]
World	286	354	24%	100%
Annex I [1]	195	228	17%	64%
Annex B [2] – USA and Australia	151	169	12%	48%
EU 25	67	107	59%	30%
Non-Annex I	91	126	38%	36%

Source: Olivier and Peters [2004], data based on IEA [2004c].

1 Annex I countries in UNFCCC ('industrialized countries' plus Turkey): OECD-24 plus EIT (Economies In Transition (former USSR countries and Eastern European countries)).

2 Countries with an emission target under the Kyoto Protocol: Annex I countries excluding Turkey and Belarus. The USA and Australia have indicated that they will not ratify the Kyoto Protocol.

figure 1 Trends in global CO_2 emissions from international aviation, 1970-2002 [IEA, 2004c]



Since 1990 the amount of international aviation fuel sold by Annex I countries has increased by about 17%. The USA, the world's #1 with a share of 14%, shows an increase of about 30%, but the amount sold by Russia, the world's #2 with an 8% share in 2002, has decreased by 1/3 since 1991. Overall, the group of EU-25 countries shows an increase of about 60% since 1990, and the Netherlands and Spain (see also table 1) more than a doubling. In the period 1990-2002, sales by non-Annex I countries increased by about 40%, however. Sales by Hong Kong, Thailand, Singapore, Mexico and the mainland of the People's Republic of China in 2002 were double or triple the 1990 level (figure 2).

figure 2 Trends in international aviation CO_2 emissions of Top-10 countries, 1990-2002 [IEA, 2004c]

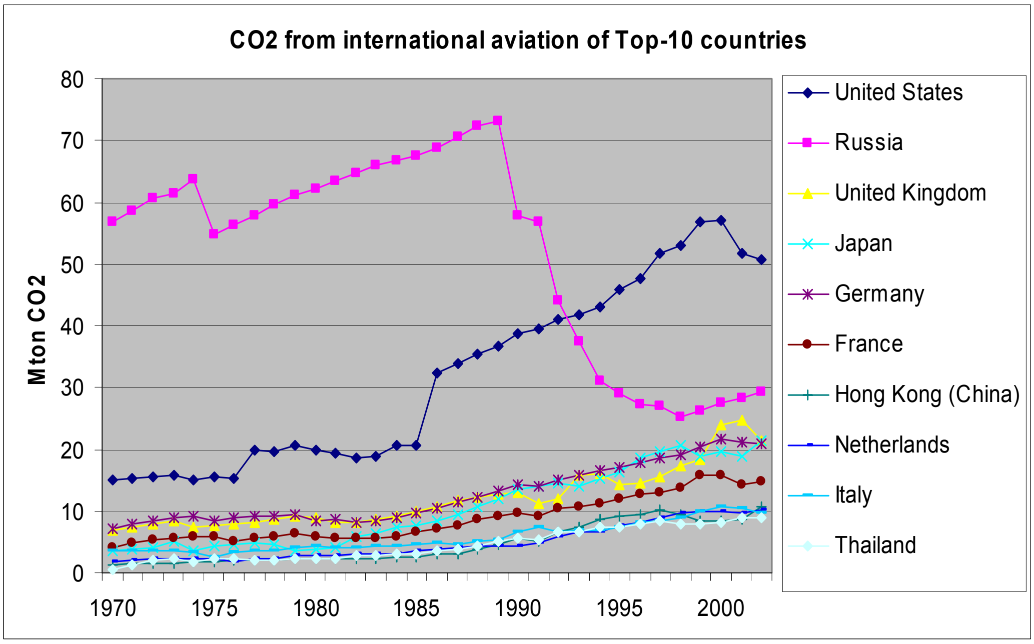


Table 2 reviews CO_2 emissions from international bunker fuels for the 25 EU Member States. In 2002 international aviation accounted for 2.8% of the total national CO_2 emissions of the EU-25. With a few exceptions, this share is below 5% for most EU Member States. A second point to be noted from the table is that the international aviation CO_2 emissions of certain EU countries have increased by over 100% since 1990 (Spain, Poland, Ireland, the Netherlands), while other countries show only minor growth or even a decrease.

table 2 CO_2 emissions from bunker fuels sales to international aviation in EU Member States (EU-25)

	CO_2 emissions from international aviation	International share in national total aviation emissions	Difference, 1990-2002, in CO_2 emissions from international aviation	Total national CO_2 emissions[5]	Share of international aviation in total national CO_2 emissions
	Sales 2002	Sales 2002			
	[Mt]	[%]	[%]	[Mt]	[%]
Austria	1.5	93%	80%	66.0	2.3%
Belgium	3.8	99%	30%	134.4	2.8%
Cyprus	1.0	100%	28%	6.8	14.0%
Czech Republic	0.5	82%	-23%	114.9	0.5%
Germany	21.0	98%	48%	844.6	2.5%
Denmark	2.1	95%	17%	54.0	3.9%
Estonia	0.1	100%		14.7	0.4%
Spain	8.2	62%	137%	320.2	2.6%
Finland	1.1	70%	6%	65.1	1.7%

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[5] Excluding international aviation and shipping (i.e. cf. UNFCCC national total).

	CO_2 emissions from international aviation	International share in national total aviation emissions	Difference, 1990-2002, in CO_2 emissions from international aviation	Total national CO_2 emissions[5]	Share of international aviation in total national CO_2 emissions
France	14.7	73%	52%	380.0	3.9%
United Kingdom	21.5	67%	65%	526.3	4.1%
Greece	2.3	66%	-4%	99.1	2.4%
Hungary	0.6	100%	26%	55.5	1.2%
Ireland	2.3	95%	113%	42.8	5.3%
Italy	9.8	97%	50%	442.4	2.2%
Lithuania	0.1	87%		12.4	0.7%
Luxembourg	1.2	100%	185%	9.3	12.4%
Latvia	0.1	100%		7.7	1.1%
Malta	0.2	100%	10%	2.6	9.3%
Netherlands	10.2	98%	130%	223.7	4.6%
Poland	1.3	100%	109%	283.8	0.5%
Portugal	1.8	80%	19%	64.1	2.9%
Sweden	1.8	72%	60%	53.3	3.3%
Slovenia	0.1	97%	4%	15.2	0.6%
Slovak Republic	0.1	100%		37.9	0.4%
EU total	*107.4*	*81%*	59%	*3876.3*	*2.8%*

Source: Olivier and Peters [2004] data based on IEA [2004]

2.2.2 Flight emission models

The impacts of aviation emissions can only be determined from up-to-date and accurate emissions databases. Currently available global emissions databases [see IPCC, 1999] are about 10 years out of date and cannot meet the current needs of policy-makers and scientists.

Two new emissions models, AERO2k[6] and SAGE[7], are currently under development in Europe and the USA, respectively. The developers of the AERO2K and the SAGE models presented their preliminary results at expert meetings in 2004 on methodological issues related to inventories of emissions from aviation and navigation. The expert meetings were organized by the ICAO and IMO secretariat in consultation with the UNFCCC secretariat.

For purposes of comparison, modeled data from the AERO model[8] (prepared for the ICAO expert meeting that took place on February 2003, [FCCC/

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[6] The AERO2K project is supported through the European Commission Fifth Framework programme and is under development by a consortium led by QinetiQ (United Kingdom) with DLR (Germany), NLR (Netherlands), Eurocontrol, Airbus (France), Manchester Metropolitan University (United Kingdom) and the Department of Trade and Industry (United Kingdom).

[7] The United States Federal Aviation Administration Office of Environment and Energy has developed the System for assessing Aviation's Global Emissions (SAGE), with support from the Volpe National Transportation Systems Center, the Massachusetts Institute of Technology and the Logistics Management Institute.

[8] The AERO model was developed by the Ministry of Transport of the Netherlands.

SBSTA/2003/INF.3, para. 51]) were also presented. It was noted that the AERO2K and SAGE models were at different levels of development and validation, with SAGE being further developed.

AERO2K

The AERO2K project will deliver the data required for European and international policy development and future assessments of aircraft impacts on climate. The main objective of AERO2K is to develop a new four-dimensional (4-D: latitude, longitude, height and time) gridded database of global aircraft emissions of priority pollutants and to improve methodologies and analytical tools.

More specifically, the key objectives of AERO2K are[9]:

1 To create a database of global aviation emissions for the year 2002 based on:
    a An aircraft movements database.
    b Aircraft fuel usage predictions.
    c Engine emissions data.
2 To produce a forecast of global emissions for 2025 based on predicted aircraft movements.
3 To improve methodologies and analytical tools that facilitate novel and improved evaluations of the impact of aircraft emissions on the global atmosphere.

Key assumptions and input parameters of the model include the following:

- The model uses a selection of 40 'representative' aircraft and engine types.
- Flight movement data were provided by Eurocontrol for all regions in the world for six weeks in 2002. These data are based on radar tracks and flight trajectory predictions. The data includes:
    - Aircraft type.
    - Departure airport, departure time, arrival airport.
    - Latitude, longitude and altitude throughout each flight.
- Emission data are based on DLR's[10] engine models, which simulate engine performance under a range of operating conditions.

AERO2K should provide the following output (selected):

- Calculates fuel used and emissions for each flight.
- Allocates fuel and emissions data onto a 4-D global grid.

Emission projections based on AERO2K

Various sources such as ICAO[2004], Airbus[2005] show that after 9/11 and SARS in ASIA, growth of aviation passenger demand is in 2004 beginning to return back to the level of 2000. Global passenger air travel is projected to grow by about 4-5% per year. Based on these demand growth levels, CO_2 emissions from civil aviation are projected by to increase by 110% in the period 2002 – 2025 (AERO2K). NOx emissions are projected to increase by 60% in the same period.

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[9] Presentation by the project manager, Chris Eyers, at SBSTA 20, Bonn, 17 June.

[10] German Aerospace Centre.

SAGE (US Federal Aviation Administration (FAA))
The project proposes a System for assessing Aviation's Global Emissions (SAGE) as a policy and regulatory analysis tool for estimating global aircraft emissions and evaluating the impact of varying parameters on aircraft emissions, for all phases of flight. The SAGE model is planned as a forecasting system, with a global emissions module as its main component. The model will be capable of incorporating functionality that will allow computation of the costs and benefits of employing various aviation emission mitigation options. Its modular design will maximize the system's flexibility; to accommodate the use of models, data, or tools developed by others and to evolve and adapt to future changes in the global aviation system.

This model will be used as a tool to estimate and evaluate the global environmental impact of aircraft emissions for all flight phases (LTO cycle and cruise). SAGE should be capable of simulating activity level, fleet mix and operational routes in order to quantify emissions for geographic regions. The evaluation will be in a 1^{o} X 1^{o} X 1 km grid. It should permit evaluation of mitigation measures such as best operational practices, new technologies, Communication, Navigation, and Surveillance/Air Traffic Management (CNS/ATM) enhancements, and market-based options.

SAGE will be used to conduct periodic forecasts of national and global emissions burdens. While SAGE is not intended to be a scientific model, its output is intended to support the input to three-dimensional chemistry and transport models that are used to assess the impact of various natural and anthropogenic perturbations on atmospheric composition and chemistry.

2.3 Marine

Even though shipping is the most energy-efficient mode of transport in comparison with, say, road transport, inland shipping or rail (expressed in MJ/tonne-km), its contribution to global emissions is growing. According to a study by ENTEC for the EC, the number of vessel movements has increased by 57% since 1990. In 2002, on the basis of recorded fuel sales, the share of shipping in total global CO_2 emissions from fossil fuels was about 2.5% [IEA, 2004b] (approx. 570 Mton per year).

2.3.1 Emissions based on bunker fuels

Since 1990, the amount of marine bunker fuel sold by Annex I countries has remained fairly constant (8% increase through to 2002), although the share of the EU-25 increased overall by over 32% during that period (see table 3). The USA, the world's #1 with a share of 16%, showed a decrease of 20%, whereas the Netherlands, #3 with 10%, showed an increase of over 30% (see table 4). However, non-Annex I sales increased by about 60% between 1990 and 2002. Sales by Singapore, #2 with a 13% share in total global sales, increased by about 80%, while sales by South Korea, Hong Kong and the mainland of the People's Republic of China, presently #7, #8 and #10 with a total share of around 10%, doubled or tripled their sales during this period (figure 4).

figure 3 Trends in international marine CO_2 emissions from bunker fuel sales of Top-10 countries, 1990-2002 [IEA, 2004c]

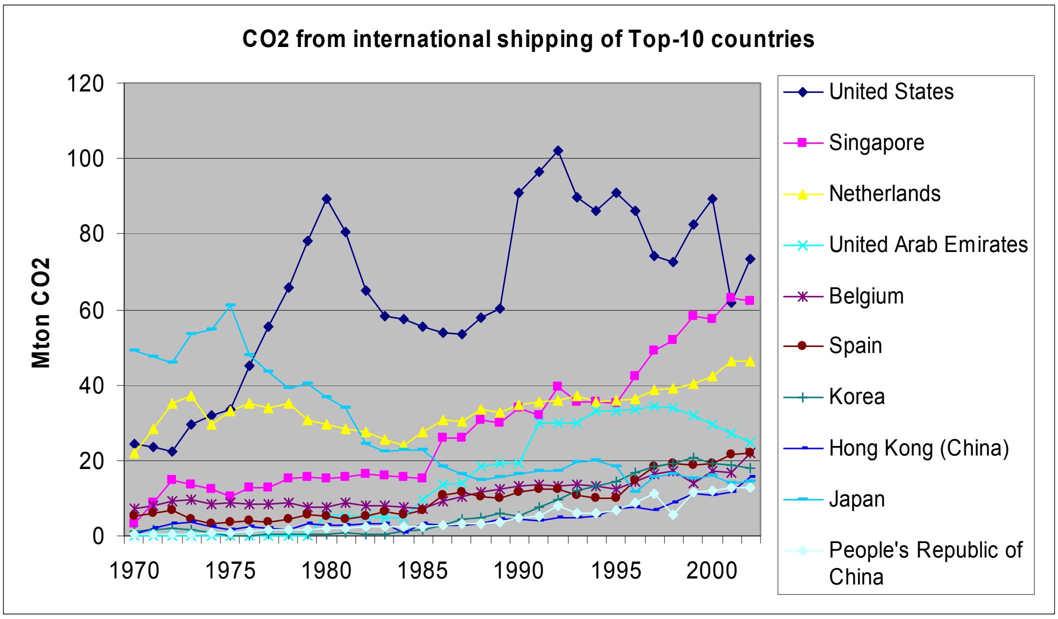

table 3 Trends in CO_2 emissions from bunker fuels sold to international shipping, 1990 to 2002, worldwide, in Annex I, Annex B and non-Annex I countries and in the EU-25

Country	1990	2002	Diff 02/90	Share in international shipping
	[Mt]	[Mt]	[%]	[%]
World	363	463	28%	100%
Annex I[1]	225	244	8%	53%
Annex B[2] – USA and Australia	131	166	26%	36%
EU 25	110	145	32%	31%
Non-Annex I	138	219	59%	47%

Source: Olivier and Peters [2004], data based on IEA [2004c].

1 Annex I countries in UNFCCC ('industrialized countries' plus Turkey): OECD-24 plus EIT (Economies In Transition (former USSR countries and Eastern European countries)).

2 Countries with an emission target under the Kyoto Protocol: Annex I countries excluding Turkey and Belarus. The USA and Australia have indicated that they will not ratify the Kyoto Protocol.

Table 4 reviews CO_2 emissions from international shipping bunker fuels for the 25 EU Member States. In 2002 international shipping accounted for 3.8% of the total national CO_2 emissions of the EU-25. There are large differences between countries, however. In the top three countries, the Netherlands, Belgium and Greece, the share of international shipping in national total CO_2 emissions is 20%, 16% and 10%, respectively. For most other EU countries this share is no more than a few percent.

A second point to be noted from the table is that the international aviation CO_2 emissions of certain EU countries have increased by over 100% since 1990

(Ireland and Cyprus), while other countries show only minor growth or even a decrease.

table 4 CO_2 emissions from bunker fuels sales to international shipping in EU Member States (EU-25)

	CO_2 emissions from international shipping	International share in national total shipping emissions	Difference, 1990-2002, in CO_2 emissions from international shipping	Total national CO_2 emissions[11]	Share of international shipping in total national CO_2 emissions
	Sales 2002	Sales 2002			
	[Mt]	[%]	[%]	[Mt]	[%]
Austria	0.0	0%		66.0	0%
Belgium	21.9	97%	68%	134.4	16%
Cyprus	0.4	100%	137%	6.8	6%
Czech Republic	0.0	0%		114.9	0%
Germany	7.5	91%	-4%	844.6	1%
Denmark	2.9	88%	-3%	54.0	5%
Estonia	0.4	97%		14.7	3%
Spain	21.8	83%	89%	320.2	7%
Finland	2.0	81%	13%	65.1	3%
France	8.3	78%	3%	380.0	2%
United Kingdom	7.6	80%	-4%	526.3	1%
Greece	9.9	84%	23%	99.1	10%
Hungary	0.0	0%		55.5	0%
Ireland	0.5	89%	732%	42.8	1%
Italy	9.4	93%	12%	442.4	2%
Lithuania	0.3	0.1%		12.4	3%
Luxembourg	0.0			9.3	0%
Latvia	0.3	100%		7.7	4,5%
Malta	0.1	100%	-25%	2.6	2%
Netherlands	46.1	98%	33%	223.7	20%
Poland	0.9	99%	-37%	283.8	0%
Portugal	1.5	85%	-21%	64.1	2%
Sweden	3.8	89%	81%	53.3	7%
Slovenia	..			15.2	
Slovak Republic	0.0			37.9	0%
EU total	*146*	*31%*	33%	*3876.3*	*3.8%*

Source: Olivier and Peters [2004] data based on IEA [2004c]

2.3.2 Research on shipping emissions

To build an emission inventory requires information on the numbers of different categories of ships, operating hours, installed engine powers, specific fuel consumption for different engine types, emission factors (mass unit emission of a certain pollutant per mass unit fuel) and the tracks followed by the ships.

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[11] Excluding international aviation and shipping (i.e. cf. UNFCCC national total).

Statistics about the world's fleet of ocean-going ships in various years are available from Lloyd's Register of Shipping and statistics about inland shipping from the OECD. Information about installed engine powers and the fuel use of the different types of engines is available in sector-specific databases [see e.g. Endresen *et al.*, 2003, and Corbett & Koehler, 2003]. Operating profiles of ships have been assembled for certain regions by national and international authorities such as the EU and Norway. Emission factors are available from the IPCC Guidelines for National Greenhouse Gas Inventories [IPCC 1997, 2001], the EMEP/CORINAIR Emission Inventory Guidebook and the Oil Industry International Exploration and Production Forum. Information on the amount of fuel used in the shipping sector is available from the International Energy Agency (IEA).

[Endresen *et al.*, 2003] is the most recent attempt to construct a global inventory of ship emissions, for the year 1996. They investigated several ways of distributing ship emissions geographically and found that different methods lead to quite different geographical distributions of the perturbations in atmospheric composition. They recommend using AMVER data (the Automated Mutual-assistance Vessel Rescue system, a voluntary global ship reporting system used by search and rescue authorities) for geographical distribution rather than Purple Finder (positions obtained from satellite communications by ships) or COADS (the Comprehensive Ocean-Atmosphere Data Set consisting of meteorological observations by ships including their positions) data. Other global emissions inventories include EDGAR3.2 [Emission Data for Global Atmospheric Research; Olivier *et al.*, 2002 and Corbett *et al.*, 1999]. [Corbett *et al.*, 1999] used COADS for geographical distribution and EDGAR3.2 used traffic intensity along the world's major shipping routes. There are also several regional inventories, for the EMEP area and southeast Asia (RAINS-ASIA), for example.

table 5 Fuel use and total emissions of CO_2, NO_x and SO_2 from international shipping according to various sources

Inventory	Base year	Fuel (Tg)	CO_2 (Tg)	NO_x (Tg NO_2)	SO_2
Endresen, 2003	1996	170-200	461	10.8	6.1
Corbett, 1999	1993	147	451	10.1	8.5
Edgar 3.2 [1], 2002	1995	140	429	9.6	7.3
Corbett and Koehler [2], 2003	2001	289	913	22.6	13
IEA, 2004c	2002	-	463	-	-

[1] Based on IEA statistics.

