National allocation of international aviation and marine CO_2-emissions

A study commissioned by the Dutch Civil Aviation Authority

Delft, September 2000

Authors:
A. van Velzen (Resource Analysis)
R.C.N. Wit (CE Delft)

RESOURCE ANALYSIS

Centre for energy conservation and environmental technology (CE)

Table of contents

1 Introduction

On 10 December 1997 the Kyoto Protocol of the UN Framework Convention on Climate Change (UNFCCC) was adopted by 160 countries. For each of the so-called Annex I countries the Protocol sets a reduction target for total national greenhouse gas emissions for the period 2008-2012 relative to the base year 1990. These individual targets are for ’national emissions’, i.e. emissions due to economic activities taking place on national territory, which must be reported to the Conference of the Parties of the UNFCCC in a ’National Greenhouse Gas Inventory’. International emissions of greenhouse gases associated with fuels bunkered by international aviation and marine shipping are not included in these national targets, and are to be reported separately. Emissions due to domestic aviation and shipping are regarded as ’national emissions’, to be included as such in the national inventory.

Article 2.2 of the Kyoto Protocol states that “the 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 Organisation (ICAO) and the International Maritime Organisation (IMO), respectively.”

In 1996 the Subsidiary Body for Scientific and Technological Advice (SBSTA) of UNFCCC elaborated eight options for allocating responsibilities for greenhouse gas emissions from international aviation and marine shipping. In the first option international emissions are not allocated to individual countries but remain in the international sphere. In the other seven options a variety of criteria are employed for allocating international emissions to individual countries.

In order to facilitate the debate on the allocation issue at the meetings of UNFCCC, SBSTA and ICAO’s Committee on Aviation Environmental Protection (CAEP), the Dutch Civil Aviation Authority (RLD) commissioned the present study to assess the distributional consequences for 23 individual countries of each of the UNFCCC/SBSTA CO_2 emissions allocation options[1]. The study has been executed by a consortium consisting of Resource Analysis (RA) and the Centre for Energy Conservation and Environmental Technology (CE) and the results are reported in this document.

This study focuses primarily on allocation of international aviation emissions, with allocation of international marine emissions being assessed in broader brush strokes. Under each of the eight SBSTA allocation options international aviation emissions are nationally allocated for the base year (1992) and for the year 2010, a horizon deemed representative for the first commitment period (2008-2012) within which national Kyoto targets are to be met. For some parts of the study data use was made of the AERO modelling system (AERO-MS), which is recognised internationally as a suitable system for addressing issues of aviation emissions. It has already been used in several ICAO/CAEP-commissioned studies on air transport emission abatement, for example, as well as in a study on kerosene taxation for the European Union.

---

1 Members of the European Union and/or CAEP.

Chapter 2 of the report explains the methodology adopted in the present study, introducing the relevant elements of AERO-MS. The chapter also examines the eight emission allocation options defined by SBSTA and how they are operationalised here.

Chapter 3 begins by reviewing the total *national* CO_2 emissions of each of the 23 countries, thus to obtain a basis for comparing the national distribution of international aviation CO_2 emissions under the eight different allocation options. In addition, chapter 3 reviews the global CO_2 emissions of international aviation in the base year 1992 and the 2010 horizon. Since these global emissions form the starting point of all the allocation options, the AERO-MS base year figures are compared with data from other computational sources (e.g. NASA, ANCAT and DLR) and with international bunker fuel statistics for the 23 countries considered. Finally, chapter 3 describes the underlying assumptions of the AERO scenario specification used in this study for forecasting global international aviation emissions in 2010.

Chapter 4 presents the quantitative results of the study. For each of the eight allocation options and each of the 23 countries reviewed, the nationally allocated international aviation CO_2 emission is presented i) in absolute terms, ii) as a percentage of global international aviation emissions, and iii) as a percentage of the country's total national emissions. The results are presented in parallel format for the base year and the year 2010.

In chapter 5 the results of the less detailed analysis of allocation of international marine CO_2 emissions are reported. Chapter 6, finally, summarises the principal conclusions drawn from the overall analysis. In this context it should be noted that the aim of the present study was to make a quantitative estimate of the share of international aviation and marine emissions assigned to the individual countries under the respective allocation options. No pronouncement is therefore made here on any differences regarding feasibility of implementation.

2 Methodology

2.1 General features of the methodology

The aim of this study is to provide quantitative insight into how the eight options identified by SBSTA (FCCC/SBSTA/1996/9/Add.2) for national allocation of international aviation and marine emissions of the greenhouse gas carbon dioxide (CO_2) translate into assigned amounts accruing to individual countries. The eight SBDTA allocation options examined are as follows:

1 No allocation.
2 Allocation of global bunker fuel sales and associated emissions to Parties in proportion to their national emissions.
3 Allocation to Parties according to the country where the bunker fuel is sold.
4 Allocation to Parties according to the nationality of the transport operator.
5 Allocation to Parties according to the country of destination or departure of aircraft or vessel.
6 Allocation to Parties according to the country of destination or departure of passengers or cargo.
7 Allocation to Parties according to the country of origin of passengers or owner of cargo.
8 Allocation to the Party of all emissions generated in its national space.

The emissions of the following 23 countries have been specifically considered: the countries of the European Union (15), Switzerland, Norway, USA, Canada, Russia, Brazil, Japan and Australia. Except for Brazil, all these countries are so-called Annex I countries. For each of the eight options, the nationally allocation is compared to the country's total national emissions inventory.
The methodology adopted in this study comprises the following steps:

1 Quantification of total national CO_2 emissions in the base year and in 2010.
2 Quantification of global CO_2 emissions from international aviation in the base year.
3 More detailed specification of the eight allocation options.
4 Quantification, for each option, of nationally allocated international aviation CO_2 emissions in the base year.
5 Development of a scenario for estimating global international aviation CO_2 emissions in 2010.
6 Quantification, for each option, of nationally allocated international aviation emissions in 2010.
7 Allocation of international marine emissions.

As can be inferred from this list of steps, the present study focuses mainly on allocation of international aviation emissions (steps 2 through 6). As mentioned in the introduction, allocation of international marine emissions has been carried out with broader brush strokes, with only the consequences of the first three allocation options being examined.

The choice of *base year* for this study was problematical, owing to a lack of complete and consistent data sets. There was no one year for which all the necessary data were available. For constructing the baseline used in this

study we therefore opted to use data for two years: 1990 and 1992. Given the Gulf War at the start of the decade these years are fairly comparable. A comparison of the fuel bunker statistics for these two years reported in the UN 1992 Energy Statistic Yearbook (UN, 1994) shows that total fuel sales to international aviation rose by less than 1% during this period. Consideration of a random sample moreover indicated that the share of individual Annex I countries in total international fuel use changed by less than 10% during this period. Given these relative minor changes we assume that the outcome of this study would not have differed significantly if data for only one year had been used. In the remainder of this study, then, the term 'base year' refers to the year 1990 or 1992.
The various methodological steps are now described in more detail.

1 Quantification of total national CO_2 emissions in the base year and in 2010

In this step, for each of the 23 countries reviewed total national CO_2 emissions from anthropogenic sources are assessed in the base year and in 2010. These emissions are also broken down by sector (energy, industry, transportation). The base year CO_2 emission figures for these countries are based on the respective National Communications collected, processed and published by the secretariat of the United Nations Climate Change Convention.
With respect to projected national emissions for the year 2010, the assumption has been made that these countries will meet the Kyoto emission reduction targets set for the first commitment period (2008-2010). It should be noted that the quantitative level of these targets (percentage reductions in 2010 relative to 1990) varies from country to country.

2 Quantification of global CO_2 emissions from international aviation in the base year

SBSTA proposes that the eight options for emission allocation are to be based on emissions relating to bunker fuels. However, the official statistics and reviews employed in international policy-making vis-à-vis aviation fuel use and associated CO_2 emissions contain significant gaps and errors (cf. Wit (1996) and UN (1996)). A simple example is that many countries do not distinguish between bunker fuels used for national and international aviation activities. In addition, a variety of methods have been used by countries for calculating the emissions associated with bunker fuels, IPCC standards notwithstanding.
Because the available statistics on international aviation fuel bunkers are incomplete and to some extent inconsistent, in this allocation study the AERO modelling system was used to assess the CO_2 emissions due to international aviation in the base year. In this context it is noted that 1992 serves as the base year in AERO-MS. The AERO-computed results on global aviation fuel use and emissions are compared with figures from other computational sources and with official fuel bunker statistics. In the process, the major gaps and errors in these statistics are identified.
The global inventory of CO_2 emissions from international aviation in the base year computed with the AERO modelling system serves as the point of departure for calculating the consequences of all eight options for emission allocation.

3 More detailed specification of the eight allocation options

Proceeding from the SBSTA specifications, in this step the eight options for emission allocation are further elaborated into concrete computational procedures for national allocation of CO_2 emissions. It is noted that alternative interpretations are possible with respect to the exact definition of a number of options. The choices made in the present study are described in detail in section 2.3, providing for each option:

- an unambiguous and clear interpretation of the allocation option;
- an allocation procedure based on this interpretation;
- a review of the data employed.

4 Quantification, for each option, of nationally allocated international aviation CO_2 emissions in the base year

In this step the international aviation emissions allocated to each of the 23 countries under each of the eight options are calculated for the base year. These national allocations are compared with each country's total anthropogenic CO_2 emissions and with global international aviation CO_2 emissions. Specifically, the results are presented:
in absolute terms, in Megatonnes;
as a percentage of global international aviation emissions;
as a percentage of the country's total national emissions.

5 Development of a scenario for estimating global international aviation CO_2 emissions in 2010

In order to forecast global CO_2 emissions from international aviation in 2010, a scenario was developed in AERO-MS reflecting projected trends in air transport demand volume, fuel use characteristics of new aircraft and so on.

6 Quantification, for each option, of nationally allocated international aviation emissions in 2010

This step yields parallel results to step 4, but for the year 2010. The two sets of results are compared and a number of observations made regarding differences in the international aviation emissions allocated to individual countries in the respective years under the various allocation options.

7 Allocation of international marine emissions

In this step the international marine emissions allocated to each of the 23 countries under options 1, 2 and 3 are calculated for the base year. These national allocations are compared with each country's total anthropogenic CO_2 emissions and with global international marine CO_2 emissions. Specifically, the results are presented:

- in absolute terms, in Megatonnes;
- as a percentage of global international marine emissions;
- as a percentage of the country's total national emissions.

2.2 Review of relevant AERO-MS modules

As mentioned in section 2.1, the AERO modelling system was used for much of the analysis of aviation emission allocation. This section therefore provides a short overview of the modules of relevance for the analyses performed in this study.

AERO-MS comprises a series of modules, covering description/generation of aviation demand right through to assessment of the environmental impacts of aviation emissions, within the context of emissions from other (ground) sources. By defining future scenarios, model users can analyse the environmental effects of a wide range of autonomous trends (economic, technical and political) and abatement measures (regulatory, fiscal, operational and technical) at both the global and regional level. The AERO model can also be used to assess the socio-economic impact of trends and measures on aviation industry operations, moreover.

For the purpose of this study two situations were defined:

1 a baseline, providing the best possible description of the base year;
2 a scenario for 2010 which assumes no additional measures to reduce aviation emissions, as detailed below (Chapter 3).

Only certain AERO modules were used, viz. those relating to:
1 air transport supply and demand, and aircraft flight stages,
2 aircraft type classification and associated fuel use characteristics, and
3 fuel use and emissions in three-dimensional space.

These are described in turn below. It should be emphasised that no attempt has been made here to provide a complete overview of the AERO modelling system; interested readers are referred to the complete documentation (RLD, 2000).

1 Air transport demand, supply and aircraft flight stages

At the core of the AERO modelling system is the Unified Database, which holds data on civil aircraft movements and air passenger and cargo demand for 1992. It provides worldwide coverage, although data are stored at the level of individual major city pairs and groups of minor city pairs. With its spatial coverage and detail, and in holding passenger and cargo demand data as well as aircraft movements, the Unified Database is the basic motor behind AERO's comprehensive forecasting capabilities. In the forecasting process the same detailed data structure is retained.

The Unified Database merges the content of four other major aviation databases:

- the ICAO 1992 "Traffic by Flight Stage" (TFS) data for international scheduled movements,
- the US Department of Transport 1992 "T-100" data for US domestic scheduled flights,
- the July 1992 ABC (now OAG) timetable for scheduled movements, and
- the ANCAT (Abatement of Nuisances Caused by Air Transport) database for April 1992.

As a consequence the Unified Database is more comprehensive than any of these individually in its coverage of:

- international and domestic flights,
- scheduled and non-scheduled operations,
- passenger and freighter aircraft movements, and
- passenger and cargo demand.

The availability of demand data is particularly distinctive among aviation databases. This feature is fundamental to the forecasting processes of the AERO model, in which the future volume of aircraft movements is determined largely by projected demand for passenger and cargo air services.

The Unified Database covers flights between over 50,000 city pairs. After a grouping of minor city pairs, this results in some 19,000 city-to-city flight stages being explicitly distinguished in the model schematisation. For each city pair, it can be ascertained whether connecting flights are domestic or international simply by checking whether the cities of departure and destination are in the same country. With AERO-MS it is thus relatively simple to isolate international flights and, subsequently, the associated fuel use and emissions.

2 Aircraft type classification and associated fuel use characteristics

In AERO, aircraft flights are specified by nine generic *aircraft types* (based on relevant combinations of range and capacity) and two *technology levels*. The nine generic aircraft types are presented in Table 2.1. The two technology levels ('old' and 'current') are defined by certification age. The old fleet consists of all aircraft of certification age 12 years or more prior to the review year (baseline or horizon). The current fleet is the remainder, i.e. those of more recent certification age. Table 2.1 reviews the average fuel use characteristics of the generic aircraft types at each technology level, expressed in terms of average fuel use per LTO cycle (kg/cycle) and per kilometre (kg/km) for the baseline situation (1992).

Table 1 Fuel use per LTO cycle and per kilometre in 1992, by generic aircraft type and technology level, as computed by AERO-MS

Generic aircraft type in AERO-MS	Average fuel use per LTO cycle (kg/cycle)			Average fuel use per km (kg/km)		
	Old	Current	Fleet average	Old	Current	Fleet average
Short haul, less than 20 seats	51.6	39.4	46.1	0.31	0.24	0.28
Short haul, 20 to 79 seats	182.7	143.4	154.9	1.145	0.90	0.96
Short haul, 80 to 124 seats	646.5	493.9	588.7	3.57	2.73	3.20
Short haul, 124 to 179 seats	911.5	745.2	827.6	5.31	3.90	4.63
Medium haul, 80 to 124 seats	882.4	680.1	863.9	5.27	3.64	5.10
Medium haul, 124 to 179 seats	725.9	606.2	649.9	4.09	3.29	3.59
Medium haul, 180 to 299 seats	1269.9	1019.2	1098.8	6.34	4.83	5.24
Long haul, 180 to 299 seats	1450.7	1181.7	1231.4	6.77	5.37	5.57
Long haul, 300 to 499 seats	3273.3	2536.9	3036.2	15.27	11.72	13.90

The differences in the fuel use characteristics of the 'old' and 'current' 1992 fleets are due to progressive technological improvement (i.e. fuel use reduction) of newly bought aircraft. In AERO the rate of technological improvement of autonomous energy efficiency improvement of aircraft bought prior to 1992 is taken to be 2% per annum, a figure based on empirical data. The assumptions regarding annual technological improvement after 1992 are made as part of the scenario specification (chapter 3).

3 Fuel use and emission computation in three-dimensional space
Using the aforementioned data on aircraft movements and fuel use characteristics, broken down according to generic aircraft type and technology level, the AERO model now computes fuel use and CO_2 emissions at the national and global level. As mentioned above, AERO thereby immediately distinguishes between domestic and international air traffic. In computing emissions a fixed ratio was taken between fuel use and CO_2 emission, 1 kg of kerosene yielding 3.157 kg of CO_2.
AERO computes emissions in three-dimensional space, employing a global geographic grid of 1° by 1° longitude/latitude and 15 equidistant altitude bands of 1 km. In this study the model's capacity to compute emissions on a global grid is used in relation to allocation option eight (national allocation of emissions generated in national space).

2.3 Methodology per allocation option

In this section, for each of the eight emission allocation options specified by SBSTA the methodology adopted in the present study is described in greater detail. More specifically, for each option we provide:
- an unambiguous and clear interpretation of the allocation option;
- an allocation procedure based on this interpretation;
- a review of the data used.

Option 1: No allocation
Under this option there is no national allocation of international aviation emissions. The underlying idea is that global international aviation emissions will be appropriately reduced by the international community (through ICAO, for example) without emissions first being allocated to individual countries. This option merely requires an assessment of the global emissions due to international aviation activities (see step 2, section 2.1).

Option 2: Allocation of global bunker sales and associated emissions to Parties in proportion to national emissions

In this option global international aviation emissions are nationally allocated according to a country's share in global CO_2 emissions, viz. pro rata according to a percentage *p* of global international aviation emissions, where *p* is the country's percentage contribution to global anthropogenic emissions. Total national and total global anthropogenic emissions follow from step 1 of the methodology (see section 2.1), global international aviation emissions from step 2.

Option 3: Allocation to Parties according to country where bunker fuel is sold
For this option use was made of AERO-MS which explicitly identifies over 19,000 city-to-city flight stages, as mentioned in section 2.2. The fuel use and emissions associated with each of these flight stages can thus be computed and the category of international flight stages readily isolated, by considering only those flights with cities of departure and destination in different countries. As part of the further specification of this option the assumption was made that all fuel used on a given flight stage is sold in the country of departure of that flight. It should be stressed here this assumption means that the effects of 'tankering' (taking on board extra fuel to be used on the *next* flight) are ignored. In this option, then, all the emissions associated with a given flight are allocated to the country of departure of that flight.

Option 4: Allocation to Parties according to airline nationality
The SBSTA's full specification of this emissions allocation option is "allocation to Parties according to the nationality of the airline, the country where the airline is registered or the country from where the airline is operated". Considering the difficulty in collecting data for the second and third variant (a difficulty acknowledged by SBSTA), in this study only the first variant has been evaluated (allocation according to airline nationality). Ideally, for evaluating this variant the following data should be available:
1 an overview of the airlines of the countries reviewed;
2 the annual fuel consumption of these airlines.

On a confidential basis ICAO knows approximately how much fuel is used by each airline and since 1991 it has been possible to distinguish between national and international services[2]. However, these fuel data have several shortcomings:

[2] As defined by ICAO. ICAO defines as domestic all flight stages flown between domestic points in a given state by an airline registered in that state and therefore excludes flights between domestic points by foreign airlines. This treatment of 'domestic' and 'international' differs from the Revised IPCC Guidelines for the National Communications. According to these guidelines the type of activity is independent of the nationality of the carrier.

- non-scheduled operations are not included (a significant factor in some regions);
- the information is not uniformly reliable across all regions;
- fuel consumption is somewhat underestimated (aircraft being assumed to fly direct by a Great Circle route).

Because of this lack of reliable information on airline fuel consumption and because no other complete and accurate databases are available, it was opted to allocate emissions proportionally to the total annual Revenue Tonne Kilometres (RTK) of the airlines of the country in question. (RTK is a measure of total aviation activity, i.e. both passenger and cargo demand, whereby average passenger weight (including baggage) is assumed to be 100 kg.) These national RTK data were obtained from two sources: ICAO statistics (tonne-kilometres performed) and AERO-MS. The two sources are complementary. The airline information in AERO is not stored on the basis of airline nationality but in 'airline clusters', groups of carriers based in the 14 different world regions identified in AERO. Although the ICAO statistics do provide information on airline nationality, the ICAO secretariat states that the data they provide may not be entirely accurate or complete.
The AERO airline cluster data were therefore used as a starting point for assessing national shares of total international RTKs based on the nationality of the transporting airline. This yielded figures for the shares of North America (USA and Canada) and the European Union, and within these two regions RTKs were then allocated nationally on the basis of data provided by ICAO[3]. These latter data also included information on the number of RTKs of airlines from the other countries considered (Australia, Brazil, Former USSR, Japan, Norway and Switzerland). In allocating emissions under option 4 in the year 2010, the estimated shares of North America and the EU were updated using the AERO projections for the year 2010. The shares of individual countries within these regions (as provided by ICAO) were not updated, however, as reliable forecasts were lacking.