[2] 'Ocean-going ships', i.e. including overseas domestic trips but excluding international shipping over rivers and canals.

The emission totals of CO_2, NO_x and SO_2 in the Endresen *et al*. estimate correspond respectively to about 2, 10 and 5 % of the global anthropogenic emissions of these compounds in the EDGAR2 inventory. The NO_x emission, in particular, is thus relatively important.

The original figure for NO_x shipping emissions in EDGAR2, 0.8 Tg, was a serious underestimate, resulting from the use of erroneous assumptions as to fuel type and emission factors and has subsequently been recalculated [Lawrence and Crutzen, 1999].

Recently, Corbett and Koehler [2003] and Endresen *et al*. [2003] suggested that the amount of fuel estimated as being used by international shipping might be substantially biased. However, the results of these studies cannot simply be compared with data reported to IEA or UNFCCC, as they do not employ the same distinction between domestic and international shipping as IEA and UNFCCC. For example, a domestic journey from Hawaii to San Diego is not included in the international totals of IEA, while Corbett and Koehler [2003] do take subsume these emissions into under ocean shipping.

3 Impacts from aviation and shipping

3.1 Introduction

This chapter provides an overview of the impacts of greenhouse gas emissions from aircraft engines and ship engines on the atmosphere and climate, based on an assessment of the scientific literature published up to the summer of 2004. In addition to impacts on climate, limited attention has been paid, in chapter 8, to the impacts of aviation and shipping emissions on regional and local air pollution.

This chapter is structured as follows:
- Summary state-of-the-art on climate impacts from aviation (Section 3.2).
- Summary state-of-the-art on climate impacts from shipping (Section 3.3).

Annex A to this report includes a detailed description of the findings regarding the climate impacts arising from aviation and shipping.

3.2 Summary state-of-the-art on climate impacts from aviation

The effects of aviation emissions on radiative forcing were estimated in the IPCC Special Report on Aviation and the Global Atmosphere [IPCC, 1999]. However, in the light of recent research results, to be summarized here, some of the forcing estimates given by IPCC (1999) need to be revised. As we feel this should be done by IPCC itself, or under some similar assessment regime, we here merely report their numbers, subsequently indicating where updates are necessary in our opinion.
- Emissions of nitrogen oxides (NO_x) lead to formation of tropospheric ozone (O_3) and a reduction of methane (CH_4) concentrations. Methane is a direct greenhouse gas, so that any reductions in atmospheric levels will reduce the warming effect. IPCC (1999) estimated that the lifetime of methane is reduced by 2% by aviation emissions of nitrogen oxides. More recent model calculations [EC, 2001] suggest that this figure might be about a factor 2 lower, viz. about -0.008 W/m^2 instead of -0.014 W/m^2.
- The radiative forcing due to aircraft contrails is presently thought to be a factor 3 to 5 times less than the figure given by IPCC (1999). Recent estimates of maximum forcing in 1992 range between 0.0035 and 0.006 W/m^2, while IPCC (1999) reports a figure of 0.02 W/m^2.
- The effect of aviation on cirrus clouds has been estimated in a few studies and appears to be not far off the high end of the range estimated by IPCC (1999). There are still uncertainties on the issue, however, and further study is required. It is still possible that aircraft-induced cirrus change constitutes the largest effect of aviation on radiative forcing (RF). Two independent studies have found a correlation between cirrus cloud increases in heavily trafficked areas [Zerefos *et al.*, 2003; Stordal *et al.*, 2004], with the latter estimating an upper-bound RF of 0.05 W/m^2.
- Sausen *et al*. [2004] have estimated the total RF due to aviation, based on air traffic in the year 2000. Since the 1992 base year of the IPCC (1999) results,

emissions of CO_2 have risen. The RF for contrails is now calculated to be lower and the best estimate for overall radiative forcing due to aviation, 0.048 W/m^2, is consequently still close to the figure reported by IPCC (1999).

- The effect of chemical processes in cirrus clouds and on particle surfaces needs to be urgently investigated, using multiple models, as one study [Pitari *et al.*, 2002] indicates that subsequent ozone destruction may exceed the ozone production due to aircraft NO_x emissions.
- In the models used for assessments, vertical transport around the tropopause, which markedly affects the residence time of aviation emissions in the atmosphere, also still needs to be further improved, as does production of nitrogen oxides by lightning, transport by convective clouds, removal by precipitation, and formation of cirrus clouds. A more general outstanding issue for future research is the possible future intensification of atmospheric circulation in the lower stratosphere owing to rising levels of greenhouse gases, which will affect the residence time of aircraft pollutants.

3.3 Summary state-of-the-art on climate impacts from shipping

The contribution of CO_2 emissions from shipping and their effect on radiative forcing are of the same order of magnitude as those from aviation. According to the only model study performed to date, the radiative forcing caused by the increase in ozone and the reduction in methane due to nitrogen oxide emissions by ships, albeit more uncertain, is also of the same order of magnitude as for aviation. However, aircraft emissions tend to grow more rapidly on average than shipping emissions. The effect on radiative forcing of particle emissions by ships and the resulting changes in cloud properties remain to be quantified.

4 Allocation, targets and distribution

4.1 Introduction

Parties to the UNFCCC have not yet been able to agree upon a methodology for allocating emissions from international aviation and shipping to Parties. This means it is not currently clear which country or entity bears responsibility for these emissions.

The structure of this chapter is as follows:
- Definitions: distinction between allocation and distribution (Section 4.2).
- History of the allocation issue (Section 4.3).
- Commitment structure: Do we need allocation to Parties? (Section 4.4).
- Which allocation options are feasible ? (Section 4.5).
- The relationship between allocation and mitigation policies (Section 4.6).
- Targets and baseline (Section 4.7).
- Caps and initial distribution of emission rights (Section 4.8).

4.2 Definitions: distinction between allocation and distribution

The distribution or allocation of responsibility for emissions amongst States is sometimes confused with the distribution or allocation of emission allowances to legal entities in the context of emissions trading. To avoid any such confusion, in this report we employ the following definitions (see also figure 4):
- **Allocation**: international aviation and maritime transportation emissions are included in the overall greenhouse gas inventories of nations that are Parties to the UNFCCC. This means that Parties are *responsible* for these emissions (with no reference to any cap).
- **Distribution**: is concerned with the question of how to distribute responsibility for emissions among the entities participating in an emissions trading scheme (i.e. not among Parties).

It should be noted, however, that this definition is not universally accepted and the distribution of emission allowances to the legal entities participating in the EU emissions trading scheme is indeed performed in the context of so-called ‘national *allocation* plans’.

4.3 History of the allocation issue

Historical developments with regard to allocation can be summarized as follows:
- The main work on allocation within the SBSTA context was done in 1996 [FCCC/SBSTA/1996/9/add 1 and 2]. Eight options for allocating responsibility for emissions from international aviation and shipping were identified and discussed [see Section 5.4 of the present report].
- Since SBSTA 10 (1999) there has been no discussion of the allocation issue within UNFCCC.

- At SBSTA 19 (2003), SBSTA agreed to continue consideration of inventory issues relating to decision 2/CP3 at its 22nd session (June 2005). At SBSTA19 the EU supported continuation of consideration of the different allocation methodologies. Decision 2/CP3 was interpreted by the EU as a decision on allocation methodologies.
- At the 6th meeting of CAEP (environmental committee of ICAO) in the spring of 2004, several European CAEP members supported the UK paper proposing that ICAO invite SBSTA to prioritize the agreement of an allocation methodology in parallel with CAEP's ongoing work to develop an emissions trading scheme. The CAEP meeting recognized (report on agenda item 2) that the issue of how to distribute emissions from international air transport was important in the development of any methodology for emissions trading (thus also including voluntary emissions trading). The meeting noted the conclusions of SBSTA19.

4.4 Commitment structure: do we need allocation to Parties?

In designing mitigation policies for international aviation, one fundamental decision that must be addressed is the question of commitment structure. A decision must, in other words, be made on who is to bear responsibility for the sector's emissions of greenhouse gases. The issue of jurisdiction must first be resolved in order to delineate the legal structure and policy context underlying policy instruments such as an emissions trading system [ICF *et al*., 2004]. Among other things, this involves the question of whether and how tradable allowances are to be created for the international aviation or shipping sector. It also has implications for the specific roles that IMO, ICAO and national governments might play in any policy regime and the various methods that might be implemented to assure that participants comply with the requirements of such a regime.

In principle, two main options are conceivable:

1 **Non-allocation**: A stand-alone binding treaty, with an international body such as IMO or ICAO being called in to take responsibility for implementing mitigation policies and setting up a system for administering emissions. For example, under an emissions trading scheme international transportation emissions might be distributed directly to legal entities (e.g. airline or shipping companies) instead of being allocated to states that are Parties to the UNFCCC[12].

2 **Allocation**: Emissions can be allocated to Parties to the UNFCCC. Depending on agreed commitments under the UNFCCC process, (some) of these Parties (e.g. EU or Annex-I) can implement mitigation policies under

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[12] To limit the administrative burden under a stand-alone treaty, emission charges would appear a somewhat easier option to implement, as such charges require no distribution of emission rights, nor creation of an emission trading market. A system of charges on fossil carbon is considerably less vulnerable to evasion, moreover, than a system of tradable CO_2 rights in which (invisible) CO_2 emissions must be monitored. Put differently, industrial output of fossil fuels is far easier to monitor than the level of CO_2 emissions. Implementation and enforcement, in particular, will be greatly facilitated, while the cost-effectiveness for the industry of carbon charges and open emission trading will be similar if the charge level is set equal to the permit price that would result on an international trading market.

regional (EU) or global (ICAO or IMO) coordination (Parties can, for example, empower legal entities to trade directly in emission rights).

The practical feasibility of non-allocation will be discussed below in Section 4.5.

Non-allocation would have the advantage of allowing the difficult issue of the assignment to states of emissions from international aviation, which has been the subject of controversial debate in the past, to be avoided.

However, a number of legal and political arguments can be brought forward against direct assignment of emission rights [IPPR 2000]. This method of assignment would be inconsistent with the structure of the UNFCCC process as well as international legal practice, because emissions affecting the climate would be assigned to private enterprises rather than to states. It is also impossible to guarantee compliance with commitments at an international level if the respective states are not involved, because ultimately only they have the power of sanction required to enforce such obligations.

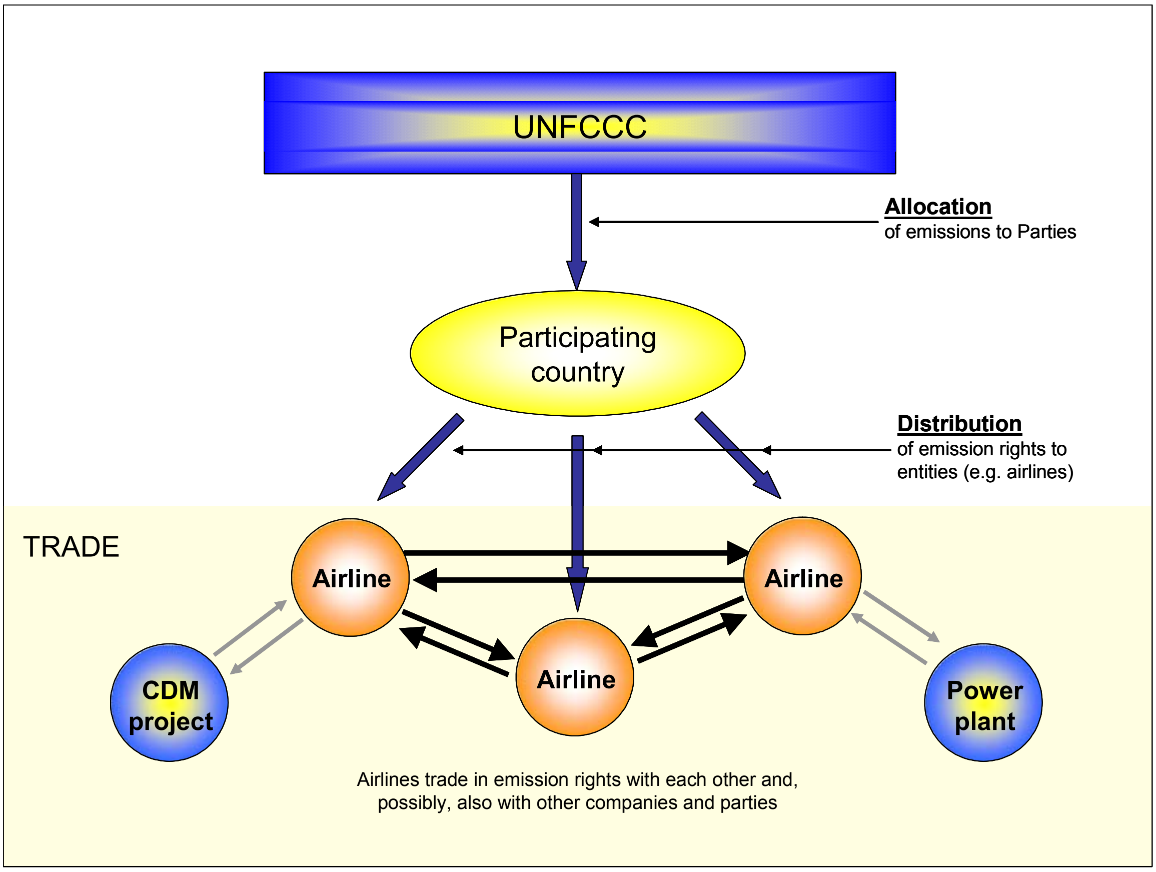
Another approach would be to establish a stand-alone binding treaty and to call in an international body to take responsibility for allocating emission rights to airline or shipping companies as well as for monitoring the system. The ICAO or IMO would be a prime choice for this task, since it has broad specialized competence in the aviation field. For such an approach, however, it needs to be examined whether the ICAO and IMO are legally in a position to enforce sanctions against parties such as national airlines or ship owners. Moreover, obtaining global consensus on the detailed rules that would be necessary to define operators' responsibilities in industry-dominated sector-specific organizations could prove very difficult in the absence of strong incentives to do so. A stand-alone treaty negotiated by ICAO and national states was rejected during the ICAO Council meeting in June 2004 (see Section 5.2). It must be stressed, however, that this rejection was not based on a profound discussion or study of the scope for detailed organization of the technical requirements under an ICAO umbrella.

Although a commitment structure under which legal entities are directly accountable to an international body may be theoretically conceivable, then, there is no precedent for such a construction and the practical relevance of this option must be characterized as rather small, as implementation of any mitigation policy would require new institutional capacities, a legal framework, monitoring and verification procedures, enforcement and sanctions, etc. to be established at a supranational level.

Accordingly, there are legal and political grounds for supporting allocation of international aviation and shipping emissions to states. figure 6 shows such a commitment structure for the case of emissions trading, under 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.

The commitment structure in figure 6 is comparable with that of the Kyoto Protocol, in which states, as contracting parties, have also committed themselves to reduction or limitation of greenhouse gas emissions. At the same time, however, the Kyoto Protocol also allows a Party to authorize legal entities to participate directly in the use of flexible instruments, under its responsibility. Legal entities thus empowered are nevertheless not accountable to the COP, but rather to their respective states. Cross-border transactions must therefore be processed in the emission registries of the states in question [Cames *et al.*, 2004].

figure 4 Possible commitment structure in the case of emissions trading



Source: Cames *et al*. [2004], adapted by CE Delft

On the one hand, this arrangement would guarantee a high level of commitment to emission reductions. On the other hand, though, it would leave the contracting states – in line with the principle of subsidiarity – to decide on the instruments with which to fulfill their commitments. However, in order to avoid economic distortions it is recommended that allocation to Parties be combined with decisions on the instruments to be implemented, possibly under the coordination of IMO or ICAO in the case of a global system or under the guidance of the European Union in the case of a European system.

Conclusion

Non-allocation, i.e. a commitment structure in which legal entities are made directly accountable to an international body such as the IMO or ICAO, is theoretically conceivable but of no practical relevance, since it would require considerable legal adaptations to the UNFCCC and the creation of new institutional capacity to administer emissions, i.e. distribution, monitoring and verification procedures, enforcement and sanctions, etc., to be established at a supranational level.

4.5 Which allocation options are feasible?

Allocation options

Parties to the UN Climate Convention have not yet been able to agree on a methodology for allocating emissions from international aviation to Parties. Consequently, these emissions are not included in the national emission inventories that are to be reported to the UNFCCC by Annex I countries, but are reported separately under international bunkers in conjunction with emissions from international marine transport.

SBSTA has considered the following options for allocating emissions from international aviation and shipping [UNFCCC/SBSTA/1996/9/Add.2]:

1. No allocation.
2. Allocation in proportion to national emissions of Parties.
3. Allocation to the country where the fuel is sold.
4. Allocation to the nationality of airlines or shipping companies.
5. Allocation to the country of destination or departure of aircraft/ship. Alternatively, the emissions related to the journey of an aircraft/ship could be shared by the country of departure and the country of arrival.
6. Allocation to Parties according to the country of departure or destination of passenger or cargo. Alternatively, the emissions related to the journey of passengers or cargo could be shared by the country of departure and the country of arrival.
7. Allocation to the country of origin of passengers or owner of cargo.
8. Allocation according to emissions generated within each party's national space.

In 1996 SBSTA 4 concluded that options 1, 3, 4, 5 and 6 should be the basis for further work[13] and that with respect to option 1 (non-allocation) the responsibilities of the international community to address issues related to international bunker fuels should be recognized.

View of the EU

By 1999, in a statement to SBSTA, the European Community stated that any decision on the inclusion of emissions from international bunker fuels in the

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[13] Options 2, 7 and 8 were discarded by SBSTA for different reasons. The main reason for discarding option 2 is lack of equity, emissions not being allocated in proportion to the volume of aviation activities performed by each Party. The problem with option 7 is that the data needed on the origin of passengers and freight is simply not generally publicly available. Finally, option 8 was discarded because of its inadequate global coverage, no emissions above international waters being allocated to Parties under this option.

national inventories of Parties (i.e. on allocation) should enter into force during the second commitment period. The EU may consider option 1 (no allocation) further, if ICAO makes demonstrable progress, taking into account the overall emission reduction target of the Kyoto Protocol. With regard to the allocation options (options 3, 4, 5, and 6), the EU proposes that the SBSTA should compare and discuss these with a view to being in a position to reach agreement on one option by 2005.

The background of the year 2005 as a horizon for reaching agreement on allocation options is based on the following view of the EU. First, it is recognized that international aviation and shipping emissions would have to be taken into account in agreeing on future commitments for Annex I Parties for the second (post-2012) and future commitment periods. Second, the EU shares the analysis in UNFCCC/SBSTA/1999/INF.4 that it might take Parties three to five years to put in place adequate systems to collect and report information in a consistent manner on emissions from international bunker fuels for options 4, 5 or 6. If one of these options is to be pursued, the necessary methodological work would have to be initiated very soon.

Assessment of Options

Allocation option 1 (no allocation) has been discussed in the previous section. Below, the four remaining allocation options, 3, 4, 5 and 6, will be assessed with reference to the following three criteria[14]:

Polluter pays principle (equity)

The option should be consistent with the ‘polluter pays’ principle and thus equitable – although it is not always clear who should be considered as the ‘polluter’ (the passengers/cargo exporters/importers, the airline/shipping company or the company selling the bunker fuel).

Data availability

It should be possible to guarantee the availability and sufficient accuracy of the data required for allocating emissions according to the option in question. In addition, the allocation option should depend to the widest extent possible on existing data rather than requiring creation of entirely new, complex data collection systems.

Evasion

Potential distortions due to evasion do not necessarily result from any particular allocation method in itself, but from the method of regulation or mitigation employed by the Party in question [Nordic Council, 2004]. This potential problem will occur mainly in the case of mitigation schemes applied on a unilateral or regional basis. The allocation method should then not enable or encourage behaviour to avoid emissions being allocated to a particular Party.

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[14] Besides new analysis, this assessment is based on the following studies: Nielsen [2003a], Velzen & Wit [2000], Nordic Council [2004] and Cames *et al*. [2004].