Option 5: Allocation to Parties according to country of departure or destination of aircraft
In this option emissions are allocated on the basis of the country of aircraft departure or destination, with SBSTA proposing an even split between the countries of departure and destination. The option is therefore defined as allocation of 50% of the emissions associated with a given flight to the country of destination and 50% to the country of departure. Hence, to evaluate this option the following data were required:
1 number of flights departing from each of the 23 countries reviewed;
2 number of flights arriving in each of the 23 countries reviewed;
3 the emissions associated with the flights under 1 and 2.
AERO-MS has dedicated capacity to provide the required data. For the base year the number of departures and arrivals in each country can be extracted immediately from the Unified Database (see section 2.2). For the 2010 horizon, as indeed for any other future situation, parallel data can be generated by means of a user-defined scenario specification. As already mentioned, AERO-MS also contains information on the types of aircraft operated on a given flight stage (by generic aircraft type and technology level) and the fuel use/emission characteristics of these aircraft, permitting calculation of the emissions associated with each and any flight. Under this option these AERO-calculated emissions are allocated 50/50 between the country of flight departure and the country of flight destination.

[3] Provided directly by the ICAO secretariat (1999).

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

For this option, too, SBSTA has proposed that emissions be equally allocated between the countries of departure and destination, in this case with regard to passengers or cargo rather than flights. As with option 4, the Revenue Tonne Kilometre (RTK) unit was again employed, adopting a three-step procedure:

1 assessment of the global average CO_2 emission per RTK for international aviation;
2 national allocation of the RTKs of individual flights: 50% to country of destination and 50% to country of departure;
3 calculation of nationally allocated emissions, based on 1 and 2.

For the first two steps AERO-MS was employed. First, the global CO_2 emissions and global RTK of international aviation were computed and the average emission per RTK derived for both the base year and the 2010 horizon. Next, in step 2, the RTKs of each individual flight stage were computed for both years and these allocated 50/50 between individual pairs of countries, as in the case of fuel use/emissions under option 5. These figures were then summed.

Option 7: Allocation to Parties according to country of nationality of passengers or cargo owner

This option requires data on the nationality of passengers and cargo owners using international flights. On this point, however, there is a lack of reliable and complete information[4]. Neither does the AERO database comprise data on passenger and cargo owner nationality. As an alternative approach, international aviation emissions were therefore allocated proportionally to a country's relative share in world Gross National Product (GNP). National GNP is thus assumed to be directly proportional to the volume of aviation activities generated by national population. Although this is clearly rather a crude assumption, interpreting this option in terms of GNP is to be deemed the best alternative for which complete and reliable data are available. The national and global GNP data used for emission allocation in the base year are based on World Bank statistics (World Bank, 1994), those for calculations for the year 2010 on World Bank projections (World Bank, 1999).

Option 8: Allocation to Parties of all emissions generated in national space

This option differs from options 2 to 7 in the sense that not all international aviation emissions are allocated to countries, but only those occurring within national airspace, i.e. that directly above land (including lakes) and excluding any part of the seas or oceans constituting national territorial waters. Evaluation of this option was again facilitated by AERO-MS, which can calculate emissions in three-dimensional space, as mentioned in section 2.2. For this option, then, the CO_2 emissions associated with each individual flight stage were analysed in 1° by 1° (longitude/latitude) grid cells and aggregated over the 15 altitude layers considered in AERO, with blocks of grid cells then being assigned to individual countries. In cases where a grid cell was only part-located in a given country, the computed emissions in that cell

4 The World Transport Statistics of IRU and the Yearbook of Tourism Statistics of the world Tourism Organisation (WTO) were consulted. However, these statistics are unsuitable for the purpose of this study because: (i) no distinction is made between domestic and foreign passengers, (ii) no distinction is made between domestic and international flights, (iii) not all airlines are included, and (iv) non-scheduled services are omitted.

were allocated to the country according to the fraction of the grid cell in that country.
The CO_2 emissions occurring in the national airspace of each of the 23 countries under review were thus calculated. A distinction was also made between emissions that would be allocated to the other countries of the world under this option and those that would remain unallocated, viz. emissions due to international aviation occurring above seas and oceans.

3 Assessment of global CO_2-emissions

3.1 National CO_2-emissions

This section outlines the procedure followed in reviewing the total national CO_2 emissions of the 23 countries reviewed in this study in the base year and the scenario year. In chapter 4 these figures are used as a backdrop to compare the international aviation emissions allocated nationally under the eight allocation options.

For the base year 1990 this review of national CO_2 emissions is based mainly on the National Inventories submitted by the countries themselves. On the basis of Article 4.1(a) of the United Nations Framework Convention on Climate Change (UNFCCC), all parties to the Convention are required to submit national inventories of greenhouse gas emissions and removals to the Secretariat. It has been assumed that the resultant UNFCCC tables provide a reliable picture of actual emissions. The Intergovernmental Panel on Climate Change (IPCC) has furnished guidelines to help ensure that the national reports are consistent and comparable. Other sources have been used only in cases where information was lacking.

Countries are requested to incorporate emission figures from several sectors in their national inventories. For the purpose of this study national emissions have been split into the following four sectors:

1 energy industry — emissions from fuel combustion in the energy industry;
2 other industry — emissions from fuel combustion in other industries;
3 transport — emissions from fuel combustion in the transport sector;
4 other — any other anthropogenic emissions related to fuel combustion.

In line with the UNFCCC guidelines, the ‘transport’ sector has been taken to include (the CO_2 emissions associated with) domestic aviation activities and national totals likewise include emissions from all sectors except forest and land-use change activities.

The CO_2 emissions of the 23 countries reviewed are presented in Table 2. The data for the base year are based on the National Communications of the Annex I countries collected, processed and published by the secretariat of the United Nations Climate Change Convention (Tables A.1 and A.3 of FCCC/CP/1998/Add.2). The data for Brazil presented in Table 2 were provided by the national Energy Information Administration. ‘Former USSR’ includes only Estonia, Latvia, Lithuania, the Russian Federation and the Ukraine; no data are available for the other former Soviet states.

Although the IPCC has provided guidelines to ensure that all national reports are consistent and comparable, it has been recognised that uncertainties in emissions estimates are inevitable. The main sources of uncertainty are:

- varying interpretations of sector/source definitions, assumptions, emission factors, etc.;
- erroneous data or data simplification through use of 'averaged' values;
- uncertainties in the basic socio-economic data driving the calculations;
- inherent uncertainties in the scientific understanding of the basic processes leading to emissions.

Table 2 also includes an estimate of global anthropogenic CO_2 emissions, based on data of the International Institute for Applied Systems Analysis (www.iiasa.ac.at).

Table 2 National CO_2 emissions for the base year and the year 2010

Country	Data for base year (source: UNFCCC, 1998)						% change 1990-2010	Data for 2010	
	CO_2 emissions per sector (Mtonne)				Total emissions			Total emissions	
	Energy industry	Other industry	Transport	Other	Mtonne	% share		Mtonne	% share
Australia	141.81	47.36	59.60	24.36	273.12	1.29%	+8%	294.97	1.28%
Austria	12.41	7.22	13.97	28.28	61.88	0.29%	-13%	53.84	0.23%
Belgium	28.14	31.03	19.96	36.96	116.09	0.55%	-7.5%	107.38	0.46%
Brazil					212.00	1.00%	+68%	356.16	1.54%
Canada	145.00	71.90	140.00	107.10	464.00	2.18%	-6%	436.16	1.89%
Denmark	25.86	5.78	10.47	10.16	52.28	0.25%	-21%	41.30	0.18%
Finland	19.50	13.70	11.50	9.10	53.80	0.25%	0%	53.80	0.23%
Former Soviet Union					3,174.51	14.94%	-0.25%	3,166.34	13.71%
France	81.88	49.60	124.92	121.98	378.38	1.78%	0%	378.38	1.64%
Germany	439.43	169.74	158.65	246.34	1,014.15	4.77%	-21%	801.18	3.47%
Greece	43.66	9.82	15.19	15.90	84.57	0.40%	+25%	105.72	0.46%
Ireland	10.86	5.43	4.88	9.54	30.72	0.14%	+13%	34.71	0.15%
Italy	148.44	78.12	95.06	110.52	432.15	2.03%	-6.5%	404.06	1.75%
Japan	339.06	339.38	207.43	238.66	1,124.53	5.29%	-6%	1,057.06	4.58%
Luxembourg	1.88	6.35	2.62	1.89	12.75	0.06%	-28%	9.18	0.04%
Netherlands	51.40	48.20	26.80	41.15	167.55	0.79%	-6%	157.50	0.68%
Norway	7.44	3.02	13.88	11.19	35.54	0.17%	+1%	35.90	0.16%
Portugal	17.01	7.22	14.06	8.82	47.12	0.22%	+27%	59.85	0.26%
Spain	75.18	47.97	58.26	45.01	226.42	1.07%	+15%	260.39	1.13%
Sweden	8.85	13.05	18.65	14.90	55.44	0.26%	+4%	57.66	0.25%
Switzerland	0.96	5.41	14.67	24.03	45.07	0.21%	-8%	41.46	0.18%
United Kingdom	231.95	97.04	117.94	136.80	583.75	2.75%	-12.5%	510.78	2.21%
United States	1,748.89	1,066.24	1,499.08	646.22	4,960.43	23.35%	-7%	4,613.20	19.97%
Total					13,606.27	64.04%	-4.2%	13,036.98	56.44%
All other countries (source: www.iiasa.ac.at)					7,639.66	35.96%	+31.7%	10,060.57	43.56%

For the 23 countries reviewed and for the rest of the world the table also shows the projected growth of national CO_2 emissions by the year 2010. These projections (in the column '% change 1990-2010') are based on the following assumptions:

- It is assumed that individual Annex I countries will meet their respective Kyoto reduction targets. For all but one of the countries considered (viz. Brazil) the percentage changes in emissions between 1990 and 2010 are thus based on the targets set in Kyoto for the first commitment period (2008-2012). For the countries of the former USSR the emission targets of individual states were used to calculate the emissions of the former USSR in the year 2010.
- The European Union has committed itself to an 8% reduction of CO_2 emissions in the period 1990 –2010. As indicated in Table 2, within the EU reduction targets vary among individual member states (as agreed by these states). Summation of the total national emissions of EU member states in Table 2 for the years 1990 and 2010 (3,317 and 3,035 Mtonne, respectively) yields an implied reduction of 8% for the EU as a whole, as agreed in Kyoto.
- For non-Annex I countries growth of CO_2 emissions between 1990 and 2010 is based on a non-intervention scenario. These emissions are thus assumed to increase on the basis of a set of assumptions with respect to economic growth, population growth and technological progress. For this purpose the 'scenario B' developed by the International Institute for Applied Systems Analysis was used (www.iiasa.ac.at), which proceeds from modest estimates of economic growth and technological advance. The estimated emissions of Brazil in 2010 are based on the forecast for the region 'Latin America' under this scenario B. This latter assumption was necessary because no data are available on individual countries.

With respect to CO_2 emissions in 2010 Table 2 shows that, despite the assumption that Annex I countries indeed meet their Kyoto targets, global CO_2 emissions are still set to grow by 8.7%. Furthermore, Table 2 illustrates that the share of the 23 countries in global anthropogenic CO_2 emissions decreases from 64.04% in 1990 to 56.44% in 2010. This follows directly from the assumption that Annex I countries will meet their Kyoto targets, while the CO_2 emissions of other countries will continue to grow.

3.2 Global international aviation CO_2 emissions in the base year

As mentioned in section 2.1, the AERO modelling system was used to quantify the global CO_2 emissions of international aviation in the base year, which in AERO-MS is 1992. In section 2.2 it was explained that AERO computes fuel use and emissions using a core database of numbers of flights in the base year, distinguishing nine generic aircraft types and two technology levels, and the fuel use characteristics of these aircraft. AERO also distinguishes between domestic and international flights and thus between associated fuel use and emissions**.** In AERO-MS domestic flights are defined as flights between two cities in the same country (regardless of the nationality of the airline operating the flight) and international flights as flights between cities in different countries.

Table 3 presents the AERO results on global fuel consumption and CO_2 emissions due to domestic and international aviation in the base year. The CO_2 emission data were computed on the fixed assumption of 1 kg of kerosene producing 3.157 kg of CO_2. As the table shows, over 60% of the fuel use and CO_2 emissions of the air transport industry were related to international aviation activities in the base year: in absolute terms, 243.20 Megatonnes of CO_2. It is this amount that is available for allocation to individual countries under the respective allocation options considered in this study.

Table 3 Fuel use and CO_2 emissions from aviation in the base year as computed by AERO-MS (Mtonne)

	Fuel use	CO_2 emissions	% share
International aviation	77.03	243.20	61.7%
Domestic aviation	47.84	151.04	38.3%
Total	**124.88**	**394.23**	**100.0%**

These figures for global aviation fuel use were compared with other available sources, both computational and statistical (the latter in the following section). Among computational sources AERO-MS is unique in distinguishing between international and domestic flights and their associated fuel use, and so comparison was restricted to totals, viz. the NASA, ANCAT/EC2 and DLR estimates of 1992 aviation fuel use published in the IPCC's report on aviation and the global atmosphere (IPCC, 1999). The respective data are presented in Table 4. As can be seen, the AERO-MS results are about 10% higher. The obvious reason for this is that the Unified Database at the heart of AERO-MS is more comprehensive than those behind the other computational results. The ANCAT computation, for example, is based solely on the ANCAT database, which is only one of the four sources used for the Unified Database (see section 2.2).

Table 4 Global aviation fuel use in 1992 according to various computational sources

	NASA	ANCAT	DLR	AERO-MS
Scheduled traffic	94.84			109.71
Charter traffic	6.57			11.30
FSU/China	8.77			
General aviation	3.68			3.86
Total civil aviation*	**113.85**	**114.20**	**112.24**	**124.88**

* All figures in this table are exclusive of fuel use related to military air traffic.

3.3 International bunker fuels compared with AERO-MS

Article 17 of the Annex to the Revised Guidelines for National Communications (FCCC/CP/1996/15/Add.1) requires emissions from international bunker fuels to be reported separately, excluding them as far as possible from national inventories. Under decision 9/CP.2, item 3, Annex I Parties are to follow these revised guidelines in preparing their national communications. The 1996 Revised IPCC Guidelines also advise on how to report on emissions generated by fuel sold for international transportation by air and sea.

The Guidelines states that "The IPCC Guidelines for National Greenhouse Gas Inventories should be used in estimating, reporting and verifying data". These inventory guidelines provide definitions, emission estimation methodologies and reporting procedures. A variety of sources[5] indicate, however, that the international bunker fuel emissions reported in the National Com-

[5] Wit, R.C.N. (CE, 1996), DNV, Final Draft June (1999), Olivier, J.G.J. and J.A.H.W. Peters (RIVM, 1999).

munications and those in international statistics (IEA, UN, ICAO, etc.) are not consistent in their interpretation of definitions and methodologies and that they also contain major gaps. Based on an assessment of the submitted second National Communications by Annex I Parties, the following conclusions can be drawn (DNV, 1999):

1. Although the definition of international bunker fuels for the aviation sector adopted in the 1996 Revised IPCC guidelines is held by most Parties to be sufficiently clear, there is found to be frequent mismatch between this definition and that adopted in individual National Communications.
2. Most Parties appear to have fairly accurate estimates of total bunker fuel sales and some countries can distinguish reasonably well between sales to the aviation and marine sectors. A break-down into national (i.e. domestic) and international sales generates inconsistencies, however.
3. In estimating national emissions most Parties appear to have adopted the IPCC methodology in principle. Some nations allude to national methodologies compatible with the IPCC Guidelines, but these are not generally available in the National Communications. Nonetheless, only minor reporting deviations were found.
4. Other sources of statistical data are often formatted for dedicated purposes and may require adaptation before they are suitable for preparing nation-by-nation global inventories.

Besides the National Communications data, fuel use statistics are available at the International Energy Agency (IEA) for international marine as well as air transport. These data, for the 29 IEA member countries and several other UN ECE member countries, are derived from joint IEA/EUROSTAT/UN ECE questionnaires. The IEA approach to emissions from international bunker fuels adopted by the IEA differs somewhat from that of the IPCC. The IEA includes fuel use by military aviation in this figure, while according to the IPCC Guidelines all such fuel use (for both domestic and international military flights) should be included in the national inventory (under the 'Energy/Other' category). The IEA also stresses[6] that the distinction between domestic and international fuel use is difficult to monitor and that an assessment of the fuel actually consumed by domestic aviation is therefore likewise problematical.
It should be stressed that the above conclusions relate to the international bunker fuel data of Annex I countries. For the purpose of this study, adequate international bunker fuel data are also required for non-Annex I countries, however. Although such information is collected by IEA and the UN, the resultant database is unreliable and incomplete. The implication is that the official bunker statistics have no reliable figure for the aggregate, i.e. global, aviation fuel sales to international aviation in the base year.

For this reason, and because additional information (on RTK, number of flight departures and arrivals, etc.) consistent with fuel use data are required for some allocation options, in this study it was opted to use the AERO modelling system for such calculations, complemented by other data as necessary[7]. This approach allows for consistent presentation of the consequences of the eight allocation options and for mutual *comparison* within reasonable margins of uncertainty, in line with the objective of this study.

---

[6] Personal communication.

[7] These data sources are specified in section 2.3, where the methodology adopted for each allocation option is discussed.

Evidently, AERO-MS is not an officially recognised data source meeting the criteria of the IPCC Guidelines. At the present time, however, the 'official' fuel use data provided by the National Communications are inadequate for meeting the objectives of this study.
To provide further insight into the differences between international fuel bunker statistics and the AERO-MS data, Table 5 presents national CO_2 emissions from international aviation fuel use in absolute terms (Mtonne) and as a percentage of global CO_2 emissions from international aviation. The data on aviation fuel use are based on:

- National Communications (FCCC/CP/1996/12/Add.2);
- UN-1992 Energy statistic yearbook, No. E/F.94.XVII.9, UN (1994) New York.
- EIA-Energy statistics of OECD countries, OECD/IEA, (1992) Paris
- EIA Oil and Gas Information 1993, IEA (1994) Paris.
- EIA, personal communication, 1999.
- Olivier and Peters (RIVM, 1999), Netherlands, report 773301 002.

Table 5 Comparison of international bunker fuel statistics and fuel use based on AERO-MS

	International bunker fuel statistics 1990			AERO-MS 1992	
Country	Int. bunker fuel sales (Mtonne)	CO_2 emission (Mtonne)	National share	CO_2 emission (Mtonne)	National share
Australia	1.35	4.26	1.56%	7.80	3.21%
Austria	0.16	0.51	0.18%	0.96	0.39%
Belgium	0.93	2.9	1.07%	2.23	0.92%
Brazil	1.73[a]	5.46	2.00%	3.30	1.36%
Canada	0.88	2.78	1.02%	6.09	2.50%
Denmark	0.61	1.9	0.71%	1.71	0.70%
Finland	0.32	1.01	0.37%	1.52	0.62%
Former Soviet Union	13.03[b]	41.1	4.90%	1.83	0.75%
France	3.06	9.66	3.53%	10.03	4.13%
Germany	4.50	14.2	5.20%	13.75	5.65%
Greece	0.76	2.4	0.88%	1.85	0.76%
Ireland	0.34	1.07	0.39%	0.89	0.37%
Italy	1.82	5.74	2.10%	4.67	1.92%
Japan	4.24	13.39	4.90%	18.29	7.52%
Luxembourg	0.13	0.41	0.15%	0.47	0.19%
Netherlands	1.41	4.45	1.63%	5.24	2.15%
Norway	0.08	0.25	0.09%	0.52	0.21%
Portugal	0.49	1.55	0.57%	1.28	0.53%
Spain	1.10	3.47	1.27%	6.63	2.73%
Sweden	0.27	0.85	0.31%	1.70	0.70%
Switzerland	0.99	3.1	1.14%	3.52	1.45%
United Kingdom	4.09	12.9	4.73%	16.57	6.81%
USA	6.17	19.5	7.13%	44.24	18.19%
Total	48.46	152.99	56.01%	155.06	63.76%
Total, other countries	38.06	120.16	43.99%	88.13	36.24%
TOTAL	86.52[b]	273.15	100.00%	243.20	100.00%

[a] IEA Energy balance data.
[b] Based on personal communication, IEA.

As a consequence of the major gaps and inconsistencies in the international bunker fuel data (see above) it is difficult to ascertain which factors are responsible for the differences relative to the AERO-MS data. In particular, there are major uncertainties with regard to the data for the former Soviet Union and the USA. For neither country is it possible to monitor or assess the respective shares of fuel use for domestic and international aviation. This may go a long way to explaining the major differences with regard to these countries.