Other criteria?
Obviously, other criteria may also be important for selecting allocation options. The aim of the following assessment, however, is to analyze the feasibility of the four allocation options in terms of these three criteria, assuming that those criteria can be decisive. We decided not to assess the four allocation methods on the criterion 'country's ability to apply effective regulatory instruments without creating economic distortions of competition', as this is not a distinguishing factor We shall briefly clarify this choice and the relevance of this criterion in the next section (4.6).

Option 3: Allocation to the country where bunker fuel is sold

Data availability
From the perspective of data availability, many studies regard this option as feasible. However, inconsistencies in current fuel bunker statistics throw up various obstacles, in particular with respect to data accuracy (see Section 7.5). However, correction or modification of the data collection of bunker statistics can be done. The feasibility is illustrated by the present reporting of these emissions of a number of Annex I countries to the UNFCCC [Olivier and Peters, 2004]. The Nordic Council of Ministers [2004] notes that none of the Nordic countries are using the IPCC criteria for distinguishing between domestic and international flights, as their data collection systems are not capable of reporting these data.
Furthermore, this allocation option is inappropriate if a basis for assessment is selected that extends beyond carbon dioxide and water vapour, as emissions that are not necessarily proportionate to the amount of fuel consumed but dependent on specific flight conditions – aircraft type, turbine engine, flight level, weather, etc. – cannot be registered.

Polluter pays principle
For aviation, in the majority of cases, the option is consistent with the 'polluter pays' principle, because the aircraft is likely to depart from the country where it buys the fuel. The problem with this allocation option is that sales in a given country do not necessarily tally with actual consumption, since tankering strategies[15] can be of considerable significance. Fuel tankering is even more significant in the shipping sector. IEA data sets on bunker fuel sales (see chapter 2) illustrate this problem, especially for countries where fuel is relatively low-priced, for example.

Evasion
In addition, introduction of mitigation policies on a regional basis (e.g. Europe or Annex I countries) will exaggerate the tankering problem. Obliged parties could partly evade their emission reduction obligations by exploiting permissible reserves (leakage) when refueling in non-participating states. Because of this potential for evasion, this allocation option is hardly appropriate for an emissions trading system or fuel charge encompassing only a restricted group of participating states.

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[15] Aircraft or ship taking extra fuel on board for use on its next flight or journeys.

Option 4: Allocation to Parties according to nationality of airline or shipping company, or to country where vessel is registered, or to county of operator

Data availability
This allocation option requires data on:

- Bottom-up movement data, CO_2 emissions based on actual fuel consumption.
- The country where the airline or shipping company is registered.

The allocation method would benefit from data collection systems at the level of the individual airline or shipping company, which can be expected to include detailed information on actual levels of fuel use, distances, origin/destination, etc. These data collection systems could potentially be expanded to include non-CO_2 effects. Flight movement data are already available in the aviation sector. The most attractive option for arriving at accepted and specific emission figures for individual aircraft would be to base the CO_2 emission on the carbon content of the trip fuel, which airlines are currently obliged to register in the weight and balance documentation. These data are not reported systematically to authorities in the EU, however. In the US, reporting of actual fuel consumption data has been required by law for many years (the so-called ‘form 41 arrangement’). The EU could consider applying similar reporting guidelines for all aircraft flying into Community airports.
British Airways (BA) has developed a similar monitoring and reporting system [ICF *et al.*, 2004]. In conjunction with its participation in the UK trading scheme, BA has developed methodologies to calculate actual on-flight fuel consumption.

Defining the nationality of an airline or shipping company is likely to be a complicated issue. SAS is a prime example, being an airline with shared ownership by three countries as well as private shareholders. Given the dynamic and volatile structure of the international airline industry, these complexities are likely to increase in the future.

In shipping, similar problems are to be anticipated. A ship may be owned by a company in one country, which is itself owned by other companies in other countries, registered in another, operated by a ship-management company in a third country and crewed from a manning agency in a fourth country, with nationals from yet other countries. Furthermore, carriage can be paid for by charterers, and in some cases a number of sub-charterers, based in other countries [IPCC, 2000].

Polluter pays principle
One main drawback of option 4 seems to be that it does not necessarily always apply the ‘polluter pays’ principle, as countries with large aviation and shipping companies or with a large number of operating companies or ships registered would be held responsible for a major proportion of global aviation or shipping emissions, even if many of the trips do not depart from or arrive in the country itself [Nielsen, 2003). However, this does not appear to be a strong argument, as this would then also hold for emissions from any stationary industry in a country, such as a steel company, which exports a large share of its production.

Evasion
Much of the activity of the airlines and shipping companies regulated would take place under circumstances over which the government may have little control, e.g. when airlines or ships operate routes that do not depart from or arrive in their home country. Furthermore, international competition would make unilateral, uncoordinated regulation potentially distortive. The possibility of outflagging airlines is likely to increase in future, which will further reduce the ability to regulate at the national level.

Option 5: Allocation to parties according to country of departure or destination of aircaft or ship

Data availability
This allocation option requires data on:
- Bottom-up movement data, CO_2 emissions based on actual fuel consumption on each trip or standard emissions factors from widely accepted tables (e.g. aircraft manuals).
- Information on country or (air)port of departure and destination.

For aviation, (modeled) bottom-up data on actual fuel consumption and other flight movement data are available but not reported systematically. However, this problem could be readily solved (see option 4 and chapter 7). Information on arrival and destination data are available from airport authorities and ATM authorities such as Eurocontrol.

With regard to shipping, the picture appears to be different. Information on departure and arrival data may be available, but there is no widely accepted monitoring methodology nor database available for the CO_2 emissions of ships.
Information about the port of departure and the destination of each trip is recorded in ships' logbooks and at shipping companies. Furthermore, a large database containing all daily movements by ships of more than 400 tonnes gross are monitored and recorded by Lloyds Marine Intelligence Unit (LMIU). Further research is necessary to determine the administrative load involved in gathering these data for allocation purposes, the risks of evasion, and so on.

It will be much more difficult to determine the CO_2 emissions associated with each specific voyage. We see two possible options for collecting these data:
- Use (standard) emission factors for each category of ship (CO_2 emission per nautical mile), combined with either the recorded length of the trip or a standardized number of miles between ports.
- Measure the actual amount of fuel used per trip (possibly on a voluntary basis).

The first option might provide a relatively simple and verifiable means of estimating CO_2 emissions per trip. However, in view of the large variation in fuel efficiency between similar ships, this option would require a fair amount of research on calculation of the emission factors to be used. Clearly, the second option would be preferable, since it can provide the most accurate data on CO_2

emissions. However, it is likely to be a very complex matter to accurately measure and monitor these data on every single ship, on every single trip.

Polluter pays principle
This allocation option corresponds best with the territoriality principle, as applied under the Kyoto Protocol. Considerations regarding the polluter pays principle are similar to those for option 3 (fuel sales). However, one concern, viz. the tankering problem, of relevance to the polluter pays principle is eliminated compared to the country of fuel sale option [Nordic Council, 2004].

Evasion
This allocation option has the advantage of remaining feasible even if only a small group of states, such as Annex I states or the EU, initiate a mitigation scheme. This is because the scope for evasion is relatively limited under this allocation option and can be additionally restricted by means of supporting measures. An important reason is that emissions are allocated to a country regardless of the nationality of the airline or shipping company. Obviously, regulation should then be implemented in a non-discriminative manner, i.e. companies from participating and non-participating countries should be subject to the same scheme. One possibility to achieve this is to restrict the regulation scheme to trips within the region (e.g. intra-EU). An alternative is to introduce a territory based scheme[16] or a route based scheme (see also Section 5.5.2). The latter implies regulation only being applied on routes between participating states, regardless of the nationality of the airline or shipping company. Under a route based system, airlines and shipping companies could however partially evade their obligations through strategic stopovers in non-participating states. A flight or voyage from Europe to Australia, for example, could first stop over in Israel and then again in Indonesia. Long-haul flights and shipping voyages would benefit from this strategy. Such strategies could be restricted, however, by introducing a variety of accompanying measures. In the aviation sector, 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. However, this needs to be further investigated.

Option 6: Allocation to Parties according to country of destination or departure of passengers and cargo

Data availability
This allocation method would be the most complex of the options under consideration by SBSTA, in terms of both the exact interpretation of the method and collection of the data that would be required to implement it. The data requirements for this allocation method will be very demanding and may in reality prove to be prohibitive [Nielsen 2003]. For each flight stage, total emissions would have to be calculated. The data requirements for this would be similar to those for allocation based on arrival/departure (option 5) of the aircraft. As the second step in the allocation procedure, the calculated emissions would be

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[16] For example, an en-route charge for all carriers (EU and non-EU) that will be levied proportional to emissions of an aircraft in a pre-defined European Airspace (see CE Delft, 2002).

distributed among individual cargo shipments and/or passengers. For this purpose, additional data would be required at the passenger/cargo level and even passengers and cargo from non-Annex I countries would have to be recorded.

Conclusions

UNFCCC has selected five allocation options for further investigation. Based on a review of the literature and an assessment based on the criteria ‘data availability’, ‘polluter pays principle’ and ‘evasion’, we conclude that only option 5 (destination/arrival) is feasible for aviation. Option 4 (nationality of airline or ship) might only be feasible under a global scheme. With regard to shipping, there is no currently feasible allocation option, owing to a lack of accurate monitoring methodologies and data sources. However, from the equity perspective (polluter pays principle) it is only Options 4 and 5 (destination/arrival) that appear feasible. Following up this conclusion would imply a need to initiate research to arrive at accepted and robust bottom-up methodologies for calculating CO_2 emissions from ships.

4.6 Relationship between allocation and mitigation policies

Another criterion that might be very relevant is whether a given allocation option enables regulation of emissions by an individual country once international emissions have been assigned to that country. In other words: what degree of control over options for emission mitigation would a country have after implementation each of the four allocation options? In this study we chose not to include this criterion, as it will not exclude any of the four allocation methods. In theory, all four allocation options assessed here permit regulation of emissions by individual countries. More important, however, is that all four allocation methods require international coordination of mitigation policies in order to be effective and to limit the possibility of strategic behavior and significant economic distortions. The implication of this is that it makes little sense to address allocation separately from regulation and commitments [Nordic Council, 2004]. Thus, both a global and a regional scheme (e.g. Annex I countries or EU) would need a coherent decision on choice of a particular allocation method and the regulatory instruments to be employed. This can be illustrated by assuming a global agreement in which emissions are allocated according to where fuel is bunkered (option 3). Without global agreement on mitigation policies, this allocation method may create *additional* incentives to strategic behavior in the form of tankering. Whether this will occur depends on whether all countries introduce regulatory measures that affect the price of fuel similarly.

4.7 Targets and baselines

The discussions within ICAO, IMO and UNFCCC have not yet addressed possible baselines and ceilings for international aviation and maritime transportation emissions. Norway endeavoured to discuss this issue at the MEPC-51 meeting, but discussion was blocked by the developing countries. At MEPC it was decided to not discuss this issue at this stage and to focus on the purely technical issues.

Although some initial discussions concerning possible targets were started within CAEP in 2001, these were not reiterated until CAEP/6 and were not the subject of the work undertaken by the responsible CAEP working group.

There is not a lot of work available dealing directly with definition of possible baselines and targets for international aviation and maritime transportation. On the other hand, there is voluminous information available from a variety of sources about the development of aviation and shipping (mainly historical), which could form the basis for defining targets and – if appropriate – baselines.

4.8 Cap and initial distribution of emission rights

Cap

In Section 4.4 we concluded that in terms of responsibility for emissions, allocation to Parties may be inevitable, as the option of 'non-allocation' is of theoretical relevance only.

In the case of a system whereby international transport emissions are allocated to Parties, the decision on the nature and magnitude of the cap – for both the overall system and each member state (or Party) – may be somewhat limited by the structure of commitments by Parties under the Kyoto Protocol or its successor. Depending on how closely the assignment of aviation or shipping emissions follows those commitments, Parties may choose their own emission reduction target and the amount of allowances to be distributed or auctioned (in the case of emissions trading).

It should also be remarked that once emissions from international aviation and navigation are allocated to Parties, the distinction between domestic and international emissions will no longer be relevant.

Initial distribution

Generally speaking, emission rights or allowances can either be initially auctioned or distributed free of charge to the parties obliged to surrender allowances. If the latter option is based on historical emissions, it is termed 'grandfathering'.

Initial distribution of allowances on the basis of historical emissions has the drawback that airlines using relatively old and polluting technologies are comparatively better off than operators that have already invested in cleaner technology. It might therefore be better to base 'grandfathering' on different criteria. For example, distribution might be based proportionally on historical Revenue Tonne Km (RTK), with the RTKs of each trading entity (e.g. aircraft operators) being translated into emissions based on a given emission / RTK reflecting the desired cap. A more refined system would make due allowance for differences in emission / RTK for various sizes of aircraft.

When considering inclusion of aviation in emissions trading, there are several questions to be addressed with respect to initial distribution. This is particularly true if the entire climate impact of aviation is to be taken into account, for this would include climate impacts not yet covered under the UNFCCC process.

Initial distribution at Member State or EU level?
In the case of grandfathering, it must be assessed whether initial distribution numbers are to be decided at Member State or EU level. For stationary sources, this will be decided at Member State level. However, under the current EU-ETS Member States will have to comply with certain allocation criteria set out in Annex III of the Directive 2003/87/EC, which should guarantee some degree of harmonization among Member States and avoid distortion of competition. The total quantity of allowances to be allocated shall be – for example – consistent with Member State commitments under the so-called burden-sharing agreement (formally agreed on by Decision 2002/358/CE). In addition, Member States will be obliged to notify their decisions to the Commission, which may reject them in part or *in toto* and may require changes to be made.

As the climate impact of international aviation is not covered by the quantitative commitments under the Kyoto Protocol and the burden-sharing agreement, consideration might be given to a more harmonized approach. Thus, initial allocation for the climate impact of aviation might be decided at EU level such that all operators are allocated allowances according to the same rules, with allocations below what would be required according to actual or projected emissions (harmonized compliance factor). Individual Member States targets can then be calculated by aggregating the allocations to the aviation activities occurring on their territories[17].

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[17] In the Kyoto Protocol and the burden-sharing agreement a top-down approach was adopted, with Parties negotiating their overall targets in absolute terms and passing these on to the entities within their respective countries. If not implemented carefully, this kind of approach always involves a risk of distorting competition at the company level. A bottom-up approach might avoid such effects but suffer from similar drawbacks stemming from unequal enforcement efforts in different states. Following definition of an absolute target for the entire system, the Member States' targets in absolute terms might be derived by aggregating the initial allocation to all covered entities in the aviation sector. However, such an approach would also limit the discretionary leeway of the Member States.

5 Mitigation: Aviation

5.1 Introduction

The aim of this chapter is to provide an overview of current developments regarding mitigation policies in the aviation sector. The chapter is structured as follows:

- Market-based options: the global (ICAO) perspective (Section 5.2).
- Market-based options: the EU perspective (Section 5.3).
- Current EU position: keep all options open (Section 5.4).
- Emissions trading: key design issues (section 5.5).
  - methods to address the full climate impact of aviation;
  - a regional approach: route-based system.
- Ancillary benefits of tackling climate change (section 5.6).

5.2 Market-based measures: the global (ICAO) perspective

ICAO (International Civil Aviation Organization) is a specialized agency of the United Nations that was founded in 1944 through the signing of the Chicago Convention on Civil Aviation. The environmental activities of the ICAO are undertaken largely by the Committee on Aviation Environmental Protection (CAEP).

Every three years, the ICAO Council revises and updates a version of the ‘Consolidated Statement of continuing policies and practices related to environmental protection’, to be adopted by the triennial ICAO Assembly. The present version was adopted at the 35th Assembly in October 2004 [ICAO 2004].

Concerning the environmental impact of aviation on the atmosphere, in 2004 it was resolved to continue to study policy options to limit or reduce the environmental impact of aircraft engine emissions and to develop concrete proposals and provide advice as soon as possible to the Conference of the Parties of the UNFCCC, placing special emphasis on the use of technical solutions while continuing its consideration of market-based measures, and taking into account potential implications for developing as well as developed countries [ICAO 2004, appendix H].

With regard to market-based measures to address aircraft engine emissions, at its 35th Session the Assembly adopted the following substantive revisions, superseding the previous Resolution A33-7:

Voluntary measures

1 *Encourages* action by Contracting States, and other parties involved, to limit or reduce international aviation emissions, in particular through voluntary measures, and to keep ICAO informed and

2 *Requests* the Secretary General to facilitate such actions by making available guidelines that ICAO has developed for such measures, including a template voluntary agreement, and to work to ensure that those taking early action would benefit from such actions and would not subsequently be penalized for so doing.

Emission-related levies

1 *Recognizes* the continuing validity of Council's Resolution of 9 December 1996 regarding emission-related levies[18].

2 *Urges* States to follow the current guidance contained therein.

3 *Recognizes* that existing ICAO guidance is not sufficient at present to implement greenhouse gas emissions charges internationally, although implementation of such a charge by mutual agreement of States members of a regional economic integration organization on operators of those States is not precluded, and *requests* the Council to:
   a Carry out further studies and develop additional guidance on the subject.
   b Place particular focus on the outstanding issues identified in earlier studies and by the Assembly and
   c Aim for completion by the next regular session of the Assembly in 2007.

4 *Urges* Contracting States to refrain from unilateral implementation of greenhouse gas emissions charges [prior to] the next regular session of the Assembly in 2007.

5 *Requests* the Council to study the effectiveness of, and to develop further guidance on emissions levies related to local air quality by the next regular session of the Assembly in 2007, and urges Contracting States to actively participate and share information in this effort.

6 *Urges* Contracting States to ensure the highest practical level of consistency with ICAO policies and guidance on emissions levies related to local air quality.

Emissions trading

1 *Endorses* the further development of an open emissions trading system for international aviation.

2 *Requests* the Council, in its further work on this subject, to focus on two approaches. Under one approach, ICAO would support the development of a voluntary trading system that interested Contracting States and international organizations might propose. Under the other approach, ICAO would provide guidance for use by Contracting States, as appropriate, to incorporate emissions from international aviation into Contracting States' emissions trading schemes consistent with the UNFCCC process. Under both approaches, the Council should ensure the guidelines for an open emissions trading system address the structural and legal basis for aviation's participation in an open emissions trading system, including key elements such as reporting, monitoring and compliance.

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[18] The 1996 Resolution (ICAO 1996) on levies and taxes recommended that a charge be chosen in preference to a tax, and that revenues should primarily be used to mitigate 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.

5.3 Market-based options: the EU perspective

Three market-based options are currently under consideration in the European Union:

- Kerosene taxation.
- Emission-based en-route charges; and
- Inclusion of aviation in the EU emissions trading system.

Kerosene taxation

The feasibility of introducing a tax on kerosene has been discussed and analyzed for a very long time in the EU. Studies on the issue have yielded the following results[19]:

- Contrary to what is often stated, the Chicago Convention, on the basis of which ICAO was founded in 1944, does not forbid the taxation of bunker fuel sold.
- However, most of the approximately 3,000 bilateral air service agreements (ASAs) preclude taxes and levies on fuel for international aviation.
- Taxing of kerosene used for intra-EU flights is possible: Directive 2003/96 /EC on the Taxation of Energy Products allows Member States to conclude bilateral agreements on this matter.
- Besides, following a CJEC ruling in 2002, negotiations are underway for a new framework for an EU-US bilateral agreement that will supersede existing agreements between individual Member States and the US. The EU is keen to keep open the option of introducing kerosene taxation on these flights, in line with Directive 2003/96/EC.
- One disadvantage of kerosene taxation is the economic distortions it may cause: depending on the precise design and level of the tax, it could potentially provide substantial incentives to avoid it, for example by switching to airports outside the charged zone or taking untaxed fuel into a taxed area ('tankering').