For the group of 23 countries as a whole, the AERO figure for total international aviation emissions is close to that derived from international fuel bunker statistics: 153 Mtonne CO_2 in 1990 according to the latter statistics and 155 Mtonne CO_2 based on 1992 fuel consumption as computed by AERO (see Table 15). Given the Gulf War at the beginning of the 1990s, the figures for 1990 and 1992 should be fairly comparable. This close similarity of the results may indicate that this figure for the total international aviation CO_2 emissions of the 23 countries is fairly reliable. It also indicates that the *total* fuel consumption of the 23 countries in AERO-MS is consistent with international bunker fuel sales in these countries.

A more general and important explanation for the differences between the two sources for the same countries is that the international bunker fuel statistics are based on 'bunker fuel sold to international aviation' while the AERO-MS data are based on 'fuel consumption of international aviation'. The most important difference between these two data is the 'tankering' phenomenon, whereby airlines take more fuel on board than is necessary for their current flight. This practice is particularly frequent in countries where fuel is relatively cheap. As a consequence, in allocation option 3 disproportionately high international aviation CO_2 emissions will be allocated to these countries. As 'tankering' is not included in the current configuration of AERO-MS, the calculations performed for this option are not fully in line with option 3 as defined by the UNFCCC.

3.4 Global international aviation CO_2-emissions in 2010

As stated above, to estimate the global CO_2 emissions from international aviation in 2010 a scenario was developed reflecting a variety of relevant trends. The AERO modelling system has procedures to assist the user in creating such a scenario defined in terms of a coherent set of scenario variables.
In the context of the present study the main aspects of the scenario specification concern:

1 projected trend in air transport supply and demand, and
2 projected trend in aircraft technology development.

The principal assumptions underlying the scenario for 2010 used in the present study are outlined below.

1 Projected trend in air transport demand and supply

The basic assumption in the scenario projection is that sufficient air transport capacity will be supplied to match growth in demand. The trend in air transport demand used here is based on an ICAO forecast. From this data the annual percentage growth for each AERO route group was computed, as presented in Table 3.5. The ICAO data do not include a forecast of growth of cargo demand. A scenario developed by Boeing indicates that annual growth of cargo demand will be 1.6% higher than passenger demand growth. In the 2010 scenario employed here this figure has been taken for all route groups (see Table 6).

Table 6 Annual growth of passenger-km and tonne-km between 1992 and 2010 as computed in the AERO scenario.

AERO route group	Annual growth percentage (pax-km)	(tonne-km)
1. Intra-North America	4.0 %	5.6 %
2. Intra-EU	3.7 %	5.3 %
3. North America – EU	4.6 %	6.2 %
4. Intra-Asia	7.3 %	8.9 %
5. North America – Asia	6.9 %	8.5 %
6. EU – Asia	7.1 %	8.7 %
7. EU – other Europe	4.7 %	6.3 %
8. EU – rest of the world	4.1 %	5.7 %
9. All Other	4.6 %	6.2 %

Source: derived from ICAO/Boeing

2 Projected trend in aircraft technology development

Projections of technological improvements (i.e. fuel use) in new aircraft have been prepared by several institutions (e.g. ICAO/CAEP WG3, DTI/ANCAT 2015 forecasts, EISG subgroup reports, EIA Annual Energy Outlook 1994, and NASA 1992 data). These projections give a figure of between 0.8% and 2.1% for the annual improvement in the fuel consumption of new aircraft. In the 2010 scenario used in this study it has been assumed that the average fuel use of newly manufactured aircraft declines by 1% per year. In this respect it is noted that the IPCC report on aviation and the global atmosphere (IPPC, 1999) refers to a scenario in which the average fuel efficiency of new aircraft improves by 20% between 1997 and 2015, which corresponds exactly with an annual improvement of 1% for a period of 18 years.

3 Modelling results for 2010

On the basis of the scenario specification presented above, aviation fuel use and CO_2 emissions in 2010 were computed. The results are presented in Table 7.

Tabel 7 Aviation fuel use and CO_2 emissions in 2010 as computed in the AERO-MS scenario (Mtonne)

	Fuel use	CO_2 emissions	% share
International aviation	134.45	424.46	63.4%
Domestic aviation	77.58	244.92	36.6%
Total	**212.03**	**669.38**	**100.0%**

Table 8, compares global CO_2 emissions due to international aviation with global anthropogenic CO_2 emissions, for both the base year and the year 2010. At the global level in the base year international aviation emissions amounted to 1.14% of aggregate ‘national’ anthropogenic CO_2 emissions (i.e. emissions from all other sectors already allocated at the country level). As can also be seen in the table, international aviation emissions are forecast to grow faster than ‘national’ CO_2 emissions[8]. The contribution of international aviation to global anthropogenic CO_2 emissions isexpected to increase further, in other words, rising to 1.84% by the year 2010.

[8] It is hereby assumed that Annex I countries secure the national emission targets for 2010 agreed in Kyoto.

Tabel 8 Global anthropogenic CO_2 emissions and global international aviation CO_2 emissions in the base year and 2010 (Mtonne)

	Base year	2010	% increase
Global anthropogenic CO_2 emissions	21,245.93	23,097.55	8.7%
Global international aviation CO_2 emissions	243.20	424.46	74.6%
Share of international aviation CO_2 emissions in anthropogenic CO_2 emissions	1.14%	1.84%	

4 Allocation of international aviation emissions

4.1 Allocation of international aviation emissions in the base year

Proceeding from the definitions and interpretations of the eight allocation options as described in section 2.3, global international aviation CO_2 emissions in the base year have been allocated on paper to the 23 countries reviewed. The results are presented in three tables, which review the emissions allocated to each country under each option:

- in absolute terms (Table 9);
- as a percentage of global international aviation emissions (Table 10);
- as a percentage of the country's total national emissions (Table 11).

In the tables the allocation options are numbered and briefly labelled; the fuller descriptions are as follows:

1 No allocation.
2 Allocation of CO_2 emissions to countries according to national emissions.
3 Allocation of CO_2 emissions to countries according to fuel sold.
4 Allocation of CO_2 emissions to countries according to airline nationality.
5 Allocation of CO_2 emissions to countries according to flight departure/destination.
6 Allocation of CO_2 emissions to countries according to RTK departure/destination.
7 Allocation of CO_2 emissions to countries according to passenger/cargo owner nationality.
8 Allocation of CO_2 emissions to countries according to emissions in national airspace.

In interpreting Tables 9 through 11 the following should be noted:

- In Table 9 the allocated CO_2 emission is expressed in Megatonne (1 Mtonne = 10^9 kg). For each option the total allocation to the group of 23 countries is indicated as well as the emission that would be allocated to 'other countries', viz. the difference between global international aviation CO_2 emissions in the base year (243.20 Mtonne) and the total allocation to the 23 countries.
- Under option 1 there is no emissions allocation; for this option Table 9 therefore shows only the global total of international aviation CO_2 emissions.
- Under option 8 international aviation CO_2 emissions are not fully allocated to individual countries. The unallocated portion is formed by emissions occurring outside the national airspace of any country (i.e. international aviation emissions above seas and oceans).
- Table 10, detailing national emission allocations as a percentage of global international aviation emissions, shows that a different share of global international aviation emissions is allocated to the group of 23 countries under the espective options.
- The (absolute) national CO_2 emissions data in Table 11 are based on the National Communications of the respective countries (cf. Table 2). The percentage allocations of international aviation emissions presented in this table are thus percentages of these absolute numbers. The table also gives the average percentage allocation for the group of 23 countries. For options 2 through 7 the ratio between global international aviation CO_2 emissions and global anthropogenic 'national' CO_2 emissions is

equal, as already presented in Table 8. In the case of option 8 the average percentage is lower, as not all CO_2 emissions are allocated.

A number of observations can be made regarding emissions allocation in the base year. Each allocation option is now considered, providing an indication of the uncertainties in the computational results.

Under **option 1** emissions remain unallocated by definition and the tables therefore show only the global emissions volume. As the idea behind this option is that global international aviation emissions will be appropriately reduced by the international community (through ICAO, for example), the 'total' shown in the table for option 1 represents the aggregate emissions for which the international community would be 'responsible'. Uncertainties with respect to 'allocation' under this option relate solely to the quantification of global international aviation emissions, as described in chapter 3. It should be noted that these uncertainties apply to *all* allocation options, as in all cases this is the basic 'pie' to be divided.

Option 2 allocates international aviation emissions according to the percentage share of a country's national emissions in global anthropogenic emissions. By definition, these national percentages are the same as those presented in Table 2. In Table 11, showing allocated aviation emissions as a percentage of national emissions, the allocation key is the same for all countries: 1.14% (cf. Table 8). Under option 2 countries with relatively low national emissions in the base year will be allocated a similarly small share of international aviation emissions. A case in point is France, where national CO_2 emissions are comparatively low owing to the high share of nuclear power in national energy production. For France, option 2 would mean allocation of significantly less emissions compared to the other allocation options. In contrast, the countries of the former USSR, with relatively high national emissions in 1990, would be allocated a comparatively large share of international aviation emissions. Uncertainties with respect to allocation under option 2 relate directly to uncertainties and possible inconsistencies in the reporting of national emissions in the National Communications of the respective countries. These uncertainties are identified in section 3.1.

Under **option 3** emissions are allocated according to the country of fuel sale. As indicated in section 2.3, the principal assumption in relation to this option is that the fuel used on international flights (as computed by the AERO modelling system) is bought in the country of departure of the flight. Under this option countries with a relatively well-developed aviation industry (in terms of number of departing flights) will be allocated a relatively large share of global international aviation emissions. Cases in point are Greece, Portugal and Spain, where relatively large number of tourists make use of aviation services. Other examples of countries with a relatively well-developed aviation industry include Australia (with its peripheral location) and the Netherlands (with its relatively large share of transfer passengers). As Table 9 shows, for these countries option 3 would result in greater allocations than options 2 and 7, for example (based, respectively, on relative national emissions and relative GNP).
The uncertainties in the results for option 3 are due in the first place to those in the underlying AERO data (see section 2.2). A second uncertainty relates to the fact that in this study no allowance has been made for fuel 'tankering' (taking more fuel on board than required for the current flight). If a significant proportion of actual fuel sales in any of the countries reviewed is used on flights departing from another country, the allocation results presented for option 3 will be rather less accurate. Given the fact that no tankering data

are available for the base year and international fuel bunker data are inconsistent and incomplete (as discussed in chapter 3), the results for option 3 are to be deemed the best available estimate.

Option 4 allocates emissions according to airline nationality. For lack of appropriate data this option was operationalised by allocating emissions proportionally to the total annual Revenue Tonne Kilometres (RTK) of the airlines of the country in question (cf. section 2.3). As Table 9 shows, significantly more emissions are allocated to the 23 countries under this option than under most others. This can be explained by the fact that the airlines of some of these countries service relatively more flight stages to and from overseas airports. Another notable difference is that under this option 'holiday' countries like Spain, Greece and Portugal are allocated less aviation emissions than in options 3, 5 and 6. This seems consistent with the facts, for a substantial share of international aviation to and from these countries consists of charter services operated by foreign airlines.

The results for **option 5** (allocation according to country of aircraft departure/destination) are very similar to those of option 3 (based on fuel sales). The differences follow from slight differences in average flight length (and associated emissions) of departing versus arriving flights in any given country. Under this option half the emissions associated with an international flight are allocated to the country of departure and half to the country of destination, while under option 3 they are allocated entirely to the country of departure. As in the case of option 3, under this option countries with a relatively well-developed aviation industry (in terms of number of arrivals and departures) would be allocated a relatively large share of international aviation emissions.

As can be seen in the tables, the results for **option 6** (allocation according to country of RTK departure/destination) are similar to those of option 5 (and thus to those of option 3). While option 5 allocates emissions proportionally according to the country's share of *aircraft* departures/arrivals, option 6 does so on the basis of *RTK* departures/arrivals, i,e. the country's share in global international RTKs. There are two reasons for the slight differences in the national allocations resulting from options 5 and 6:

- inter-country differences in the average fuel use (and thus CO_2 emissions) of the fleets on incoming/outgoing flights;
- inter-country differences in average fleet load factor on incoming/outgoing flights.

As an example, Table 10 shows that under this option the countries of the former USSR are allocated slightly more emissions than under option 5 (0.84% versus 0.76%). This is because the average fuel use characteristics of the fleet used on international flights to and from the former USSR are below the global average for international flights. A large proportion of flights to and from the former USSR are naturally operated by airlines based in these countries. Although these carriers generally operate older, less fuel-efficient aircraft than the global average, the differences between options 5 and 6 are in fact fairly limited because some of these flights are operated by carriers from other parts of the world (the EU, for example), which generally operate more fuel-efficient aircraft.

Finally, it is noted that with respect to both options 5 and 6 the main uncertainties in results are due to uncertainties in the underlying AERO data (see section 2.2).

The results for **option 7** (allocation according to nationality of passengers/cargo owner) diverge strongly from those of the other options. As Table 4.2 shows, under this option over 80% of international aviation CO_2 emissions are allocated to the group of 23 countries reviewed in this study, which is significantly higher than under all other allocation options. In relation to this option it should also be stressed that allocation was performed on the basis of GNP (as a proxy for pax/cargo owner nationality). As Table 10 shows, compared with other options a relatively large share of international aviation emissions are allocated to the USA and Japan, in particular, reflecting these countries' substantial share in global GNP.
The main uncertainty with respect to option 7 relates to how well allocation according to GNP approximates allocation by pax/cargo owner nationality. Although there is clearly a relation between a country's GNP and the aviation activities of the country's citizens, whether the relationship is as direct as assumed in the present study is basically unknown.

Under **option 8** (allocation according to national airspace) a substantial proportion of emissions remains unallocated: 53.06% (Table 10). These are the emissions occurring outside the airspace of individual countries, i.e. above seas and oceans. As a result, only about 30% of global international aviation emissions are allocated to the group of 23 countries. By its nature, this option automatically allocates a major share of emissions to large countries. As Table 10 shows, Canada and the former Soviet Union are assigned more emissions than under most other options, even though only about half of international aviation emissions are now allocated. As Table 11 shows, expressed as a percentage of national emissions, national allocations of international aviation emissions now average 0.54%, compared with 1.14% for all other options.

Table 9 National allocations of international aviation CO_2 emissions, by allocation option, in Megatonnes (base year)

Option		Allocation according to:						
	No allocation	National emissions	Country of fuel sale	Airline nationality	Country of aircraft dest. or departure	Country of pax dest. or departure	Country of origin of pax or cargo owner	Emissions in national airspace
Country	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Australia		3.13	7.80	6.22	7.80	5.39	3.19	3.79
Austria		0.71	0.96	0.87	0.96	0.92	1.87	1.24
Belgium		1.33	2.23	2.06	2.29	2.25	2.21	0.79
Brazil		2.43	3.30	3.27	3.31	3.13	4.51	2.54
Canada		5.31	6.09	7.65	6.13	6.10	6.01	9.77
Denmark		0.60	1.71	1.75	1.68	1.76	1.42	1.15
Finland		0.62	1.52	1.40	1.52	1.01	1.17	0.51
Former Soviet Union		36.34	1.83	3.83	2.05	1.84	6.24	7.57
France		4.33	10.03	12.07	10.02	10.13	13.50	7.44
Germany		11.61	13.75	16.88	13.74	13.99	19.62	5.62
Greece		0.97	1.85	1.07	1.84	2.08	0.79	0.52
Ireland		0.35	0.89	0.85	0.90	0.81	0.46	0.89
Italy		4.95	4.67	4.17	4.62	4.65	12.50	2.00
Japan		12.87	18.29	15.75	18.32	17.50	36.96	2.58
Luxembourg		0.15	0.47	0.07	0.42	0.58	0.15	0.05
Netherlands		1.92	5.24	7.35	5.25	5.90	3.29	0.92
Norway		0.41	0.52	0.95	0.56	0.53	1.17	0.32
Portugal		0.54	1.28	1.15	1.28	1.50	0.78	0.67
Spain		2.59	6.63	4.57	6.61	6.81	5.77	2.31
Sweden		0.63	1.70	1.43	1.73	1.59	2.48	0.70
Switzerland		0.52	3.52	4.51	3.54	3.55	2.63	1.25
United Kingdom		6.68	16.57	20.50	16.54	17.80	10.88	3.72
USA		56.78	44.24	52.91	44.50	45.77	62.65	11.25
Total		155.75	155.06	171.28	155.60	155.61	200.24	67.59
Total, other countries		87.45	88.13	71.91	87.60	87.59	42.96	47.74
Total, non-allocated	243.20							127.86
TOTAL	243.20	243.20	243.20	243.20	243.20	243.20	243.20	243.20

Table 10 National allocations of international aviation CO_2 emissions, by allocation option, as a percentage of global international aviation emissions (base year)

Option		Allocation according to:						
	No allocation	National emissions	Country of fuel sale	Airline nationality	Country of aircraft dest. or departure	Country of pax dest. or departure	Country of origin of pax or cargo owner	Emissions in national airspace
Country	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Australia		1.29%	3.21%	2.56%	3.21%	2.22%	1.31%	1.56%
Austria		0.29%	0.39%	0.36%	0.39%	0.38%	0.77%	0.51%
Belgium		0.55%	0.92%	0.85%	0.94%	0.93%	0.91%	0.32%
Brazil		1.00%	1.36%	1.35%	1.36%	1.29%	1.85%	1.04%
Canada		2.18%	2.50%	3.15%	2.52%	2.51%	2.47%	4.02%
Denmark		0.25%	0.70%	0.72%	0.69%	0.72%	0.58%	0.47%
Finland		0.25%	0.62%	0.57%	0.62%	0.41%	0.48%	0.21%
Former Soviet Union		14.94%	0.75%	1.57%	0.84%	0.76%	2.56%	3.11%
France		1.78%	4.13%	4.96%	4.12%	4.17%	5.55%	3.06%
Germany		4.77%	5.65%	6.94%	5.65%	5.75%	8.07%	2.31%
Greece		0.40%	0.76%	0.44%	0.76%	0.86%	0.33%	0.21%
Ireland		0.14%	0.37%	0.35%	0.37%	0.33%	0.19%	0.36%
Italy		2.03%	1.92%	1.71%	1.90%	1.91%	5.14%	0.82%
Japan		5.29%	7.52%	6.48%	7.53%	7.19%	15.20%	1.06%
Luxembourg		0.06%	0.19%	0.03%	0.17%	0.24%	0.06%	0.02%
Netherlands		0.79%	2.15%	3.02%	2.16%	2.42%	1.35%	0.38%
Norway		0.17%	0.21%	0.39%	0.23%	0.22%	0.48%	0.13%
Portugal		0.22%	0.53%	0.47%	0.53%	0.62%	0.32%	0.27%
Spain		1.07%	2.73%	1.88%	2.72%	2.80%	2.37%	0.95%
Sweden		0.26%	0.70%	0.59%	0.71%	0.65%	1.02%	0.29%
Switzerland		0.21%	1.45%	1.86%	1.45%	1.46%	1.08%	0.51%
United Kingdom		2.75%	6.81%	8.43%	6.80%	7.32%	4.47%	1.53%
USA		23.35%	18.19%	21.76%	18.30%	18.82%	25.76%	4.63%
Total		64.04%	63.76%	70.43%	63.98%	63.98%	82.34%	27.79%
Total, other countries		35.96%	36.24%	29.57%	36.02%	36.02%	17.66%	19.63%
Total, non-allocated	100.00%							52.58%
TOTAL	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table 11 National allocations of international aviation CO_2 emissions, by allocation option, as a percentage of total national anthropogenic emissions (base year).