Based on the study results the European Commission concluded[20] 'that any effective approach would necessitate a system that allows for taxing/charging all carriers operating out of Community airports. Such an approach, however, if applied in the field of kerosene taxation would require fundamental changes to existing policies at ICAO-level and, in particular, to existing bilateral Air Service Agreements (ASAs) that allow for the imposition of taxation only in case of a reciprocal agreement. These changes will be difficult to achieve without considerable concessions in other fields. For these reasons, the Commission considers that the approach suggested in its 1996 report should be maintained, for the time being, pending progress in international fora. The alternative, application of kerosene taxation on all intra-EC air routes for Community carriers, though legally feasible, is unacceptable in the Commission's view. It would not strike the delicate balance between environmental, economic and internal market requirements which is necessary for a coherent policy in this area' [EC, 1999 and 2000].

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[19] CE Delft [1998] and Resource Analysis [1999].

[20] For a schematic overview of the results we refer the reader to European Commission [1999 and 2000].

On the basis of these conclusions, it can be noted that:

1 Member States, in close cooperation with the Commission, intensify their work within the ICAO framework for the introduction of taxation on aviation fuel and other instruments with similar effects.
2 Following the adoption of Council Directive 2003/96/EC of 27 October 2003 restructuring the Community framework for the taxation of energy products and electricity, aviation fuel continues to be exempt from taxes but Member States have the option to waive this exemption for fuel used both for domestic flights and, subject to mutual agreement, flights between EU Member States. It remains to be seen what use Member States make of this possibility; their scope to tax all carriers may be constrained by existing air service agreements with third countries. The Commission therefore believes that provisions requiring the mandatory exemption of aviation fuel should be removed from air service agreements when they are renegotiated.

En-route emission charge

An alternative to fuel taxation is an emission-based en-route charge, a kind of kilometer charge in the air that is levied proportional to the absolute emission (e.g. kilograms CO_2) of an aircraft in European Union airspace. A study commissioned by the EC on this option was published in 2002. This option potentially has similar benefits to kerosene taxation, with certain points in its favour [CE Delft, 2002]:

- There appear to be rather fewer legal obstacles, as the option is not explicitly mentioned in legally binding agreements.
- An en-route emission charge would not provide incentives for ‘fuel tankering’.
- Economic distortions are less pronounced than in the case of kerosene taxation, because the system is territory-based rather than fuel-based.
- The system can be designed in a revenue-neutral manner (dirtier-than-average aircraft pay, cleaner-than-average receive a bonus) so that the issue of ‘who gets the revenues and what should be done with them’ is avoided. However, this option does not comply with the ‘polluter pays principle’ of course.

Because of the advantages of this option compared with energy taxation, the EU is keen to keep it on the agenda.

Emissions trading

In its 1999 Communication [EC, 1999] the European Commission emphasized that consideration of emissions trading should take place within the context of implementation of the UNFCCC process, and that the fulfillment of emission reduction targets through emissions trading should for the most part be decided at a state level. However, the Communication also examined possibilities for implementing an emissions trading system at a national or regional level. The Commission furthermore announced that, on the basis of the results of the ICAO Assembly at the end of 2001, it would undertake a reappraisal of global, Community and local measures with a view to ensuring fulfillment of the environmental goals laid down in the Amsterdam Agreement and the Kyoto Protocol. It announced that it would update priorities, should progress not be made at the international level and/or new scientific evidence emerge on the environmental effects of air transport.

The sixth meeting of the Environmental Committee (CAEP/6) of ICAO discussed, in the spring of 2004, the following three possible approaches for implementing an open emissions trading system:

1 An ICAO-assisted voluntary emissions trading scheme.
2 A system with ICAO Guidance and linked with the UNFCCC process.
3 A stand-alone binding treaty under ICAO guidance.

As noted in the previous section, the 35th Assembly of ICAO requested the ICAO Council, in its further work on open emissions trading, to focus on approach 1 and 2. The third option, a stand-alone binding treaty under ICAO guidance, was already rejected during the sixth meeting of CAEP.

The EU supports option 2, linked to the UNFCCC process, as the only effective solution consistent with the EU emissions trading scheme coming into effect on 1 January, 2005. In this option ICAO would provide guidance for use by States, as appropriate, to incorporate emissions from international aviation into States' emissions trading schemes consistent with the UNFCCC process.

As part of an ongoing process, the European Commission intends to launch a study to investigate the feasibility of addressing the full climate change impact of aviation under the EU Emissions Trading System [ETS, Directive 2003/87/EC].

5.4 Current EU position: keep all options open

In its 1999 communication, intended to steer its work on aviation and its environmental impacts in the following years, the European Commission [European Commission 1999] addressed three market-based options:

- Kerosine taxation.
- Environmental levies.
- Open emissions trading.

Since the Commission's Communication on Air transport and the Environment in 1999, recognition of the need for action at EU level has been consistently underscored by Council conclusions and European Parliamentary resolutions on the Communication itself, on the taxation of aircraft fuel, on the Commission's Transport White Paper, on the European Climate Change Programme, and on the Integration of Environment and Sustainable Development into Transport Policy[21]. Most recently, when preparing for the Tenth Meeting of the Conference of the Parties to the UN Framework Convention on Climate Change, the Council of Ministers concluded [Council, 15 October 2004b]:

> 'RECALLS the need for urgent action to reduce greenhouse gas emissions related to the use of the international bunker fuels, taking into account the agreement in the Sixth Environment Action Programme that the European Community has approved, from which specific action to reduce greenhouse gas emissions from aviation and marine transportation should have been identified within ICAO by 2002 and within IMO by 2003; REITERATES its invitation to the Commission of December 2001, October 2002 and December 2003 to consider in a timely fashion such action and to make proposals in 2005; without precluding any market-based options, LOOKS FORWARD to the study by the Commission on addressing the climate change impacts of aviation through the EU emissions trading scheme'

This very recent Council conclusion shows that the EU needs a policy framework that allows action to deal with emissions from international aviation, without precluding at this stage any market based measures – taxes, charges or emissions trading. The precise choice as to which of these different market-based options should be implemented is a matter for further consideration. The effect on competition is a particular concern of the industry. In principle, if aircraft operators are required to make a contribution, all operators should do so, irrespective of their state of registration. Not only will this avoid unfair competition it will reduce the risk of undermining the environmental integrity of the measure. Regardless of which measures are eventually applied, it is important that the full climate change impact is addressed. The IPCC Special Report [IPCC, 1999] highlighted that, in contrast to many other sources, the total radiative forcing and thus the contribution to global warming from aviation is substantially higher than the effect of CO_2 emissions alone.

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[21] Communication Air Transport & the Environment, 1 December 1999 – COM (1999) 640. European Parliament Resolution on COM (1999) 640, 7 September 2000 – A5-0187/2000. Council Conclusions on COM (1999) 640, 28 March 2001 – Adopted 2252nd Council meeting – TRANSPORT – Brussels. European Parliament Resolution on taxation of aircraft fuel, 14 December 2000 – A5-0334/2000 Council Conclusions on Taxation of aircraft fuel, 29 June 2000 – Adopted 2281st Council meeting – HEALTH – Luxembourg. Commission White Paper European transport policy for 2010: time to decide - COM (2001) 370 European Parliament Resolution on COM (20001) 370, 12 February 2003 – PT-TA(2003) 054. Council Conclusions on European Climate Change Programme, 12 December 2001 – Adopted 2399th Council meeting – ENVIRONMENT – Brussels. Council Conclusions on 2nd review of its strategy on integrating environment and sustainable development into transport policy, 13 December 2002 – TRANSPORT – Brussels.

Conclusion

The EU has repeatedly announced its intention to implement measures of its own, should consensus not be reached within ICAO. The EU does not focus on specific measures, but keeps all options open. The Commission, in consultation with EU Member States and stakeholders, will seek to agree and announce a package of proposals to deal with the full impact of aviation on climate change in 2005.

5.5 Emissions trading: key design issues

Many members within ICAO and Member States of the EU regard open emissions trading as an attractive to mitigate climatic impacts from aviation. Below we discuss two key design issues that raises important questions:

- How can we address the full climate impact of aviation, knowing there are other emissions besides CO_2 that contribute significantly to radiative forcing?
- Presuming that a global system will be hard to develop, the question arise whether and how a regional system can be developed that would not lead to legal obstacles and competitive distortions.

These two questions are discussed below.

5.5.1 Addressing the full climate impacts of aviation

A major difficulty in developing a mitigation policy for the climate impacts of aviation is how to cover non-CO_2 impacts. IPCC [1999] estimates these effects as being about 2 to 4 times greater than those of CO_2 alone. This means that the environmental integrity of any mitigation policy depends on the extent to which these effects are also taken into account.

Three approaches can be distinguished with regard to non-CO_2 effects of aviation:

1. *No additional policy in the short and medium term*. As scientific understanding of some of the non-CO_2 climate impacts of aviation is still poor, consideration might be given to limiting initial mitigation policies such as emissions trading to CO_2 and waiting for additional evidence on non-CO_2 impacts before including them in the scheme. In terms of climate impacts, however, open emissions trading involving the aviation sector on the basis of CO_2 emissions alone would undermine the environmental integrity of the entire scheme. Furthermore, focusing solely on CO_2 might provide incentives for airlines to take measures that, while reducing their CO_2 emissions, may well have the negative trade-off of increasing NO_x emissions and thus increasing atmospheric ozone concentrations.
2. *Flanking instruments.* In this option, other policy measures would be relied on to ensure the environmental integrity of an CO_2 emissions trading system, for example. Basically, the main question to be investigated here is whether flanking instruments would be able to mitigate the non-CO_2 impacts of aviation effectively and possibly more efficiently if these are not covered by, say, an emissions trading system. Potential flanking instruments include:

    - a Regulations on alternative flight altitudes [e.g. see Fichter *et al.*, 2004] to prevent contrail formation, based on Eurocontrol guidance, for example.
    - b Continued NO_x LTO stringency through ICAO.
    - c An NO_x cruise certification regime, as discussed under the *aegis* of CAEP WG3 (Alternative Emissions Task Group) and the recently completed EC Project NEPAIR.
    - d Other.
3. *Climate currency.* A methodology that addresses the full climate impact of aviation. Two methods that can be distinguished are:
    - a *Multiplier approach.* Aviation reports on CO_2 emissions and a multiplier is applied to take account of the radiative forcing due to non-CO_2 impacts, e.g. the factor 2.7 cited in IPCC [1999] for the year 1992.
    - b *Equivalent approach.* Aviation reports on CO_2 and NO_x and the conditions for formation of contrails and cirrus are taken into account. The climate change impact is calculated from actual emissions in conjunction with data on temperature and humidity on the flight route. Each of the impacts is expressed in equivalent CO_2 tonnes to calculate the full climate impact of a flight.

It should be stressed that the methodologies under option three (Climate currency) require further development, being fairly theoretical at present. The feasibility of arriving at operational methodologies for addressing the full climate impact of aviation depends not only on improving scientific understanding of non-CO_2 impacts, but also on the potential for measuring or calculating these impacts on individual flights.

5.5.2 Regional approach: route-based system?

An effective environmental policy for the aviation sector should preferably be developed at the global level. However, developments within ICAO make clear that international policy will be slow to develop and a regional initiative might therefore be desirable. Moreover, differentiated responsibilities as laid down in the UNFCCC [1992] may, during the initial phasing-in of policy instruments at the global level, even require different commitments on international aviation emissions for, say, Annex-I and non-Annex-I countries.

A real challenge in designing the scope of a *regional* system (e.g. for Europe or Annex-I countries) is to find an optimum balance between environmental effectiveness, political feasibility and economic feasibility (here: minimizing competitive distortions, e.g. by discrimination on routes). Coverage of all routes to and from, say, the EU would maximize the volume of emissions covered by the scheme, but might meet with resistance from countries that do not consider their carriers should be covered. In addition, efforts to avoid legal challenges from such countries by, say, exempting non-EU carriers from the system would cause economic distortions and reduce the feasibility of the system. Limiting a system to intra-EU flights only would compromise environmental effectiveness.

If we assume as a starting point that it is investigated whether aviation could be included in the EU Emissions Trading Scheme (ETS), the question is then how to design a regional scheme that maximizes environmental effectiveness and at the same time avoids competitive distortions. One possible route might be to define a route-based system that can be more readily tied to (a successor of) the Kyoto Protocol. More specifically, the idea is that all emissions on international routes between countries that have ratified the Kyoto Protocol can be included in an emissions trading scheme if these states wish to participate in the EU trading scheme.

For the EU Member States this would mean that, besides including emissions on domestic and intra-EU routes, the scheme would also cover all emissions on routes between EU Member States and 3rd countries that wish to participate in the EU trading scheme. If based on an opt-in approach, such a scenario would require the cooperation of these countries. In practice, it may be the case that only a small group of 3rd countries is keen to join at first, so that the system might have to be designed such that it is possible for other 3rd countries to opt in. One possibility might be to first invite those 3rd countries that have established an emissions trading scheme for stationary sources which are linked to the EU ETS. For example, Norway is preparing for its participation in the EU ETS and might be willing to participate in emissions trading in aviation as well. Canada, and to a lesser extent also Japan, have already given initial consideration to participating in the EU ETS and are therefore further candidates for participation in the emissions trading scheme for aviation.

The proposed route-based system has a number of advantages:

- First, it is flexible, as it permits phasing in of routes to 3rd countries in the future.
- Second, it limits economic distortions, as there will be no discrimination on routes (all airlines face the same obligations on the same routes).
- Third, the volume of emissions covered by the system is potentially very large.
- Fourth, it may encourage 3rd countries to opt in on a voluntary basis.

The idea behind this scenario is that the countries that have ratified the Kyoto Protocol are those most likely to sign up to an emissions trading scheme for international aviation.

IATA [2001] analyzed the effects of a route-based scheme and concluded the following: ‘On a route-based scheme, some switching between destinations by carriers and customers is conceivable, but this would be unlikely unless passengers view routes as close substitutes. However, introducing new stopovers to create new routes, which are close substitutes and distortions of competition between rival hubs that offer similar services might lead to more significant effects’.

5.6 Are there ancillary benefits from tackling climate change?

General

Policies aimed at mitigating environmental effects in one area can have significant effects on other aspects of environmental quality [RIVM, 2004]. For example, measures to tackle climate change through fuel use can have a beneficial influence on regional air pollution, as the two problems are due largely to the same activity. On the other hand, optimizing the engine design of heavy-duty vehicles with respect to NO_x emissions may lead to higher fuel use (and hence CO_2 emissions). RIVM [2004] has reported that, in general, European emissions of SO_2 are reduced by up to 14% compared with a 'no Kyoto policies scenario'. Implementation of the Kyoto Protocol would have important ancillary benefits in reducing regional air pollution.

Aviation

Benefits of climate policies for aviation will probably depend mainly on the specific design of the instruments implemented. Emissions trading or charges aimed solely at CO_2 and thus fuel efficiency may lead to negative trade-offs with regard to emissions or impacts that are not directly related to fuel consumption. However, emissions of SO_x and other such substances related directly to the amount of fuel consumed may be reduced.

figure 5 Development of global fleet-average NO_x emission factor and ICAO/CAEP standards for NO_x emissions of aircraft during Landing and Take-Off (LTO) cycle [source: UBA, 2004]

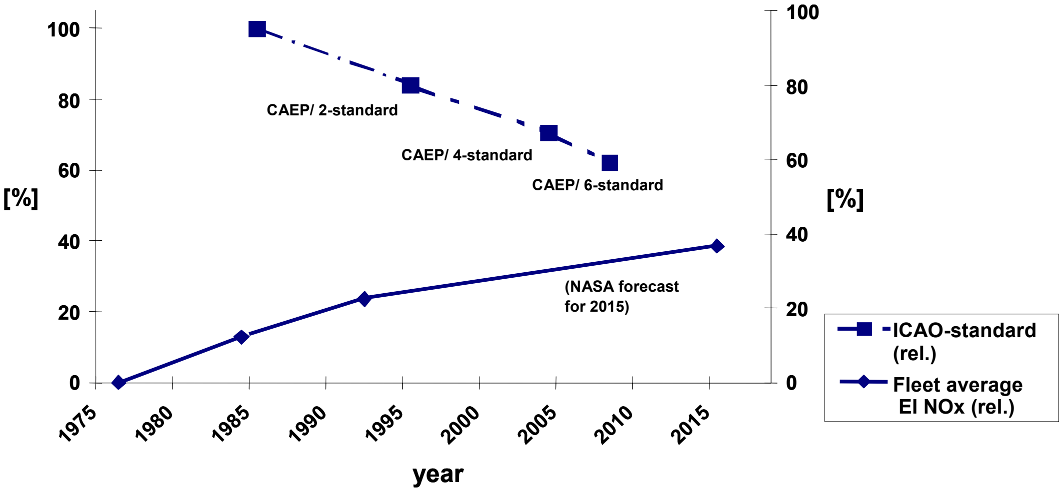

Figure 5 shows that despite NO_x emission standards for the Landing and Take-off cycle, NO_x emissions have increased in the last 25 years and may even continue to rise. The main reason for this development is that aircraft engine combustion temperatures will rise as engines become more fuel-efficient, leading to higher NO_x emissions. It should be noted, however, that NO_x emissions contribute indirectly to radiative forcing and can thus themselves be considered as a greenhouse gas (see chapter 2). Effective climate policies in the aviation sector will therefore also have to address (at least in the long run) NO_x emissions in the cruise phase of flights. This may thus also contribute to mitigating aviation contributions to acidification and ground-level air quality.

6 Mitigation: shipping

6.1 Introduction

The aim of this chapter is to review current developments regarding mitigation policies in the marine sector. The structure of this chapter is as follows:

- Distinct characteristics of shipping (Section 6.2).
- Mitigation policies: the global (IMO) perspective (Section 6.3).
- Mitigation policies: the EU perspective (Section 6.4).
- Market-based instruments in international shipping (Section 6.5).

6.2 Distinct characteristics of shipping

Marine transport has a number of distinct characteristics that need to be borne in mind when seeking policies to reduce GHG emissions in this sector [IMO, 2000]:

- It is difficult to define the nation or territory where 'generation' of marine transport services takes place. A significant portion of such transport and its emissions takes place in international waters, beyond national control.
- It is often difficult to determine the country of ownership of a vessel, or the real owner responsible for its operation. The majority of the world's cargo-carrying capacity is registered in non-Annex I countries and, furthermore, ships are often operated on a charter or lease basis, with various lease systems being used.
- The majority of the world's bulk shipments either start or finish their journey in an Annex I country.
- Bunker fuels are commonly sold by dealers independent of the major oil companies, which makes administration of bunker fuels sold and bunker fuel taxes complex.
- The mobility of ships implies that evasion of measures is hard to avoid unless the measures are global in scope. However, this does not mean that actions taken solely by Annex I countries will have no effect.
- The IMO has in the past achieved several global solutions to safety and pollution problems.

6.3 Mitigation policies: the global (IMO) perspective

Emission policy within IMO is driven mainly by air pollution, the NO_x and SO_2 emissions of shipping vessels being relatively high compared with other modes, contributing significantly to air pollution in certain coastal and harbour areas. The main policy initiative aimed at reducing these emissions is the addition of an Annex VI to the MARPOL agreement, to come into force next year. This proposal reduces the sulphur content of bunker fuels (to a maximum of 4.5%), designates SO_2 control areas in which the sulphur content of the fuels used is limited to 1.5% (e.g. in the North Sea and Baltic Sea areas) and establishes NO_x standards for ship engines. Although this Annex was issued in 1997, it was not before May 18, 2004, that it was ratified by sufficient member states (at least 15 countries, representing at least 50% of the world's tonnage). It will therefore come into force on 19 May, 2005. Also, Special Areas and Particularly Sensitive Sea Areas have been identified in which specific protection measures have been put in place.

Following the call by the Kyoto Conference of Parties to the UNFCCC to pursue the limitation of greenhouse gas emissions from ship bunker fuels (Article 2.2 of the Kyoto Protocol), attention has also been given to GHGs. IMO started work on this topic in 1998 by commissioning a study on ship GHG emissions in 2000 to a consortium led by Marintek [IMO, 2000]. In addition, a correspondence group was established by the Marine Environment Protection Committee (MEPC), which was asked to collate any information received, prepare an IMO Strategy/Policy on GHG emissions from ships and to draft an IMO Assembly resolution to that effect. Among the members of this group are several EU member states and the EC. GHG reduction in international shipping has since been on the agenda of the MEPC meetings.

6.3.1 Conclusions of the IMO report on GHG reduction

In the following, we briefly summarize the results of the Marintek study, and report on the current status of the discussions regarding this topic.

The main objective of the Marintek study for the IMO was to examine the potential for reducing GHG emissions through a variety of technical, operational and market-based approaches.

Regarding the short-term potential of technical measures to reduce CO_2 emissions, it was concluded that the potential in new ships was 5-30% and 4-20% in old ships. These reductions could be achieved by applying current energy-saving technologies vis-à-vis hydrodynamics (hull and propeller) and machinery on new and existing ships. The short-term potential of operational measures was even greater: 1-40%. These CO_2 reductions could be achieved mainly by optimizing fleet planning, aimed at, among other things, speed reduction.

The long-term reduction potential was estimated for several types of vessel, as specific case studies. The result of this analysis was that the estimated CO_2 emission reduction potential of the world fleet would be 17.6% in 2010 and 28.2% in 2020. Even though this potential is significant, it was noted that this would not be sufficient to compensate for the effects of projected fleet growth (at 3% per annum growth[22]: a 36% increase in CO_2 emissions in 2010, 72% in 2020). Speed reduction was found to offer the greatest potential for reduction, followed by implementation of new and improved technology.

When considering technical measures in marine shipping, it needs to be borne in mind that ships have a useful life of over 20 years [IMO, 2000] and it will therefore be a long time before technical measures can be implemented in the fleet on any significant scale. Operational measures can often be implemented rather more quickly.

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[22] In line with the 3%-plus average annual growth over the past 20 years.

Besides these technical and operational measures, Marintek investigated the feasibility and effectiveness of the following market-based policy options for GHG reduction in international shipping.

Environmental indexing

Environmental criteria would be used to index vessels according to their environmental performance. This index could then be used for policy purposes, for example to differentiate taxes, port dues and charges.

A voluntary agreements programme

This type of agreement is negotiated between industry or an individual company and government, and is used in several counties, for example to improve the energy efficiency of a specific industry. The EU has also used entered into a voluntary agreement with the automobile industry, agreeing on a certain reduction of the CO_2 emissions of new passenger cars by 2008. In shipping, agreements might be envisaged to adopt emission or efficiency standards, to adopt certain approved practices or agree to take certain actions, or to report emissions or efficiency levels, describing actions being taken to improve them. However, it was considered that are only weak incentives for international shipping to enter into this kind of programme.

Carbon charge on bunker fuel

The cost of bunker fuel (untaxed) is currently the only incentive for the shipping sector to improve its fuel efficiency. A carbon charge would increase this incentive. This effect is confirmed by historical data, which show that bunker fuel demand indeed responds to changes in bunker fuel price. However, there are several obstacles to implementing this policy option, for the following main reasons:

a Unless implemented globally, bunker charges can be readily evaded. If they apply in a limited number of counties only, evasion will depend on the location of the ports where bunkers can be tanked free of carbon charge and on the costs of fuel transport versus the level of the charge.

b Revenues need to be allocated, which may raise distributional complications similar to the rules needed for distributing emission allowances under an emissions trading system.

Common emission standards

CO_2 standards were also considered in the Marintek study. Safety and pollution standards have been common in international shipping for years and the first NO_x standards will introduced next year, when Annex VI comes into force. Standards could be set for fuel efficiency (fuel consumption per cargo tonne-mile, as a function of ship size and type) and could be implemented relatively easily for new vessels. However, defining these standards would not be an easy task.

Emissions trading

GHG reduction policy in shipping could be brought in line with the Kyoto process by using one of the three flexible mechanisms approved under the Kyoto Protocol:

1 Cross-border emissions trading among Annex I countries.
2 Joint Implementation (JI) emissions mitigation projects developed within Annex I.
3 Mitigation projects outside Annex I, through the Clean Development Mechanism (CDM).

The first mechanism, emissions trading, would imply either that international shipping emissions need to be included in national emissions inventories, or that these shipping emissions would be included in the Protocol, outside the assigned amounts of Annex I parties (under auspices of IMO or others). Including shipping emissions in the national emissions requires that they be allocated to counties, as discussed in chapter 4.

Alternatively, ship owners could be allowed to earn credits for reducing emissions below a baseline. These credits could then be sold in an international trading market such as the ETS, in line with the CDM mechanism. However, this system would require a lot of work to define proper baselines (describing what could be expected to happen if there were no credit system) and credits, as well as enforcement of the rules. Furthermore, the UNFCCC Conference of the Parties (COP) would need to approve the programme.

Regarding the various policy instruments analyzed, the report concludes:

- *A carbon charge* on bunker fuel is not a viable option at a regional level, e.g. Annex I or EU level, due to the huge scope for evasion.
- *A voluntary agreements programme* does not seem very efficient, although some reductions may be achieved by local agreements, or agreements between Annex I countries/IMO and ship owners.
- *Environmental indexing* does not seem to be a very efficient tool for reducing emissions, even though certain reductions might be achieved on a voluntary basis.
- *Emission allowance trading*, either along with other sectors in Annex I countries or as a separate system outside the Annex I countries, appears unviable as an option, because of the severe problems involved in capturing emissions from the shipping industry.
- *Energy or emission efficiency standards* seem a promising option, especially for new vessels.
- *Emissions credits sales* resulting from abatement measures is also a very promising option, and could in the long run provide very strong economic incentives for ship owners to reduce emissions through technical measures.

Based on these conclusions, the report proposes the following strategy for IMO to implement policy to curb GHG emissions:

- Explore interest in entering into voluntary agreements, including between the IMO and ship owners, or in using environmental indexing.
- Start work on design of emission standards for new and possibly also existing vessels.
- Pursue the potential of trading of credits earned from additional abatement measures implemented on new and possibly also on existing vessels.

Relationship with other policies

Any measures to reduce ship GHG emissions should make due allowance for other policy issues and goals, such as pollution prevention and safety policies. Some examples:

- There is a trade-off between CO_2 and NO_x: engine-based CO_2 reduction measures often increase NO_x emissions and vice versa (inherent to all combustion engines).
- More stringent safety regulations may evoke measures that reduce the fuel efficiency of (marine) transport. For example, double-hull oil tankers are less fuel-efficient that single-hull tankers.
- Designation of environmentally sensitive areas might lead to detours or to a shift of goods to other (land-based) modes. Both effects are likely to lead to an increase in CO_2 emissions.

6.3.2 Recent discussions in IMO

Since the report was issued in 2000, the IMO Marine Environment Protection Committee (MEPC) and its correspondence group on GHG emissions have continued to work on this topic. In 2002, the working group published a report describing the outcome of the work performed to date. The main results were the following [IMO, 2002]:

- Views differed on how IMO should formulate an overall policy on reduction of CO_2 emissions. Some members supported a policy with the objective of reducing unitary emissions from ships (e.g. emissions per tonne-mile) and using this to define and obtain a target of relative reduction of ship emissions. Others were in favor of IMO only identifying mechanisms for achieving emission reductions, considering it inappropriate for IMO to define actual reduction targets.
- A voluntary environmental indexing scheme was found to be the most appropriate mechanism at this stage for reducing ships' emissions (see also [EC, 2002]).
- The following alternative options were identified for further elaboration by IMO: a) development of standards, b) linking shipping emissions to emissions trading with other sectors or general international mechanisms (e.g. CDM).
- It was furthermore proposed that the MEPC should also work on methodological aspects related to the reporting of GHG emissions from ships.

The group also issued a draft Assembly resolution regarding IMO's GHG strategy. This resolution was adopted by the Assembly in a slightly modified form in 2003 as Assembly resolution A.963(23). It urges the MEPC to establish a GHG emission baseline, to develop a methodology to determine the GHG emission index for ships, to develop guidelines for practical implementation of the GHG emission indexing scheme, and to evaluate technical, operational and market-based solutions.

At the 51st meeting of the MEPC (March 2004), Norway submitted a document with considerations on the development of an operational-based index as a starting point for an IMO indexing scheme. The document further argues that the establishment of a GHG emission target for international shipping should be examined. However, during the meeting of the MEPC, the delegations of China, India and Saudi Arabia were not willing to discuss this issue further. Their main concern was that the report did not adhere to the principle of common but differentiated responsibilities for the developed and developing countries as formulated by the UNFCCC, i.e. between the Annex I and non-Annex I countries. Since no agreement was reached on this issue, the MEPC decided to postpone the discussion until the next meeting, to be held in October 2004.

In preparation for this 52nd meeting of the MEPC, several papers were submitted that mainly reflect the opposing views on this subject: India stresses that the basis of common but differentiated responsibilities is key for further discussion of GHG emission reductions (MEPC 52/4/9), whereas Norway argues that any GHG policies should be applicable to all ships, irrespective of their nationality. Their main arguments are that:

a The Kyoto Protocol is aimed at domestic emissions, while the characteristics of international shipping emissions require fundamentally different treatment.
b The IMO has a strong tradition of developing mechanisms that do not discriminate between Member States.

At MEPC52 it was agreed only to focus at the technical issues at this stage and to further elaborate on the indexing scheme. IMO Members were asked to carry out trials, using the draft guidelines and to report to the MEPC53.

6.3.3 CO_2 emission indexing

As already mentioned, the IMO considers development of a CO_2 emission indexing scheme to be an appropriate starting point for reducing marine GHG emissions. The delegations of Norway, Germany and the United Kingdom have therefore started work in this issue, developing draft guidelines for such a scheme (MEPC 52/4/2) and investigating the possibilities embodied in this approach (MEPC 51/INF.2).

The basic idea behind a CO_2 emission index is that it describes the CO_2 efficiency (i.e. the fuel efficiency) of a ship, i.e. the CO_2 emission per tonne cargo per nautical mile. This index could, in the future, assess both the technical features (e.g. hull design) and operational features of the ship (e.g. speed). However, the current first draft addresses the latter only.

In the current proposal by the MEPC [MEPC 52/4/2], the CO_2 emission index is defined as:

*the ratio of mass of CO_2 per (mass of cargo * transport distance).*

Its unit is t CO_2/(t cargo * nautical mile).
For passenger ships, 'mass of cargo' should be replaced by number of passengers carried, while for car ferries the number of cars could be used, and so on. One would generally first determine fuel consumption rather than the mass of CO_2 emitted, later converting these data to mass of CO_2.

The initial index of a ship should:
- Cover the fuel used by both the main and auxiliary engines.
- Be based on a representative time window of operation.
- Cover a typical operational pattern for the ship being considered.

For example, the CO_2 emission index could represent an average value of the energy efficiency of a ship's operation over a period of one year.

To establish the CO_2 emission index, information needs to be collected on:
- Distance traveled.
- Quantity of fuel used.
- Total power output.
- Relevant fuel quality information.
- The type, weight and/or number of cargo (items) on board, in the appropriate measurement unit.

Monitoring and measurement procedures should be incorporated in an environmental management system (ISO 14001) and should be verifiable. The index can thus also be used as a performance indicator under ISO 14001, allowing trends to be analyzed and targets set.

However, even though these guidelines show the main features and methodology that can be used for a CO_2 emissions index, there are still a fair number of hurdles to take before such a system could become operational. The main bottleneck appears to be that there is major variation in the fuel efficiency of similar ships, which is not yet well understood.

This is illustrated by research by the German delegation of IMO's Working Group on GHG emission reduction (MEPC 51/INF), in which the specific energy efficiency (i.e. a CO_2 emission index) was calculated for a range of container ships, taking into account engine design factors rather than operational data. The results of this study show that there is considerable scatter in the specific engine efficiency of the ships investigated, which could not be properly explained by the deadweight of the ships, year of build, ship speed and several other ship design characteristics.
The paper therefore concludes that the design of any CO_2 indexing scheme, and its differentiation according to ship type and characteristics, requires in-depth investigation. Before such a system can be used in an incentive scheme, the reasons for the data scatter need to be understood. This is a prerequisite for

reliable prediction of the economic, competitive and environmental effects of any incentive based on this method. Only then can incentives involving this index be properly designed and optimized for achieving political and environmental objectives.

6.4 Mitigation policies: the EU perspective

In 2002, the EU published a European Union strategy to reduce atmospheric emissions from seagoing ships [EU, 2002]. The background of this strategy is the 6th Environmental Action Programme (6EAP), which lays down targets for both air quality and greenhouse gas reduction. Since shipping contributes to both these types of emission, the strategy likewise addresses both. In the following, we focus on the strategy set out for the greenhouse gasses.

In the context of Article 2.2 of the Kyoto Protocol, the EU Council of Ministers has urged IMO to adopt a concrete, ambitious strategy on greenhouse gases. Furthermore, the 6th EAP requests the Commission to identify and undertake specific actions to reduce GHG emissions from marine shipping if no such actions are agreed within IMO by 2003.

In the EU strategy [EU, 2002] a number of objectives are being proposed to guide EU and national policies. For GHG emissions the objective is to reduce ships' unitary emissions of CO_2. However, no quantitative goal was proposed.

The strategy concludes with the following actions and recommendations related to GHG reduction[23]:

- International action through IMO is the best way to regulate the environmental performance of ships of all flags. The Commission will continue to develop coordinated EU positions at IMO to press for tougher measures to reduce ships' emissions of air pollutants, greenhouse gases and ozone-depleting substances.
- Member States should support IMO work on developing a strategy to limit GHG emissions from shipping, initially establishing a system of voluntary environmental indexing for such emissions, but ensuring that further mandatory measures are not ruled out in the longer term if necessary. If IMO has not adopted a concrete, ambitious strategy by 2003, the Commission will consider taking action at EU level to reduce ships' unitary GHG emissions.
- Member States should support the IMO's consideration of methodologies related to the reporting of GHG emissions based on fuel sold to ships engaged in international transport, with a view to allocating ship emissions to national inventories of parties to the UNFCCC.
- Member States should continue to develop and support coordinated EU positions at IMO pre-meetings, and should also support new transitional measures allowing the Presidency or the Commission to formulate the European position at the IMO.

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[23] Note that although we here only consider those parts of the strategy that relate to GHG emissions, the strategy covers all atmospheric emissions from seagoing ships.

- Maritime transport will be part of the EU framework on transport infrastructure charging that the Commission was scheduled to propose in early 2003, with the maritime charging regime to be developed on the basis of ships' environmental performance, including CO_2 emissions.
- A new Clean Marine Award Scheme will be introduced in 2002, and annual workshops on best practice in low-emission ship technologies will be held.
- The Commission urges port authorities to consider, among other things, introducing voluntary speed reductions.
- Under the 6th Framework Programme, the Commission will continue to fund research into low-emission ship technologies.

At the end of 2003, the European Parliament adopted a motion regarding this strategy, in which greenhouse gas emissions were addressed as follows:
- It supports the Commission's overall objective to reduce the contribution of ships' atmospheric emissions towards environmental and human health problems in the EU, but underlines that this overall objective should be extended so that it explicitly also aims to reduce ships' GHG emissions and their contribution to global warming.
- It calls on the Commission to come forward – before the end of 2004 – with proposals for EU-wide economic instruments aimed at reducing atmospheric emissions from ships.
- It notes the Commission's intention to identify and undertake specific actions to reduce GHG emissions from marine shipping if the IMO has not adopted a concrete ambitious strategy on ship GHG emissions by 2003.

Also at the end of 2003, the Council of the European Union reached conclusions regarding this strategy, including the following statements on greenhouse gases:
- The Council supports the development of an IMO Strategy to limit GHG emissions from shipping, underlines the need to improve the methodologies for estimating and reporting emissions from ships, and urges the Member States and the Commission to work together at IMO to ensure that methodologies are improved and that the IMO GHG strategy is concrete and ambitious.
- It urges the EU Member States to submit concrete proposals on the different aspects of the IMO GHG Strategy.
- It recognizes the need to investigate specific EU actions with respect to the reduction on GHG emissions by marine transportation, and invites the Commission to report on possible actions on ship GHG emissions in 2005.

6.5 Market-based instruments in international shipping

There are currently only a few cases of counties or ports introducing economic instruments to create incentives to reduce shipping emissions. Examples include:
- Environmentally differentiated fairway dues in Sweden.
- The Green Award scheme in place in 35 ports around the world.
- The Green Shipping bonus in Hamburg (now discontinued).
- Environmental differentiation of tonnage tax in Norway.

None of these incentives are based on GHG emissions, but generally relate to fuel sulphur content, engine emissions (mainly NO_x), ship safety features and management quality.
Elsewhere, seagoing ships are hardly taxed at all, paying only the cost of the services provided in ports [EU, 2002].

In 2003 the European Commission commissioned NERA to investigate the feasibility of a broad range of market-based approaches to regulate atmospheric emissions from seagoing ship in EU sea areas. The study focused primarily on policies to reduce the air pollutants SO_2 and NO_x, but the approaches adopted were also deemed applicable to other emissions, including CO_2.

Six market-based programmes were analyzed, three trading and three charging schemes:

Trading
- Credit-based trading programme:
  - Distinguishing between a simple and a rigorous credit approach.
- Benchmark trading:
  - Distinguishing between universal benchmarking and trading consortia.
- Cap and trade.

Charging
- Taxation/charging:
  - At point of sale.
  - Fuel use tax/charge.
  - Emission tax/charge.
- En-route charging.
- Differentiated port or fairway dues.

Subsidies were also identified as a possible approach, but these were not studied further.

The feasibility of these policy options was then assessed using various environmental, efficiency, distributional and institutional criteria.

The study concludes that there seems to be a trade-off between cost savings and environmental gains on the one hand, and legal and political acceptability and administrative costs on the other. Approaches involving limited costs and legal and political obstacles also yield more limited environmental gains. It is therefore recommended to begin with a more gradual approach, to gain experience with market-based policies in the marine sector, which could be expanded to more ambitious policy instruments in the future. Three approaches were identified as most promising in this respect:
- Voluntary port dues differentiation.
- Consortia benchmarking approach.
- Rigorous credit-based approach.

A follow-up study is currently being launched by the EC. In scope it includes both pollutant and GHG emissions and consists of three parts:

- Assigning ship emissions to European countries (EU Member States and candidate countries), according to seven different approaches:
  - According to location of emissions.
  - According to flag of ship.
  - According to industry fuel sales estimates.
  - According to reported fuel consumption.
  - According to freight tones loaded.
  - In proportion to national emissions.
  - According to country of departure/destination.
- Investigation of costs, emission reduction potential and practicalities of ship emissions abatement technologies (all vis-à-vis reduction of pollutant emissions).
- Elaboration of practical details of the following three possible EU market-based instruments to reduce shipping emissions of NO_x, SO_2 and CO_2, building on the NERA study:
  - Simple credit-based approach.
  - Consortia benchmarking.
  - Voluntary differentiated dues.
  - Subsidies.

This study can therefore be expected to provide valuable information on data availability for the various allocation options, at least for the region relevant to the European Union. The final report is due one year after the start of the project.

7 Data requirements and availability

7.1 Aim and background

The aim of this chapter is to provide an overview of:

- Data requirements related to ‘allocation’ and ‘mitigation’ (Section 7.2).
- The UNFCCC/IPCC reporting requirements (Section 7.3).
- The EC reporting requirements (Section 7.4).
- Inconsistencies in international bunker fuel statistics (Section 7.5).
- Availability of data to determine CO_2 emissions from ships (Section 7.6).
- Conclusions: the way forward (Section 7.7).

At the request of SBSTA 18, in the spring of 2004 ICAO and IMO organized expert meetings together with the UNFCCC Secretariat in order to improve the inventories of emissions from aviation and navigation and recommend the results to the IPCC as input for the revision of the revised 1996 reporting guidelines. One important issue was to improve the definitions of international bunkers, which differ considerably among the various international organizations (IPCC, IEA, IMO, ICAO, etc.) and lack consistency.

This chapter aims to clarify why bunker fuel statistics are of limited use for policy objectives that can be pursued as part of the UNFCCC process by any substantial number of Parties. To this end, we shall first identify the data requirements ensuing from such policy objectives. Next, available data sources will be reviewed and problems identified. Finally, we will elaborate on the way forward.