Option			Allocation according to:						
Country	Anthropogenic CO_2 emissions (Mton)	No allocation (1)	National emissions (2)	Country of fuel sale (3)	Airline nationality (4)	Country of aircraft dest. or departure (5)	Country of pax dest. or departure (6)	Country of origin of pax or cargo owner (7)	Emissions in national airspace (8)
Australia	273.12		1.14%	2.85%	2.28%	2.86%	1.97%	1.17%	1.39%
Austria	61.88		1.14%	1.55%	1.40%	1.54%	1.48%	3.01%	2.00%
Belgium	116.09		1.14%	1.92%	1.78%	1.97%	1.94%	1.90%	0.68%
Brazil	212.00		1.14%	1.56%	1.54%	1.56%	1.48%	2.13%	1.20%
Canada	464.00		1.14%	1.31%	1.65%	1.32%	1.31%	1.30%	2.11%
Denmark	52.28		1.14%	3.27%	3.34%	3.21%	3.37%	2.72%	2.19%
Finland	53.80		1.14%	2.82%	2.60%	2.82%	1.87%	2.18%	0.94%
Former Soviet Union	3,174.51		1.14%	0.06%	0.12%	0.06%	0.06%	0.20%	0.24%
France	378.38		1.14%	2.65%	3.19%	2.65%	2.68%	3.57%	1.97%
Germany	1,014.16		1.14%	1.36%	1.66%	1.35%	1.38%	1.93%	0.55%
Greece	84.58		1.14%	2.18%	1.27%	2.18%	2.46%	0.94%	0.61%
Ireland	30.72		1.14%	2.91%	2.75%	2.92%	2.65%	1.49%	2.89%
Italy	432.15		1.14%	1.08%	0.96%	1.07%	1.08%	2.89%	0.46%
Japan	1,124.53		1.14%	1.63%	1.40%	1.63%	1.56%	3.29%	0.23%
Luxembourg	12.75		1.14%	3.68%	0.57%	3.32%	4.58%	1.14%	0.37%
Netherlands	167.55		1.14%	3.13%	4.39%	3.13%	3.52%	1.96%	0.55%
Norway	35.54		1.14%	1.46%	2.67%	1.59%	1.50%	3.29%	0.91%
Portugal	47.12		1.14%	2.72%	2.44%	2.71%	3.19%	1.65%	1.42%
Spain	226.42		1.14%	2.93%	2.02%	2.92%	3.01%	2.55%	1.02%
Sweden	55.45		1.14%	3.07%	2.58%	3.12%	2.86%	4.47%	1.26%
Switzerland	45.07		1.14%	7.80%	10.01%	7.85%	7.89%	5.84%	2.77%
United Kingdom	583.75		1.14%	2.84%	3.51%	2.83%	3.05%	1.86%	0.64%
USA	4,960.43		1.14%	0.89%	1.07%	0.90%	0.92%	1.26%	0.23%
Total	13,606.27		1.14%	1.14%	1.26%	1.14%	1.14%	1.47%	0.50%
Total, other countries	7,639.66		1.14%	1.15%	0.94%	1.15%	1.15%	0.56%	0.57%
TOTAL	21,245.93	1.14%	1.14%	1.14%	1.14%	1.14%	1.14%	1.14%	0.52%

4.2 Allocation of international aviation emissions in 2010

In this section global international aviation CO_2 emissions are once more allocated to the 23 countries, but now for the year **2010**, again proceeding from the definitions and interpretations of the allocation options detailed in section 2.3. The results are again presented in three tables, reviewing the emissions allocated to each country under each option:

- in absolute terms (Table 12);
- as a percentage of global international aviation emissions (Table 13);
- as a percentage of the country's total national emissions (Table 14).

In this section there is no further discussion of differences among the eight options, these having been discussed in section 4.1. The focus here is rather on the differences in emissions allocation between 2010 and the base year, as reflected in differences between Tables 12 through 14 and Tables 9 through 11, respectively. The following observations can be made:

- Under all options the *absolute volume* of CO_2 emissions allocated to the 23 countries reviewed would be between 55% and 70% higher in 2010, compared with 1992. This is due to an average increase of about 75% in international aviation emissions over this period (see Table @@), offset by somewhat slower growth in air transport demand in these countries.
- Under all options the *relative share* of global international aviation CO_2 emissions allocated to the 23 countries would be lower in 2010 because of an increase in the share of *other countries*. This is due mainly to the relatively high growth projections for air transport and thus emissions in these other countries, particularly in Asia.
- In the case of option 2 (allocation proportional to national emissions) the increase in the share of emissions allocated to the 23 countries in 2010 is relatively small compared with the other options, because the national emissions of most of these countries are assumed to have then been reduced as per the Kyoto reduction targets.

Table 12 National allocations of international aviation CO_2 emissions, by allocation option, in Megatonnes (2010)

Option		Allocation according to:						
	No allocation	National emissions	Country of fuel sale	Airline nationality	Country of aircraft dest. or departure	Country of pax dest. or departure	Country of origin of pax or cargo owner	Emissions in national airspace
Country	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Australia		5.42	12.72	10.21	12.94	8.24	5.48	6.52
Austria		0.99	1.51	1.37	1.50	1.40	3.08	1.91
Belgium		1.97	3.25	3.24	3.42	3.49	3.59	1.11
Brazil		6.55	4.61	5.38	4.58	4.67	12.27	3.55
Canada		8.02	9.77	13.24	9.90	9.93	8.40	15.95
Denmark		0.76	3.01	2.74	2.90	2.88	2.53	1.81
Finland		0.99	2.44	2.19	2.45	1.44	1.83	0.88
Former Soviet Union		58.19	3.04	6.28	3.33	2.94	7.04	15.90
France		6.95	15.96	18.96	15.97	16.27	20.34	11.06
Germany		14.72	22.55	26.51	22.13	22.24	30.41	8.85
Greece		1.94	2.94	1.68	3.08	2.98	1.75	0.79
Ireland		0.64	1.34	1.33	1.33	1.19	1.18	1.33
Italy		7.43	7.31	6.55	7.25	7.27	16.63	2.99
Japan		19.43	38.07	25.85	38.10	39.47	48.32	5.82
Luxembourg		0.17	0.71	0.11	0.64	0.95	0.24	0.07
Netherlands		2.89	8.80	11.55	8.84	10.11	5.56	1.44
Norway		0.66	0.83	1.56	0.91	0.82	2.12	0.56
Portugal		1.10	1.90	1.80	1.91	2.04	1.55	0.97
Spain		4.79	9.75	7.19	9.72	9.02	8.02	3.36
Sweden		1.06	2.73	2.25	2.78	2.30	3.27	1.18
Switzerland		0.76	5.77	7.41	5.79	5.47	3.84	1.87
United Kingdom		9.39	27.38	32.20	27.53	28.82	19.27	5.56
USA		84.78	73.01	91.54	74.03	79.90	119.32	18.06
Total		239.58	259.41	281.14	261.02	263.85	326.04	111.57
Total, other countries		184.88	165.05	143.32	163.44	160.61	98.42	91.81
Total, non-allocated	424.46							221.08
TOTAL	424.46	424.46	424.46	424.46	424.46	424.46	424.46	424.46

Table 13 National allocations of international aviation CO_2 emissions, by allocation option, as a percentage of global international aviation emissions (2010)

Option		Allocation according to:						
	No allocation	National emissions	Country of fuel sale	Airline nationality	Country of aircraft dest. or departure	Country of pax dest. or departure	Country of origin of pax or cargo owner	Emissions in national airspace
Country	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Australia		1.28%	3.00%	2.41%	3.05%	1.94%	1.29%	1.54%
Austria		0.23%	0.35%	0.32%	0.35%	0.33%	0.73%	0.45%
Belgium		0.46%	0.77%	0.76%	0.81%	0.82%	0.85%	0.26%
Brazil		1.54%	1.09%	1.27%	1.08%	1.10%	2.89%	0.84%
Canada		1.89%	2.30%	3.12%	2.33%	2.34%	1.98%	3.76%
Denmark		0.18%	0.71%	0.65%	0.68%	0.68%	0.60%	0.43%
Finland		0.23%	0.57%	0.52%	0.58%	0.34%	0.43%	0.21%
Former Soviet Union		13.71%	0.72%	1.48%	0.78%	0.69%	1.66%	3.75%
France		1.64%	3.76%	4.47%	3.76%	3.83%	4.79%	2.61%
Germany		3.47%	5.31%	6.25%	5.21%	5.24%	7.16%	2.08%
Greece		0.46%	0.69%	0.40%	0.73%	0.70%	0.41%	0.19%
Ireland		0.15%	0.32%	0.31%	0.31%	0.28%	0.28%	0.31%
Italy		1.75%	1.72%	1.54%	1.71%	1.71%	3.92%	0.70%
Japan		4.58%	8.97%	6.09%	8.98%	9.30%	11.38%	1.37%
Luxembourg		0.04%	0.17%	0.03%	0.15%	0.22%	0.06%	0.02%
Netherlands		0.68%	2.07%	2.72%	2.08%	2.38%	1.31%	0.34%
Norway		0.16%	0.20%	0.37%	0.22%	0.19%	0.50%	0.13%
Portugal		0.26%	0.45%	0.43%	0.45%	0.48%	0.37%	0.23%
Spain		1.13%	2.30%	1.69%	2.29%	2.13%	1.89%	0.79%
Sweden		0.25%	0.64%	0.53%	0.66%	0.54%	0.77%	0.28%
Switzerland		0.18%	1.36%	1.75%	1.36%	1.29%	0.91%	0.44%
United Kingdom		2.21%	6.45%	7.59%	6.48%	6.79%	4.54%	1.31%
USA		19.97%	17.20%	21.57%	17.44%	18.82%	28.11%	4.26%
Total		56.44%	61.12%	66.24%	61.49%	62.16%	76.81%	26.29%
Total, other countries		43.56%	38.88%	33.76%	38.51%	37.84%	23.19%	21.63%
Total, non-allocated	100.00%							52.09%
TOTAL	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table 14 National allocations of international aviation CO_2 emissions, by allocation option, as a percentage of total national anthropogenic emissions (2010)