7.2 Data requirements related to ‘allocation’ and ‘mitigation’

Many studies and policy documents have been published in the last ten years on the issue of emission data inventories and monitoring methodologies, for international aviation and shipping alike. All sources provide a list of possible monitoring methodologies, data sources and problems. What is remarkable, however, is the very limited attention that has been paid to the criteria the data should meet. Because of political considerations, discussions on the issue of data availability and requirements have often been limited to the reporting requirements under the UNFCCC process. One disadvantage of discussing reporting requirements and data availability in isolation lies in the lack of guidance that can be derived from other objectives. Obviously, reporting on emissions from international transport modes may also serve as a basis for other policy objectives[24] such as:

- Allocating responsibilities to Parties.
- Implementing policy instruments like emissions trading.

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[24] It should be emphasized here, based on the UNFCCC principle ‘common but differentiated responsibilities’, that not all Parties (e.g. developing states) would have to be subject to these policy developments in the initial phase.

Below, we discuss the data requirements related to each of these policy objectives.

Data requirements related to allocation

Chapter 5 already discussed in detail the data requirements of different allocation options.

With regard to aviation, it was concluded that only option 5 (destination/arrival) would be feasible under both a regional *and* a global scheme. Option 4 (airline companies) may only be feasible under a global scheme, as outflagging, lease constructions, etc. will no longer suffice to avoid cost increases due to mitigation policies. Option 4 and 5 both require data based on aircraft/vessel movements and fuel/emission data of airline or shipping companies.

Furthermore, both with regard to aviation *and* shipping, it was concluded, that Option 3 (bunker fuel sales) is in our opinion unfeasible because it does not meet the two criteria ('PPP' [25] and 'evasion') considered in this study. This implies that allocation may need to be based on other allocation options which require movement data.

Based on these findings, the **first conclusion** that can be drawn is that allocation of responsibilities for international aviation and shipping emissions requires (actual) movement data (fuel consumption, distance, vessel/aircraft type). Assuming that option 3 (fuel bunker sales) is unfeasible, any efforts to improve fuel bunker statistics are therefore of limited use for the purpose of 'allocation' to Parties.

Data requirements related to policy instruments

Many potential policy instruments, such as (voluntary) emissions trading and emission charges, need to be based on ex-ante (modelled values) or ex-post movement data of individual aircraft or ships[26]. Only instruments based directly on fuel, such as fuel levies or an emissions trading system among fuel suppliers, could be based on data of actual bunker fuel sales. It should be stressed, however, that these instruments which apply directly to fuel, are only feasible under global schemes. Regional introduction of, say, emissions trading among EU bunker fuel suppliers may encourage airlines or ships to avoid the cost increase by taking more fuel on board at (air)ports outside the EU than actually required for the execution of a trip. The extra fuel can then be used for the next trip. This phenomenon is called 'fuel tankering'. The avoidance behaviour of fuel tankering reduces the effectiveness (in terms of emissions reduction) and thus the feasibility of the instrument.

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[25] In the current situation *without* climate policy instruments, tankering already takes place, particularly by by shipping Important reasons for tankering of aviation fuel include [IPCC, 1999]: (i) high fuel costs resulting from expensive distribution infrastructure and local taxes, (ii) low fuel availability at certain remote airports, (iii) concern about fuel quality at particular locations, and (iv) slot availability.

[26] By *ex-ante* calculation we mean that the emission level of a given flight or trip is determined *before* the trip has taken place, based on parameters like calculated distance and aircraft or vessel characteristics. By *ex-post* calculation we mean that the emission level is determined *after* the flight/trip has taken place, based on flight parameters like actual fuel use or on measured settings. From the perspective of economic efficiency, ex-post calculation of emissions is preferable, as it leaves operators a wider range of options to reduce emissions (for example, emissions calculated ex-ante provide no incentives for operational measures).

The **second conclusion** that can be drawn from the perspective of data requirements is that implementation of emission-related policy instruments can only be based on flight movement or navigation data such as actual fuel consumption. Statistics on bunker fuel sales cannot form an adequate database for monitoring protocols for policy instruments like emission trading or charges that are indexed directly to aircraft or ship emissions. The main reason is that the amount of bunker fuel sold is not necessarily equal to the fuel consumed on the trip in question. Furthermore, existing emission models are of limited use only, as the available data are too limited to form a definitive basis for emissions trading or charges. Models might be used, however, to establish a first-pass estimate of emissions, based for example on aircraft or ship type, distance and engine used on a specific trip.

Conclusion

Allocating responsibility to Parties and establishing an adequate monitoring and enforcement system for policy instruments both require *accurate* data on current vessel and aircraft operations. These data, i.e. actual fuel consumption, might either be measured or an estimated average value taken as a basis, depending on the ship/aircraft, engine and route.

Statistics on bunker fuel sales are not necessary for the purpose of feasible allocation options and cannot form a suitable database for monitoring protocols for emissions trading or levies. Bunker fuel statistics might be used, however, to verify the quantified level of emissions based on operational data.

7.3 UNFCCC/IPCC reporting requirements

All Parties to the Convention have an obligation to report national inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not covered by the Montreal Protocol. Parties must report on CO_2, CH_4, N_2O, PFCs, HFCs and SF_6. They should also provide information on emissions of CO, NO_x and NMVOCs (non-methane volatile organic carbon compounds), and are encouraged to provide information on emissions of SO_2.

According to decision 18/CP.8, Parties shall use the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* on reporting. In preparing the inventories, they also shall use the IPCC *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*. These IPCC guidelines also lay down how emissions of bunker fuels are to be estimated and reported. According to these guidelines, *Parties should report emissions from international aviation and marine bunker fuels as two separate entries in their inventories*. The domestic, civil part of these emissions is reported in table 1.A.3 of the Common Reporting Format (CRF) as defined in the UNFCCC guidelines on reporting and review 18/CP.8, the military part in table 1.A.5 and the international part as a 'Memo' item in table 1.A. Multilateral (military) operations should be reported as another memo item of table 1.A.

In the National Inventory Reports (NIR), Parties shall explain how they distinguish between domestic and international fuel consumption and emissions. According to the IPCC guidelines, fuel use data distinguishing between domestic and international aviation may be obtained in different ways (bottom-up and top-down data sources).

Bottom-up data can be obtained from:
- ‘Self-reported’ data by airlines: under current legislation, trip fuel must be registered by the flight instruments, by the flight data recorder ('black box') and in the mass and balance documentation that must be prepared before and after each flight.
- Average values of emissions, based on ‘modeled’ aircraft movement data and tables of fuel consumed.
- Data from ATM authorities, which keep detailed track of all flights undertaken in their airspace. For example, Eurocontrol currently keeps track of distances, aircraft/engine types, environmental data and O-D pairs for every flight handled.

Top-down data can be obtained from:
- National energy statistics.
- Data from current operations of bunker fuel suppliers.
- Surveys of airports for data covering the delivery of jet kerosene and aviation gasoline.
- Production by refineries (production of aviation fuels), corrected for import and export (i.e. apparent domestic consumption of these fuels).

Combinations of these options might also be feasible. For example, ATM data could be used as a worst-case estimate on which airlines could improve by self-reporting actual post-flight data.

Calculation of CO_2 emissions from fuel combustion might be carried out at three different levels, referred to in the IPCC Guidelines as Tiers 1, 2a and 2b. The three methods differ in terms of accuracy, detail and complexity. This set-up is similar to the CORINAIR and ANCAT/EMCAL reporting guidelines. All methods are based on distinguishing between domestic fuel use and international fuel use (see Annex B).

7.4 EC requirements

The monitoring decision of the European Council (280/2004/EC) requires Member States to report once a year to the European Commission their national inventory data on emissions and removal of the greenhouse gases covered by the Kyoto Protocol. The deadline for submission of the inventory to the European Commission is three months ahead of the deadline for submission to the UNFCCC, to allow the European Commission to submit the European Community’s (EC) greenhouse gas inventory in time to the UNFCCC.

In the EC inventory, total international bunker fuel emissions are the sum of the international emissions of the Member States. In this inventory, no correction is made for the part of the international bunker emissions of the Member States which is intra-EU transport and, thus, for the UNFCCC Party EU to be considered as 'domestic' (= non-international) transport. The data basis for the EC IPCC *reference approach* for CO_2 - used only for verification of the sectoral CO_2 emissions reported for fossil fuel combustion - is the Eurostat New Cronos database. Member states submit energy statistics to Eurostat using joint Eurostat/IEA (International Energy Agency)/UNECE (United Nations Economic Commission for Europe) questionnaires. Based on this information, Eurostat compiles annual energy balances, which are used to estimate CO_2 emissions from fossil fuels by Member States and for the EU as a whole.

For international bunkers, data on 'international' aviation (from EU perspective) are not estimated separately in the above process. This means that the total Eurostat-calculated CO_2 emissions estimated with the reference approach include CO_2 emissions from international aviation, which limits the comparison with the sectoral CO_2 emissions reported as part of the EU total. Moreover, for international marine bunkers in the IPCC *reference approach* also no correction is made for intra-EU shipping. The IPCC default carbon emission factors adjusted for the fraction 'non-oxidized' are used in the Eurostat New Cronos database.

7.5 Inconsistencies in international bunker fuel statistics

In many cases, national practices for distinguishing between energy use for domestic and international transport do not or do not fully comply with the definitions of the UNFCCC/IPCC/IEA reporting guidelines. This has been identified and explained by the IEA in their energy statistics publications [IEA, 2004ab] and by the UNFCCC Secretariat in their analysis of the fuel use for this so-called 'Memo Item' reported by Annex I countries [UNFCCC, 2004]. IMO and ICAO, as well as the various national emission inventory reports to the UNFCCC, have also discussed these issues.

Many of the deviations from international reporting standards arise from the following factors:

- In most countries there are no taxes or excise duties to be paid on bunker sales for international transport. In national energy statistics these *tax-free amounts of transport fuels sold* are often classified as being for *non-domestic consumption* (i.e. outside the so-called 'special trade system' boundary). However, since the destination of a ship or airline is not always clear – i.e. for fishing vessels sailing to the open sea, or vessels transporting goods on rivers and canals – this fuel consumption category may include fuels and associated emissions that should, according to IPCC, UNFCCC and IEA definitions, be classified as domestic transport [IPCC, 2000; IEA, 2004c; UNFCCC, 2004]. IEA [2004c] states that many OECD countries, when reporting on international civil aviation incorrectly exclude the fuel used by domestically owned carriers for their international departures.
- Another approach used by some countries is to classify aviation as domestic or international according to the flag of the airline/ship, thus irrespective of the destination [IEA, 2004c; DNV, 1999]. The IEA [2004c] states that many OECD countries, when reporting on domestic aviation, also incorrectly

include fuel used by domestically owned carriers for outbound international traffic.

- In *international marine transport* in particular, because of favorable fuel prices at some ports compared to others – e.g. due to the proximity of many oil refineries –much more fuel is generally purchased than required for the next stop. Examples are the high ranking numbers 2, 3 and 4 of Singapore, the Netherlands (Rotterdam) and the United Arab Emirates in global marine bunker fuel sales [EDGAR/IEA 2004a,b,c]. This makes the allocation of these fuels sales as 'all used for foreign journeys' questionable.
- For *international aviation* ‘tankering’ is generally less of an issue, as most aircraft will – for flight economy reasons – only carry the fuel required to get to their next destination (including some additional amount for safety reasons, of course). However, in some cases airlines may 'tanker' fuel for subsequent flights (e.g. return flight), for various reasons (availability, quality and price of jet fuel at next airport) [UNFCCC, 2004].

The distinction may be further blurred by the following factors:

- A trip between two locations in the same country may look like an international trip if the route includes *transport over the open ocean or over the territory of other nations*. Examples are ships sailing from San Diego, USA to Hawaii, USA, or from Marseilles in France, Europe to Reunion, France in the Indian Ocean. For air transport, domestic journeys may mean flying over other countries (e.g. from Alaska to mainland USA or from southern to northern Norway).
- In addition, a ship or aircraft with a foreign port as its final destination may first have to make *a stop at another domestic port* to deliver or pick up goods or passengers. In such cases, different conventions may be used to classify the first, 'domestic' part of the journey, which relates partly to items transported only domestically, and other items, for which the first segment is part of their international journey.
- In the time series of a number of countries (see figures 3 and 4) several rather *abrupt interannual changes* can be observed, which one would not expect (apart from impacts from the crises in oil prices or of economies in general, or from major international events such as the 9/11 attacks). Apparently, either statistical definitions or the statistical data collection system underwent some change at these points in time, without the data for previous years being recalculated. These features can therefore also be considered as indicators of the apparent uncertainty in the national datasets.

Finally, there is the question of where the fuel use and emissions of military transport activities are to be allocated:

- For reasons of confidentiality, most countries report these activities in combination with other information or do not report it at all [IEA, 2004a]. Since the relative size of these sources is unknown, it is hard to judge the extent of misreporting.

IMO expects that the USA is probably the only country where this may be a substantial fraction of marine transport. The Memo item for multilateral operations used by Annex I countries provides insight on the size of activities reported under this heading.

The IPCC Good Practice estimates the uncertainty in total aircraft activity data to be small in the case of complete survey data (about 5%), but incomplete surveys, i.e. for the domestic part, may increase the uncertainty to a factor of two. For marine transport, similar qualifications have been made [IPCC, 2000].

Recently [Corbett and Koehler, 2003] and [Endresen *et al*., 2003] suggested that the amount of fuel estimated to be used in international shipping could be substantially biased. However, these results of these studies cannot simply be compared with the data reported to IEA or UNFCCC, as they make no allowance for the fact that some marine shipping may be domestic and some non-ocean-going ships may be engaged in international transport.

7.6 Availability of data to determine CO_2 emissions from ships

Allocating emissions to countries and establishing policy instruments to mitigate emissions both require a highly accurate and reliable monitoring and reporting system. In Section 7.2 we already concluded that bottom-up data such as actual fuel consumption of a journey, vessel characteristics or movement data are only sufficient to serve as a basis for policy instruments such as emission standards, charges or emissions trading schemes.
For example, if carbon charges or dues are to be differentiated according to fuel efficiency, information is needed about the fuel efficiency of a ship compared with other vessels of the same type. In this section we therefore briefly describe what relevant data are currently available for determining the CO_2 emissions of oceangoing vessels.

Lloyds Marine Intelligence Unit (LMIU) database
LMIU owns a comprehensive database [www.lloydsmiu.com] containing all ship movements world-wide. It currently comprises data on over 112,000 vessels above 100 tonnes gross tonnage (GT), owned by over 40,000 shipping companies, containing data such as:

- Vessel type.
- Ownership structure (parent company, registered owner, manager and charterer).
- Flag.
- Vessel size.
- Arrival, bound-for and departure details from over 4,000 ports, daily.
- Tonnage.
- Dimensions.
- Capacities.
- Full engine details (incl. fuel efficiency at designed operating load).
- A range of other vessel characteristics.

Their primary information source is the Lloyds Agency Network.

This database is commercially available and was, for example, used for the quantification of ship emissions by [Entec, 2002].

Although this database is very comprehensive, however, some data relevant to the measurement of CO_2 emissions shipping are lacking:

- The database is limited to vessels > 100 GT, thus excluding smaller vessels.
- Not all ferry movements are recorded, since ports of call are registered on a daily basis only. If ferries makes multiple crossings on one day, this will not be recorded.
- The route taken between ports is not recorded. In the Entec study [Entec, 2002] it is assumed that the shortest route (around land) is chosen.
- Only fuel efficiency at designated operating load is recorded. Actual fuel consumption or parameters relevant to fuel efficiency, such as speed and energy produced by auxiliary engines, are not recorded.
- No information about in-port fuel consumption is recorded.

National and global bunker fuel consumption

National and global data on bunker fuels supplied to international shipping are collected by the International Energy Agency, the UN Statistical Division and the UNFCCC. However, these databases presently have certain shortcomings, especially regarding the distinction between domestic and international shipping, as discussed in the previous section.

Bunker delivery notes

Once Annex VI of the Marpol agreement (see Section 6.3) comes into force, in 2005, a bunker delivery note and a representative sample from each bunkering will be mandatory for ships larger than 400 GT.

These notes will include information on ship IMO number, size, type, date and place of bunker operation and quantity of all delivered bunkers [SBSTA, 2004]. A register will be maintained of local bunker suppliers by port (or other) authorities, and bunker suppliers shall retain the bunker receipts for three years from the date of supply. Consequently, data will be available from all port authorities on all bunker loading, for vessels > 400 GT. These will allow verification of the sulphur content of the bunker fuels on board, which is regulated in this regulation.

These bunker delivery notes may therefore be an accurate and comprehensive information source on the fuel consumption of ships > 400 GT. Although not explicitly specified in Annex VI, a bunker receipt of some type will also be supplied to ships of less than 400 GT [SBSTA, 2003]. At this SBSTA meeting, it was suggested that a national/international split might be estimated by the selection of a lower limit of ship gross tonnage (currently 400 GT).

However, even though bunker delivery notes might provide very valuable data on *total* bunker fuels tanked and consumed, they cannot be used to specify the fuel used on specific voyages or in specific regions or time periods, as it common shipping practice to sail multiple voyages between bunkerings. Furthermore, they do not permit distinction between domestic and international shipping, unless the assumption described in the previous paragraph is made. Nevertheless, the delivery notes could provide a means for improving and validating (quality control) statistics or reported fuel consumption.

7.7 Conclusions: The way forward

Based on the findings of this chapter and other parts of this report, we arrive at the following conclusions and recommendations with regard to the establishment of inventories for climate emissions from international aviation and shipping:

- 'Allocation' of responsibility for international climate emissions to Parties and creation of an adequate monitoring and enforcement system for policy instruments both require sufficiently *accurate* data on current flight or navigation operations.
- In the aviation sector, flight movement data are already available. The most attractive option for arriving at accepted and specific emission figures for individual aircraft would be to base the CO_2 emission on the carbon content of the trip fuel, which airlines are currently obliged to register in the weight and balance documentation. In the United States these fuel consumption data are already available for above a certain size of airlines, as these are required by law to report their financial and operating statistics to the Bureau of Transportation Statistics (BTS) of the Department of Transportation (the so-called 'form 41 arrangement'). Form 41 should be filed monthly by all air carriers that have annual operating revenues of $20 million or more. Among many other reporting requirements they shall report on their actual fuel consumption by type of service and by route group. In the United States, therefore, there is already a comprehensive database comprising the fuel consumption data of airlines and their aircraft that goes back several decades.
- We therefore recommend that other authorities (e.g. EC and IPCC) establish similar reporting requirements as those in force in the US. The oft-heard argument concerning the confidentiality of airline fuel consumption data can be addressed similarly to the reporting of fuel data for stationary resources in national GHG Inventories. For example, by reporting only aggregated data to the public domain.
- A monitoring system based on data on individual flights provides an opportunity to establish data collection systems (measurement of temperature, humidity, etc.) that can be adapted in the future to include non-CO_2 emissions such as the indirect effects of NO_x emissions and cirrus cloud formation.
- In the shipping sector, the availability of movement data is still a problem that needs to be resolved and current research efforts should therefore be continued.
- Statistics on bunker fuel sales are not required for the purpose of feasible allocation options (as discussed in chapter 4) and cannot form an adequate database for monitoring protocols for emissions trading or levies. Bunker fuel statistics might be used, though, to verify the quantified amount of emissions based on operational data. However, current inconsistencies in fuel bunker data sets may require a pragmatic approach and a discontinuation of efforts

along this trajectory, as these data sets cannot support feasible allocation options nor the monitoring requirements of feasible policy options.

8 Regional and local air pollution

8.1 Introduction

The aim of this chapter is to provide a brief review of the emissions and impacts of international aviation and shipping on regional and local air pollution. The chapter is structured as follows:

- Contribution of aviation to regional and local air pollution (Section 8.2).
- Contribution of shipping to regional and local air pollution (Section 8.3).
- Air pollution shipping: the case of the Netherlands (Section 8.4).

8.2 Contribution of aviation to regional and local air pollution

The effect of aircraft emissions on local air quality has been an issue for many years, with the earliest legislation being passed in the United States. Older-generation aircraft (now largely phased out) emitted considerable amounts of visible smoke (soot). The International Civil Aviation Organization subsequently set standards (periodically tightened) for emissions of NO_x, unburned hydrocarbons (HCs), CO and smoke from new engines. Arguably, the principal current problem associated with aircraft and local air quality is now nitrogen dioxide (from NO_x emissions).
Increasing air traffic and NO_x emissions could contribute to breaches of NO_2 limit values under European regulations designed to maintain local air quality, in particular around major airports. In the UK, for example, this seems to be resulting directly in constraints to expansion of capacity (London Heathrow) unless it can be shown that future air quality standards will not be breached.

In comparison, far less attention has been paid to the impact of aviation nitrogen oxide emissions, both near-ground and during the cruise phase, on regional ozone levels and on acidification and eutrophication.

Recently, [Pison and Menut, 2004] found that aircraft emissions of nitrogen oxides have a non-negligible impact on low-level ozone concentrations in large urban areas, such as around Paris. A maximum increase of ozone occurs during daytime at remote areas and at altitude. Closer to the airports, under heavily polluted circumstances and at night, ozone levels decrease due to titration by nitrogen oxides. This implies that these emissions need to be taken into account by urban policy makers and planners.

Until recently it was also assumed that non-LTO (non-Landing-Take-Off Cycle) emissions were unimportant for local to regional air quality. However, [Tarrason *et al.*, 2004] have shown that aircraft emissions of nitrogen oxides above 3,000 feet over Europe make a small but significant contribution to nitrogen deposition (2-3 %) and mean surface ozone (about 1%). Their contribution to exceedance of European air quality standards, such as AOT40 (5-10%) and AOT60 (about 30%) is even more significant. In the future, when background tropospheric ozone levels are expected to rise and surface emissions have been reduced, their importance may grow even further. These estimates still need further refinement and confirmation from studies with other models, however, and also lack support by observational evidence. For other aircraft pollutants such as carbon monoxide and non-methane volatile organic carbon, the emissions occurring during taxiing and idle phases are more important than those during non-LTO, as these are relatively larger at low power settings. However, these emissions are relatively small compared with other surface emissions and therefore not as relevant for air quality policies.

8.3 Contribution of shipping to regional and local air pollution

Even though shipping is relatively fuel-efficient, its emissions of SO_2, NO_x and PM10 are high in comparison with other transport modes. This is due to the different kinds of fuel used by shipping (containing, among other things, relatively large amounts of sulphur) and to the lack of emission standards for engines, for years a very common policy in the realm of road transport.

Research by the Norwegian Meteorological Institute [Jonson, 2000] shows that most of the nitrogen and sulphur emissions from shipping are deposited in the sea[27], close to the sources. The remaining pollutants are then dispersed through the atmosphere, with some fraction later being deposited on land, mainly in coastal regions. For many countries bordering the sea, sulphur emissions from shipping are among the largest contributors to this form of pollution: close to or over 10%. Marine shipping was found to contribute even more to NO_x emissions in various coastal countries (roughly between 10 and 20%, with Malta an exception at 38%), owing to the longer residence time of nitrogen compounds in the atmosphere. Evidently, all these percentages are higher along coasts.

The study also looked at the effects of these depositions, by analysing to what extent shipping emissions contribute to exceedances of critical loads of acidity and nutrient nitrogen. The conclusion was that shipping contributes significantly to the exceedance of both. For acidity, shipping traffic was found to contribute over 50% to exceedances in most of the coastal areas along the English Channel and the North Sea, in the Baltic sea along the coast of Germany and Poland, and also in large parts of Sweden and Finland. For nitrogen, sea shipping contributes to over 50% of exceedances along large parts of the Baltic coast and in Greece, Croatia, Italy and Spain.

A preliminary estimate of the influence of shipping emissions on atmospheric concentrations of particulate matter, again by the Norwegian Meteorological Institute [Fagerli, 2001], concludes that shipping traffic contributes between 10% and 30% to particulate emissions in most West European coastal areas. However, these calculations are only considered to be a first, rough estimate, based on a limited amount of data, so that further research on this topic was recommended.

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[27] Note that this study and [Fagerli, 2001] used 1990 emission data.

In 2002, Entec published a study, performed for the European Commission, which quantified and analyzed the emissions of ships associated with movements between ports in the EC, using data from 2000 [Entec, 2002]. This study yielded, among other things, the following results:

- A quantification of ship emissions of SO_2, NO_x, CO_2 and hydrocarbons in the North Sea, Irish Sea, English Channel, Baltic Sea and Mediterranean, as well as in-port emissions of these pollutants plus particulate matter.
- Ship emissions per vessel type and flag state, differentiating trips according to whether the starting port or destination port is inside or outside the European Community.
- Future emission projections and effects of a number of different scenarios for the maximum sulphur content of fuels.

Emissions were calculated within the EMEP area (European Monitoring and Evaluation Programme), an area north of 30 deg N that includes the entire territory of Europe and its Seas. Data for 2000 were used for the analyses, of which some (e.g. ferry movements) had to be estimated for lack of monitoring.

Some of the main conclusions were as follows:

- Approximately 40% of pollutant emissions originate from vessel movements between ports within the EU-15, 14% from EU-15 to non-EU/non-accession countries (NON) and 12% from NON to EU-15 movements. The remaining 34% are due to other movements (from, to or between accession countries, between NON-countries).
- Approximately 49% of the emissions arise from NON-flagged vessels, 31% from EU-flagged vessels and 18% from accession country-flagged vessels.
- For particles emitted in ports, just over 50% arises from EU-15 to EU-15 vessel movements. The majority (40%) were contributed by NON-flagged vessels, followed by 36% from EU-flagged and 24% from accession country-flagged vessels.

In the Entec report, emissions were calculated using detailed geographical models, so that it is known where the emissions take place. Striking, though not surprising, is that most emissions occur relatively close to shore, in the Baltic, in the North Sea, in the Mediterranean, along the coast of Portugal, etc. Approximately 30% of all emissions in the EMEP region under investigation were emitted in the North Sea and Baltic.

8.4 Air pollution shipping: the case of the Netherlands

Trends in annual transport emissions of NO_x and SO_2 in the Netherlands are shown in figure 6 for the period 1990 – 2003 [RIVM, 2004]. The figures also distinguish the emissions of road transport and of sea shipping, both in port and on the Dutch continental shelf[28]. They clearly demonstrate that while emissions of these pollutants by road transport have been successfully reduced, marine shipping emissions have steadily risen. The share of shipping emissions in total transport emissions has therefore significantly increased over this period. In

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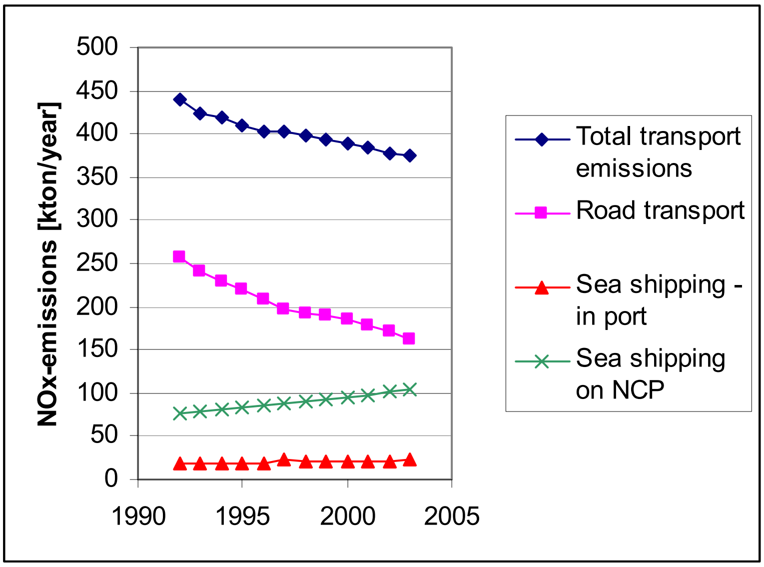
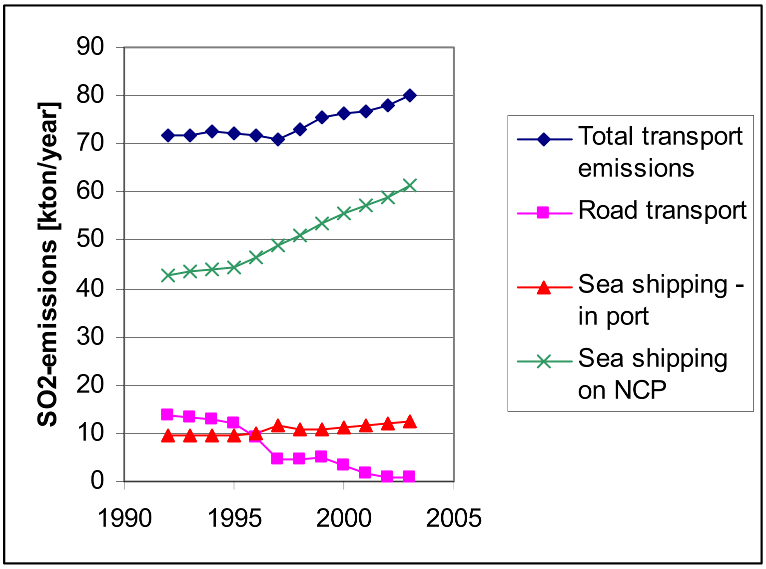
[28] NB: Sea shipping emissions on the continental shelf are excluded from the NEC directive.

2003, sea shipping contributed 28% of the NO_x emitted by transport, 76% of SO_2 emissions and 34% of particle emissions.

figure 6 Emissions in the Netherlands in the period 1990 - 2002: total emissions of transport (incl. shipping emissions on the Netherlands Continental Shelf (NCP)), emissions of road transport, sea shipping emissions in port and sea shipping emissions on the NCP





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Annexes

A Climate impacts

A.1 Introduction

Chapter 3 (Climate impacts) presents our main findings and conclusions on the state-of-the-art with regard to climatic impacts from international aviation and shipping. This annex presents the background study behind these findings, carried out by Peter van Velthoven and Ernst Meijer of the Royal Netherlands Meteorological Institute (KNMI) in cooperation with David S. Lee of the Manchester Metropolitan University.

A.2 Climate effects of aviation: detailed findings

This section provides a more detailed overview of scientific results on the impact of aviation emissions that have been published since the 1999 IPCC Special report on Aviation and the Global Atmosphere. First, we briefly discuss the main conclusions of the Special report (Section A.2.1). Subsequently, we show in Section A.2.2. that some of the forcing estimates given by IPCC (1999) need to be revised. Whilst no international assessment has been undertaken to revise the IPCC RF estimates, an international group of European researchers has undertaken to update the aviation RF chart, but for a base year of 2000 (TRADEOFF project, Sausen *et al.*, 2004); here we provide comments indicating where updates to IPCC are clearly necessary.

A.2.1 1999 IPCC Special Report findings

Carbon dioxide
Carbon dioxide is one of the end products of the combustion of fossil fuels such as kerosene. It has a very long lifetime in the atmosphere and is therefore distributed more or less uniformly in the atmosphere. Since it is a greenhouse gas, its emission has a direct warming effect.

Ozone
Due to the high inlet temperatures and pressures to aircraft engine combustors, nitrogen and oxygen are combined in the high temperature zone of the combustor, i.e. the primary combustion zone [Bowman, 1992]. In the atmosphere below about 16 km, chemical reactions involving nitrogen oxides lead to the formation of ozone, to which aviation is a contributor through its NO_x emissions. As ozone is a greenhouse gas, its increase leads to warming, particularly at cruise altitudes, since the radiative effect of ozone is at its maximum around the upper troposphere and lower stratosphere.

Methane
Although the emissions of methane by aviation are negligible, chemical reactions involving nitrogen oxides emitted by aviation lead to a reduction in the atmospheric concentration of this gas. Methane is a greenhouse gas that is

distributed almost uniformly throughout the atmosphere. Its reduction (by around 2%) leads to a cooling.

Water vapor

Water vapor is a greenhouse gas and its emission by aviation therefore leads to warming. However, the amount emitted into the troposphere by aircraft is very small compared to evaporation of water at the surface, and it is removed within a few weeks by rainfall or snowfall. In the stratosphere its lifetime can be considerably longer, because removal processes are almost absent. Nevertheless, these emissions make a relatively unimportant contribution to aggravation of the greenhouse effect due to subsonic aviation.

Contrails (condensation trails)

Persistent contrails may be formed when the moist hot air from the aircraft plume mixes with cold ice-supersaturated ambient air. Contrails have two radiative effects: first, to reduce solar radiation (a cooling effect) during the day and, second, to trap the thermal radiation emitted from the atmosphere below and from the earth's surface and thus have a warming effect. The reduction of incoming radiation from the sun is a less efficient process than the trapping of outgoing radiation. Thus, on a daily average basis they are estimated to cause a warming.

Particles

New particles are formed in the exhaust of aircraft owing to the emissions of sulphur containing compounds, hydrocarbons, electrically charged molecules (chemi-ions) and directly emitted (primary) soot particles. These particles may change the radiative properties of already existing clouds. The effect of this is highly uncertain. The effect on contrails is probably small, as there are usually already a sufficient number of particles present in the background atmosphere that can serve as nuclei for condensation. The direct radiative effect is estimated to be quite small; sulphate particles cool, whereas soot particles warm.

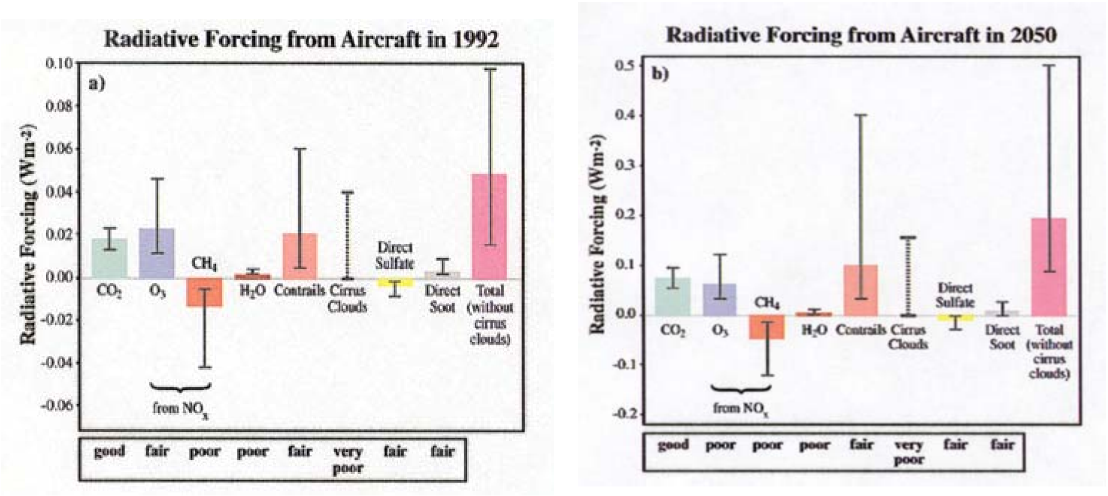
High clouds (cirrus)

Thin cirrus has similar radiative effects to contrails. If aircraft increase the amount of cirrus, this could have a substantial warming effect. Cirrus may be increased or affected in a number of ways. First, the formation of persistent contrails itself already leads to an increase in thin cirrus, as line-shaped contrails are transformed into cirrus as they spread out and are no longer recognizable as such, as can be readily observed. Second, particulate aircraft emissions may affect the nucleation properties of particles and enhance cirrus formation; this is a possible but as yet hypothetical effect. Third, the additional particles emitted by aircraft in the upper atmosphere may result in cirrus cloud formation at a later time, when conditions of temperature and humidity favor cloud formation; again, this is a possible but hypothetical effect.

Radiative forcing

In order to quantify the climate effect of perturbations in atmospheric composition, IPCC uses the concept of radiative forcing (RF) of climate. The RF of a perturbation is the global mean change in net radiation at the altitude of the tropopause, measured in W/m^2. Positive values indicate warming, negative ones cooling of the lower atmosphere. The reason that this simplified metric is used is that there is an approximately linear relationship between a change in the global mean RF and the change in the global mean temperature at the surface of the earth. It should, however, be noted that perturbations by two different pollutants with identical radiative forcing generally lead to different climate changes, as the geographical and altitudinal distribution of the perturbations also play a role in determining climate response. Figure 7 shows the changes in RF due to aviation in 1992 as estimated by IPCC (1999).

figure 7 Estimates of globally and annually averaged radiative forcing (Wm^{-2}) by aviation in 1992 and in 2050 for a scenario (Fa1) with mid-range economic growth and application of technology for both increased fuel efficiency and NO_x reduction, according to IPCC (1999). Coloured bars indicate best estimates of forcing, the vertical lines in each bar a 2/3 uncertainty range based on best available knowledge and tools in 1999. Evaluations below each bar are relative appraisals of level of scientific understanding. See text for further explanations



The total forcing in 1992 (excluding cirrus enhancement) was calculated to be approximately 0.05 W/m^2. For comparison, the increases in well-mixed greenhouse gases (carbon dioxide, methane, nitrous oxide and CFCs) since pre-industrial times are estimated to have given rise to an RF of about 2.5 W/m^2 at present (IPCC, 2001).
For aviation-induced changes in cirrus clouds only an estimate of the potential range of the climate effect was given by the IPCC, because it was considered highly uncertain. It was therefore not included in the calculation of overall forcing.

IPCC (1999) also estimated the changes for a number of possible future scenarios in 2050. Figure 1 also shows the radiative forcing estimate for one of these (Fa1), which was considered to be a ‘central’ scenario. The total forcing for 2050 under scenario Fa1 was 0.19 W/m^2, or 5% of total anthropogenic forcing (or 3.8 times that in 1992). The upper and lower scenarios - Fe1 and Fc1, respectively – resulted in total aviation RFs of 0.56 and 0.13 W/m^2, respectively (i.e. 11 and 2.6 times the forcing in 1992). The scenarios were largely dependent on the growth rates assumed of aviation. Two technology scenarios were explored (e.g. Fa1 vs. Fa2), but this was very much a second-order effect (0.193 vs. 0.192 W/m^2).

A.2.2 New scientific results since IPCC (1999)

The effect of nitrogen oxides on ozone and methane

The intensity of vertical transport and mixing of aircraft emissions in the lower stratosphere and upper troposphere (8-14 km altitude at mid-latitudes) strongly affects the residence time of aircraft emissions in the atmosphere and hence their radiative forcing. Rogers *et al*. (2002) showed that there are major uncertainties in modelling the vertical transport of aircraft pollutants in the lower stratosphere. Models using meteorological analyses to describe the vertical transport exhibit an excessively strong residual circulation and too much exchange between the tropics and mid-latitudes [Schoeberl *et al*., 2003]. Methods to improve the model descriptions of vertical transport are under development [Chipperfield, 2003; Van Noije *et al*., 2004] IPCC (1999) has estimated that the lifetime of methane is reduced by 2% by aviation emission of nitrogen oxides. More recent model calculations performed in the TRADEOFF project [Isaksen *et al*., 2004] suggest that this figure is about a factor 2 lower. They also report a slightly lower estimate for the radiative forcing due to ozone formed from the nitrogen oxide emissions of aircraft: the reasons for this are unclear, but it can be speculated that the improved vertical resolution of the models (compared with those used in [IPCC, 1999]) makes them less numerically diffusive.

Heterogeneous chemistry

There are still some uncertainties as to the effects of nitrogen oxide emissions from aviation on ozone, in particular with respect to their chemical interactions with aerosol and cloud particles (heterogeneous chemistry). Pitari *et al*. (2002) estimated the effect of sulphate particle heterogeneous chemistry on ozone production due to aviation emissions of nitrogen oxides. The heterogeneous chemistry involving both the background sulphate aerosols and the sulphate aerosols formed from sulphur compounds emitted by aviation give rise to a significant reduction of ozone. This study should be repeated using other models, since this issue is quite sensitive to model formulation, e.g. with respect to vertical transport in the tropopause region. Pitari *et al*. assumed 10% conversion of sulphur into sulphate particles, which is probably at least a factor 2 too high. Recent results from the PARTEMIS project indicate S^{IV} to S^{VI} conversion rates of around 0.6%

It has also been suggested that heterogeneous reactions in cirrus clouds might be important as a sink for reactive nitrogen, NO_y (Meilinger *et al*., 2001). A sensitivity study by Meier & Hendricks (2002) has subsequently indicated that the dominant effect would be the removal of nitrate by sedimentation of ice particles (Lawrence & Crutzen, 1998). Large amounts of NO_y in ice particles have been observed at temperatures below 215 K, e.g. by Kondo *et al*. (2003) in the Arctic. Ziereis *et al*. (2004) analyzed a larger observational data set and conclude that substantial amounts of NO_y are found in cirrus ice particles only at temperatures below 217 K. On average they found only 1 percent of the available NO_y was in particles.

Contrails

The radiative forcing due to contrails is presently thought to be a factor 3-5 smaller than estimated in IPCC (1999). [Ponater *et al.*, 2002] have developed a contrail parameterisation for global circulation models and found that contrails are optically thinner in most areas than assumed by [Minnis *et al.*, 1999], whose calculations constituted the basis for the estimate in IPCC (1999). Moreover, for their radiative forcing calculations [Minnis *et al.*, 1999] unrealistically positioned all contrails at 200 hPa, the altitude where the radiative response is largest. [Marquart *et al.*, 2003] gave a new estimate of the radiative forcing due to line-shaped contrails which amounts to 0.0035 W/m^2 in 1992 and 0.02 W/m^2 in 2050, taking into account the anticipated increase in propulsion efficiency as well as global warming. The IPCC (1999) estimates were 0.02 and 0.10 W/m^2, respectively. The [Marquart *et al.*, 2003] estimate has been calibrated to give 0.375% average daily cover by contrails over Central Europe in 1992.

High clouds (cirrus)

There are now many indications that there is an increase of up to a few percent in high cloud cover in regions with busy air traffic. This may be caused either by the spreading of line-shaped contrails (a direct effect) or by changes in the properties of cloud condensation nuclei due to particle emissions by aircraft (an indirect effect). The total effect of additional cirrus on radiative forcing is therefore probably not far away from the high end of the range estimated by IPCC (1999), but it is still quite uncertain.

Mannstein & Schumann (in EC, 2004) found an approximately linear relationship between cirrus cloud cover and mean air traffic density over Europe using Meteosat cloud observations and traffic data from EUROCONTROL. They derive that the radiative forcing from additional cirrus might be 10 times higher than that of line-shaped contrails. [Minnis *et al.*, 2001] found, from ISCCP data, that cirrus formed from line-shaped contrails has about a 4 times larger cover than contrails themselves. [Zerefos *et al.*, 2003] found significant decadal trends of a few percent in high cloud cover observations from the ISCCP D2 dataset in areas with busy air traffic, while trends were mostly insignificant in neighbouring areas with little air traffic. Similar, but quantitatively different, results were obtained by [Minnis *et al.*, 2001]. The most recent study by [Minnis *et al.*, 2004] indicates increases in cirrus cover over the US and Europe of between 0.3 and 2.3 % per decade. Their numbers vary strongly, depending on whether they are derived from surface or satellite observations. Further in-depth analyses should be performed to interpret these results and their differences. The high-cloud cover is highly variable, because of meteorological variability on a wide range of time scales from hours to years [Minnis *et al.*, 2003]. [Minnis *et al.*, 2004] estimate a maximum radiative forcing of aircraft-induced cirrus and contrails of 0.025 W/m^2, somewhat less than the 0.04 W/m^2 given in IPCC (1999) for maximum radiative forcing by cirrus increase only. Stordal *et al.* (2004) also recently examined ISCP data with updated traffic density data. In Europe, they found trends of approximately 2% per decade attributable to air traffic; extrapolating these results gave a global RF of 0.05 W/m2 as an upper limit. This estimate is greater than the upper estimate given by IPCC (1999). However, more work is required to make a global estimate more robust and provide a best estimate.

Finally, [Travis *et al*., 2002] have claimed that the difference between minimum and maximum temperatures increased by 1 degree across the United States in the 3 days after the September 11 terrorist attack on the World Trade Center, when air traffic was stopped. If true, these findings would indicate that the effects of aviation on clouds are much higher than currently estimated. The statistical evidence for this is weak, however.

Further studies on the interaction between cirrus and aerosols, on the effect of increased cirrus on the life cycle of water vapor in the upper troposphere, and on the climate feedbacks involved are needed to reduce the uncertainties surrounding the impact of additional cirrus.

Soot, sulphate particles and chemi-ions

It has been found that aircraft emit positive and negative chemi-ions (molecules that have taken up or released up to a few electron charges) with masses up to 8500 amu (atomic mass units) that promote the growth and coagulation of particles [Arnold *et al*., 2000; Kiendler and Arnold, 2002 a and b].

The conversion of fuel sulphur to sulphuric acid (sulphate particles) is of the order of 1 to 5%, less efficient than previously thought. IPCC (1999) gave an upper limit for sulphur conversion of about 20 %, while values up to 60% can be found in the literature. Ice crystals can be formed in the atmosphere from pure water vapor cooled to temperatures several tens of degrees below the freezing point of water i.e. at large supersaturations. This is called homogeneous freezing. Several other gases or particles (condensation nuclei) are usually present In the atmosphere, causing ice crystals to form already at temperatures closer to the freezing point – this is heterogeneous freezing. [Lohmann & Karcher, 2002] implemented a parameterization for the nucleation (formation) and initial growth of ice crystals in cirrus clouds in a climate model. They found that anthropogenic aerosol and precursor emissions have little effect on cirrus formed by homogeneous freezing, but that homogeneous freezing may be limited by the number of hygroscopic aerosols present. Aircraft emissions of sulphate aerosols are not likely to be important for cirrus formation. Aircraft soot emissions could be important if the soot particles nucleate more efficiently than by homogeneous freezing.

Combustor measurements in the PAZI project (Karcher *et al*. in EC (2004)) have shown that aircraft exhaust soot contains a significant amount of organic material, in addition to several sulphur compounds, which enhances its hygroscopicity (its ability to take up water). Model calculations by [Van Cassel *et al*., 2004] show, furthermore, that the interaction between soot and ions may be quite important. When ions are included in the model, at least 80% of the soot particles become electrically charged and thus hygroscopic. Soot may therefore act as condensation nuclei even if fuel void of sulphur were used. Measurements in an aerosol cloud chamber have indicated, moreover, that soot particles may freeze under cirrus conditions (Karcher *et al.* in EC (2004)). A recent model study of the black carbon cycle (Hendricks, 2004) reports a contribution of up to 30-40% from aviation soot to the number concentration of black carbon particles in regions with busy air traffic. The effect maximizes in winter. The contribution to black carbon mass does not exceed a few % and the direct radiative forcing of aircraft soot is probably smaller than the figure given in IPCC (1999). Further model experiments (Hendricks *et al.* in EC, 2004) suggest that if the soot particles allow for efficient nucleation, there might be large changes in the number of ice nuclei and in cirrus microphysical properties.

Climate sensitivity

Radiative forcing can be defined as a measure of the importance of perturbations to the planetary radiation balance and is measured in Watts per square meter (W m^{-2}). One of the main reasons for its use as a convenient metric is that there is an approximately linear relationship between the change in global mean radiative forcing (ΔF) and the global mean surface temperature change (ΔT_s), i.e.:

$$\Delta T_s \approx \lambda \Delta F$$

where λ is the climate sensitivity parameter (K (W $m^{-2})^{-1}$), which tends to vary between models but is constant for different forcing mechanisms. However, it has been suggested that λ may be different for aviation-induced ozone (Ponater *et al.*, 1999). [Joshi *et al.*, 2003] performed an inter-comparison study with three-dimensional climate models of the climate sensitivity of ozone and carbon dioxide perturbations, as had been done in the past with simpler climate models (e.g. Bintanja *et al.*, 1996). They found generic deviations in climate sensitivity between ozone and carbon dioxide perturbations. Upper tropospheric ozone perturbations generally have a climate sensitivity that is about 30% smaller than global carbon dioxide perturbations, while lower stratospheric ozone perturbations have a climate sensitivity about 40% greater. The implication of this for the bulk of the air traffic flying in the northern hemisphere lower stratosphere is that the climate sensitivity is stronger for aviation-induced ozone than was previously thought.

Climate response

[Sausen and Schumann, 1999] used a simplified climate response model to study the climate response, in terms of changes in mean global surface temperature, to aviation emissions of NO_x (forming O_3) and CO_2. The climate sensitivity response to O_3 is a very uncertain parameter but at its lower estimated bound the temperature response was similar to CO_2, whilst at the best estimate it was at least twice that of CO_2 for approximately the same radiative forcing. This has implications for future policy options to minimize aviation's impacts on climate. The model is currently being extended to examine the effects on contrails, although no results are yet available.

Changing flight altitude

The effect of changing aircraft cruise altitudes was investigated in the EU TRADEOFF project [Isaksen *et al.*, 2004]. Current atmospheric models predict that reducing flight altitudes will strongly reduce contrail occurrence and will also reduce the formation of ozone from aircraft nitrogen oxide emissions. It will increase carbon dioxide emissions, however. The net impact on radiative forcing appears to be a reduction of the warming. Increasing flight altitudes has the opposite effect. For instance, the main effect of lowering cruise altitudes by 6000 feet would be a reduction of contrail radiative forcing by a factor 2 [Fichter *et al.*, 2004]. All other effects are an order of magnitude smaller, e.g. CO_2 emissions would increase by about 6 %.

A.3 Climate effects of shipping: Detailed findings

A.3.1 Climate impacts from shipping

As set out in Sections 2.3.2 and 2.3.3, ship emissions will be important for air quality and acidification in coastal areas close to busy seas such as the North Sea, the Baltic Sea and the Mediterranean. They may also significantly increase ozone production over otherwise clean oceanic areas. [Endresen *et al.*, 2003] find a 12 ppbv ozone increase over the North Atlantic and Pacific in summer. As a global average, the tropospheric ozone column increases by 0.7 DU. They estimate that sulphate has increased by 3% globally and by 8% along the West European coast. Ship emissions of nitrogen oxides lead to a reduction of the global methane concentration by about 6 %.

Endresen *et al.* (2003) give the following figures for radiative forcing (for 1996):

CO_2		0.030 W/m^2
O_3		0.029 W/m^2
CH_4	-	0.028 W/m^2
Sulphate	-	0.020 W/m^2
		_________+
Total		0.011 W/m^2

It is important to note that the geographical distribution of these different elements of forcing are quite different, so that zero total radiative forcing would still imply an impact on regional climate. Also note that the numbers for CO_2, O_3 and CH_4 are of the same order of magnitude as the radiative forcing exerted by emissions from aviation (0.018, 0.023 and – 0.014 W/m^2, respectively, in 1992 according to IPCC [1999]). However, as discussed above, aircraft emissions are growing more rapidly than ship emissions. The indirect effect of particle emissions (sulphate) is not included in the above estimates.

[Jonson *et al.*, 2000] performed a regional model study on the effects of ship emissions on air quality and acidification. They found that emissions from shipping contribute more than 10 % to the deposition of sulphur and nitrogen in several European countries, e.g. Denmark, The Netherlands, Greece and Sweden. For Europe, increases in exposure to accumulated critical ozone levels are confined mainly to the Mediterranean countries. They used an emission inventory compiled by Lloyd's for 1990.

The calculations performed by [Endresen *et al.*, 2003] need to be repeated using other global atmospheric chemistry models in order to estimate uncertainties due to model formulation. The effects of chemical conversions in the plumes of ships might considerably affect the estimates, furthermore, and therefore need to be quantified. In particular, the lifetime of nitrogen oxides seems to be shortened by plume conversions by a factor 2-10 [Song *et al*., 2003]. This would significantly reduce the large-scale impact on ozone and methane. [Von Glasow *et al*., 2003] estimated that the effect on ozone is overestimated by 50 % and the effect on methane by 100 % if plume processes are ignored. Comparison with observations shows that global chemistry models (without plume parameterisations) generally overestimate the NO_x perturbations caused by ships [Endresen *et al*., 2003; Davis *et al*., 2001; Kasibhatla *et al*., 2000; Lawrence and Crutzen, 1999].

Ships, like aircraft, can cause perturbations of clouds. Ship tracks are line-shaped regions within a shallow marine cloud layer that can persist for several hundred kilometres behind ships and are visible in satellite photographs (Conover, 1966). They are typically several hundred metres deep and extend to close to the top of the marine boundary layer. For ship tracks to be observable, certain conditions must prevail in the marine environment. The boundary layer must be not be too thick and topped by a cloud layer. [Durkee *et al*., 2000a] found no ship tracks in boundary layers thicker than 800 m. The number of cloud condensation nuclei must be small; the brightest ship tracks are usually observed when the boundary layer is relatively clean [Durkee *et al*., 2000a]. Furthermore, winds are usually moderate and air-sea temperature differences small [Durkee *et al*., 2000b].

The Monterey Area Ship Track (MAST) study was performed in the Pacific along the coast of California in June 1994 in order to investigate the mechanism responsible for formation of ship tracks (see special issue of J.Atmos.Sci., 57, 15 August 2000, e.g. Durkee *et al*., 2000c). It was found that ship tracks are caused by the emission of particles by ship engines. Heat and water vapor emissions do not play a significant role. Ship tracks were absent behind nuclear-powered ships. Ship tracks were even mostly absent behind ships with steam-turbine or gas-turbine engines. Only behind ships with diesel engines were ship tracks frequently observed. This is because diesel engines emit particles with a larger mode radius (about 0.03-0.05 μm) and larger maximum size than steam and gas turbines (mode radius 0.02 μm). These larger particles are more likely to be activated as cloud condensation nuclei.

Increasing the number of cloud droplets in the ship track relative to the adjacent cloud deck leads to a reduction of cloud droplet size and hence an increase of the albedo, the amount of sunlight reflected by the cloud. This indirect effect of aerosols on climate is known as the Twomey effect [Twomey, 1977].

The changes in the droplet size spectrum in ship tracks can also have secondary effects. [Radke *et al*., 1989] observed a higher liquid water content in ship tracks and a suppression of drizzle due to a decrease of droplets with sizes larges than 200 μm relative to the adjacent clouds. However, the liquid water content is not always larger in ship tracks than in the surrounding clouds [Ferek *et al*., 2000]. It has also been suggested that changes in cloud dynamics may occur, for instance due to stabilization by absorption of solar radiation by soot in the upper part of the ship track cloud [Coakley Jr. and Walsh, 2002]. Hence, the changes in microphysics may change the lifetime of the clouds.

Global estimates for the radiative forcing of ship tracks have not been published. The direct radiative effect is probably small, owing to the limited coverage of ship tracks. For the indirect effects of the emissions of particles and particle precursors by ships in the clean marine environment this is less evident.

B Emission calculation methods

Tier 1 method
The Tier I method is a top-down methodology enabling rough estimates to be made of CO_2, CH_4, N_2O, NO_x, CO and NMVOV. If assumptions are made regarding fuel sulphur content, the method also permits estimation of SO_x. The Tier 1 method focuses on estimating emissions from the carbon content of fuels supplied to a country as a whole (the reference approach) or to the main fuel combustion activities (source categories).

The **Reference Approach** assumes that carbon brought into an economy is either saved or released to the atmosphere. Carbon released is estimated without knowledge of the processes undertaken through the transformation. This *top-down approach* provides only aggregate estimates of emissions by fuel type supplied to the country and does not break down the emissions by sector nor distinguish between stationary and mobile combustion emissions.
A sectoral breakdown of national CO_2 emissions using the IPCC-defined source categories is required for abatement measures and monitoring. Estimates of emissions based on the Reference Approach will not be exactly the same as those based on the Sectoral Approach, as emissions are measured at different points.

The Tier 1 method is based on aggregate figures for fuel consumption for civil aviation multiplied by average emission factors. Data on fuel consumption are all that are needed, with resulting emissions estimated on the basis of fuel consumed and average emission factors based on fleet average values. These emission factors are calculated on the basis of the assumption that 10% of the fuel is used in the Landing and Take Off (LTO) phase of the flight.

Tier 2 methods
The detailed Tier 2 methodologies also account for the process of combustion. The Tier 1 method is purely fuel-based, whereas Tier 2 methods are based on actual activity data, including the number of LTO cycles and related fuel use. Tier 2 methods also base emission estimates on the composition of the aircraft fleet.

In the IPCC Guidelines, the Tier 2 Method consists of four steps:
1 Estimate total fuel.
2 Split into domestic and international.
3 Split each into LTO fuel use and cruise fuel use.
4 Apply emission factors for the gas concerned.

Tier 2 methods distinguish between emissions below and above 3000 feet (914 m). This improves the accuracy of emission estimates because emission factors depend on flight phases. Emissions in the two flight phases are thus estimated separately. The method is applied at either the aggregated level of all aircraft (Tier 2a) or at the level of individual aircraft types (Tier 2b).

Emissions and fuel used in the LTO phase are estimated based on the number of LTOs (aggregate or per aircraft type, depending on the data available) and default emission factors or fuel use factors per LTO cycle (average or per aircraft type). Cruise emissions depend on the length of the flight and other factors. In the Tier 2 method, the fuel used in the cruise phase is estimated as total fuel use minus fuel used in the LTO phase of the flight.

Estimated fuel use is multiplied by aggregate emission factors (again, average or per aircraft type) in order to estimate emissions.

In the Tier 2b approach, the estimate should include all aircraft types frequently used for domestic and international aviation. In the Tier 2a approach, the IPCC Guidelines provide aggregate emission factors per LTO. These aggregate emission factors are given for national and international aviation separately, and for an old and an average fleet.

Both Tier 2 approaches use the following equations to estimate emissions:

Emissions = LTO Emissions + Cruise Emissions

where
LTO Emissions = Number of LTOs x LTO Emission Factor,

LTO Fuel Consumption = Number of LTOs x Fuel Consumption per LTO

Cruise Emissions = (Total Fuel Consumption – LTO Fuel Consumption) x Cruise Emission Factor

Tier 2a corresponds to the CORINAIR Simple Methodology (see Annex C), while Tier 2b resembles the CORINAIR Detailed Methodology, but is less detailed than CORINAIR with respect to the number of aircraft categories and emission factors.

C Other reporting methodologies

Beside IPCC methodologies, other important international methodological frameworks and data sources for emissions calculation and reporting are the following:

CORINAIR
CORINAIR is a joint European project that manages a European air emission inventory and database system. All the Nordic countries are covered by the CORINAIR project, which is not limited to emissions relevant to climate change. The CORINAIR emission data are at a higher level of detail than required for reporting under international obligations. The latest version of the CORINAIR methodology can be used to determine atmospheric emissions for individual flights. However, there remain significant differences between countries in terms of data availability.

TRENDS
The TRENDS project, involving Eurostat, EUROCONTROL and EEA, has produced detailed estimates of fuel consumption and emissions. Detailed flight data from EUROCONTROL in combination with the CORINAIR emission calculation methodology could develop into a system of precise and comprehensive data on European aviation emissions that also allows for distinction between domestic, intra-EU, and international traffic.

Other sources
International Civil Aviation Organization (ICAO) Member States are obliged to ensure that its international airlines submit the statistics requested by the ICAO Council. The ICAO statistical programme is capable of providing detailed fuel consumption figures for individual flights. This could provide the basis for inventories, although only for *scheduled* international flights.

International Energy Agency (IEA) statistics are based on national reporting using a Joint IEA/Eurostat/UNECE annual questionnaire. The IEA data differ from the IPCC data in that they include military aviation fuel use. Other differences compared to IPCC are: 1) IEA does not calculate emissions of other greenhouse gases and 2) other emission factors can be used.

The European Civil Aviation Conference (ECAC) has established a ‘Group of Experts on the Abatement of Nuisances Caused by Air Transport’ (ANCAT). Guidelines developed under ANCAT are parallel to the different tiers provided under IPCC and CORINAIR.

The Long Range Transboundary Air Pollution Convention (UNECE) collects data on CO_2 emissions for the entire flight duration and on non-CO_2-emissions for the LTO phase only.

Emission inventory models for international aircraft emissions have been developed in several projects. As a general rule, these model-based inventories are not based on accurate data on flights actually performed by all airlines globally.