Option			Allocation according to:						
Country	Anthropogenic CO_2 emissions (Mtonnes)	No allocation (1)	National emis-sions (2)	Country of fuel sale (3)	Airline nationality (4)	Country of aircraft dest. or departure (5)	Country of pax dest. or depar-ture (6)	Country of origin of pax or cargo owner (7)	Emissions in national airspace (8)
Australia	294.97		1.84%	4.31%	3.46%	4.39%	2.79%	1.86%	2.21%
Austria	53.84		1.84%	2.80%	2.54%	2.78%	2.60%	5.72%	3.55%
Belgium	107.38		1.84%	3.03%	3.02%	3.19%	3.25%	3.34%	1.03%
Brazil	356.16		1.84%	1.29%	1.51%	1.29%	1.31%	3.45%	1.00%
Canada	436.16		1.84%	2.24%	3.04%	2.27%	2.28%	1.93%	3.66%
Denmark	41.30		1.84%	7.29%	6.64%	7.02%	6.97%	6.13%	4.39%
Finland	53.80		1.84%	4.54%	4.08%	4.55%	2.67%	3.39%	1.64%
Former Soviet Union	3,166.34		1.84%	0.10%	0.20%	0.11%	0.09%	0.22%	0.50%
France	378.38		1.84%	4.22%	5.01%	4.22%	4.30%	5.38%	2.92%
Germany	801.18		1.84%	2.81%	3.31%	2.76%	2.78%	3.80%	1.10%
Greece	105.72		1.84%	2.78%	1.59%	2.91%	2.82%	1.65%	0.75%
Ireland	34.71		1.84%	3.86%	3.83%	3.82%	3.44%	3.39%	3.85%
Italy	404.06		1.84%	1.81%	1.62%	1.79%	1.80%	4.11%	0.74%
Japan	1,057.06		1.84%	3.60%	2.45%	3.60%	3.73%	4.57%	0.55%
Luxembourg	9.18		1.84%	7.72%	1.24%	6.95%	10.35%	2.62%	0.78%
Netherlands	157.50		1.84%	5.59%	7.33%	5.61%	6.42%	3.53%	0.91%
Norway	35.90		1.84%	2.31%	4.34%	2.54%	2.30%	5.91%	1.55%
Portugal	59.85		1.84%	3.18%	3.02%	3.19%	3.41%	2.59%	1.62%
Spain	260.39		1.84%	3.74%	2.76%	3.73%	3.46%	3.08%	1.29%
Sweden	57.66		1.84%	4.73%	3.89%	4.82%	3.99%	5.67%	2.05%
Switzerland	41.46		1.84%	13.91%	17.86%	13.97%	13.19%	9.27%	4.52%
United Kingdom	510.78		1.84%	5.36%	6.30%	5.39%	5.64%	3.77%	1.09%
USA	4,613.20		1.84%	1.58%	1.98%	1.60%	1.73%	2.59%	0.39%
Total	13,036.98		1.84%	1.99%	2.16%	2.00%	2.02%	2.50%	0.86%
Total, other countries	10,060.57		1.84%	1.64%	1.42%	1.62%	1.60%	0.98%	0.91%
TOTAL	23,097.55	0.00%	1.84%	1.84%	1.84%	1.84%	1.84%	1.84%	0.88%

5 Allocation of international marine emissions

5.1 Introduction

This chapter presents the modelling results for allocating international marine CO_2 emissions. In contrast with aviation emissions, in the case of marine emissions only allocation options 1, 2 and 3 were considered in this study. There are several reasons for this limited treatment of marine emissions:

- this was the focus of the party commissioning this study: the Dutch Civil Aviation Authority;
- the marine sector has not addressed the issue of greenhouse gas emissions to the same extent as the aviation sector (DNV, 1999);
- the average annual increase in marine bunkers is about 0.8%, while for aviation this figure was about 3.3% in the period 1970-1995;
- the insufficiency and inconsistency of statistics on international marine bunker fuels is greater than in the case of the aviation sector, due, inter alia, to the following factors: (i) the 1996 Revised IPCC Guidelines contain no direct definition of international bunker fuels for the marine sector, (ii) consequently there are various uncertainties in the definitions that have been adopted, leading to a heterogeneous database and inconsistent National Communications inventories, and (iii) to date the IMO has not undertaken any systematic collection or monitoring of the fuel use or greenhouse gas emissions of the world marine fleet.

The consequences of allocation options 1, 2 and 3 are presented for the year 1990 only. No calculations were performed for the year 2010 because no reliable emission scenarios are available on developments in marine shipping up to that year.

5.2 Results: allocation of international marine emissions

On the basis of the definitions and interpretations of allocation options 1, 2 and 3 global international marine CO_2 emissions have been allocated for the base year. The three allocation options are:

1 No allocation.
2 Allocation to countries according to national emissions.
3 Allocation to countries according to fuel sales to the international marine sector.

The results are presented in Table 15, which reviews the international marine CO_2 emissions allocated to each of the 23 countries under each option, again specifying these as follows:

- in absolute terms, expressed in Megatonne (1 Mtonne = 10^9 kg). In all cases the table also shows the aggregate emission allocated to the group of 23 countries as well as that accruing to ‘other countries’. The latter is the difference between global international marine CO_2 emissions in the base year (366 Mtonne) and the allocation to the group of 23 countries;
- as a percentage of global international marine emissions; as can be seen, a different share of emissions is allocated to the group of 23 countries under the three allocation options;

- as a percentage of each country's total national emissions.

A number of observations can be made with respect to national allocation of international marine CO_2 emissions in the base year 1990 (Table 15):

Under **option 1** emissions remain unallocated by definition and the table therefore shows only the global emissions volume. As the idea behind this option is that global international marine emissions will be appropriately reduced by the international community (through IMO, for example), the 'total' shown in the table for option 1 represents the aggregate emissions for which the international community would be 'responsible'. Uncertainties with respect to 'allocation' under this option relate solely to the quantification of global international marine emissions. It should be noted that these uncertainties regarding assessment of global international marine emissions apply to *all* allocation options, as in all cases this is the basic 'pie' to be divided.

Option 2 allocates international marine emissions according to the percentage share of a country's total anthropogenic emissions in global anthropogenic emissions. By definition, these national percentages are the same as those presented in Table 2. In the column of Table 15 showing allocated marine emissions as a percentage of national emissions, the allocation key is the same for all countries: 1.7%. Under this option countries with relatively low national emissions in 1990 will be allocated a similarly low share of international marine emissions. One consequence of this option is that international marine CO_2 emissions are also allocated to countries with no seaboard (Austria, Luxembourg and Switzerland).

Option 3 allocates global international marine emissions to countries according to national bunker fuel sales to the international marine sector. The figures used here for the absolute international marine CO_2 emissions of individual countries are derived from the international marine bunker fuel statistics[9] of IEA (1992) and the National Communications as reported by UNFCCC (1997). As already mentioned, international marine bunker fuel statistics are inconsistent owing to the use of various definitions and treatments of domestic marine fuel. It should be stressed, therefore, that there is a measure of uncertainty in the results for option 3.

As can be seen from Table 15, under option 3 (based on bunker fuel sales) by far the greatest share of total international marine CO_2 emissions is allocated to two countries: the USA (24%) and the Netherlands (9%). The shares of the other countries are substantially lower. Table 15 also shows the large measure of inter-country variation resulting when marine bunker emissions are expressed as a percentage of *national* anthropogenic CO_2 emissions. This varies from 20% for the Netherlands, 11 % for Belgium and 9% for Greece down to zero for landlocked countries such as Austria, Luxembourg and Switzerland. Major refinery activities located near important marine shipping routes and ports explain the high shares of the first three countries.

---

9 Marine bunker fuels are heavy fuel oil and diesel oil. In 1990 the share of diesel in marine bunkers is about 20% (RIVM, 1999). The CO_2 emissions presented in Table 15 under option 3 are based on a fixed ratio between fuel use and CO_2 emissions, 1 kg of diesel/heavy fuel oil being taken to result in 3.13 kg of CO_2.

Table 15 National allocations of international marine CO_2 emissions under allocation options 1, 2 and 3 (1990)

Country	Anthropogenic CO_2 emissions (Mtonne)[a]	No allocation (1)	Allocation of CO_2 emissions according to: National emissions (2) Mtonne	% of global int. marine emissions	% of national emissions	Country of bunker fuel sale[b] (3) Mtonne	% of global int. marine emissions	% of national emissions
Australia	273.12		4.70	1.3%	1.7%	1.97	0.5%	0.7%
Austria	61.88		1.07	0.3%	1.7%	0.00	0.0%	0.0%
Belgium	116.09		2.00	0.5%	1.7%	12.52	3.4%	10.8%
Brazil	212.00		3.65	1.0%	1.7%	4.76	1.3%	2.2%
Canada	464.00		7.99	2.2%	1.7%	1.93	0.5%	0.4%
Denmark	52.28		0.90	0.2%	1.7%	2.95	0.8%	5.6%
Finland	53.80		0.93	0.3%	1.7%	1.74	0.5%	3.2%
Former soviet union	3174.51		54.69	14.9%	1.7%	5.97	1.6%	0.2%
France	378.38		6.52	1.8%	1.7%	7.65	2.1%	2.0%
Germany	1014.16		17.47	4.8%	1.7%	7.51	2.1%	0.7%
Greece	84.58		1.46	0.4%	1.7%	7.70	2.1%	9.1%
Ireland	30.72		0.53	0.1%	1.7%	0.06	0.0%	0.2%
Italy	432.15		7.44	2.0%	1.7%	8.08	2.2%	1.9%
Japan	1124.53		19.37	5.3%	1.7%	15.62	4.3%	1.4%
Luxembourg	12.75		0.22	0.1%	1.7%	0.00	0.0%	0.0%
Netherlands	167.55		2.89	0.8%	1.7%	33.19	9.1%	19.8%
Norway	35.54		0.61	0.2%	1.7%	1.38	0.4%	3.9%
Portugal	47.12		0.81	0.2%	1.7%	1.87	0.5%	4.0%
Spain	226.42		3.90	1.1%	1.7%	11.23	3.1%	5.0%
Sweden	55.45		0.96	0.3%	1.7%	2.04	0.6%	3.7%
Switzerland	45.07		0.78	0.2%	1.7%	0.00	0.0%	0.0%
United Kingdom	583.75		10.06	2.7%	1.7%	7.73	2.1%	1.3%
USA	4960.43		85.45	23.3%	1.7%	88.08	24.1%	1.8%
Total	13606.27		234.39	64.0%	1.7%	223.97	61.2%	1.6%
Total, other countries	7639.66		131.61	36.0%	1.7%	142.03	38.8%	1.9%
TOTAL	21245.93	366.00	366.00	100.0%	1.7%	366.00	100.0%	1.7%

[a] Source: National Communications (Table A.1 and A.3 of FCCC/CP/1998/Add.2). For Brazil: Energy Information Administration of Brazil.

[b] Source: Based on Second National Communications (UNFCCC, 1997), Energy Statistics of OECD countries 1980-1990 (OECD/IEA, 1992), RIVM (1999) and personal communication with IEA.

6 Summary and conclusions

Background
On 10 December 1997 the Kyoto Protocol of the UN Framework Convention on Climate Change (UNFCCC) was adopted by 160 countries. For each of the so-called Annex I countries the Protocol sets a reduction target for total national greenhouse gas emissions for the period 2008-2012 relative to the base year 1990-1992. These individual targets are for 'national emissions', i.e. emissions due to economic activities taking place on national territory, which must be reported to the Conference of the Parties of the UNFCCC in a 'National Greenhouse Gas Inventory'. International emissions of greenhouse gases associated with fuels bunkered by international aviation and marine shipping are not included in these national targets, and are to be reported separately. Emissions due to domestic aviation and marine are regarded as 'national emissions', to be included as such in the national inventory.

Article 2.2 of the Kyoto Protocol states that "the 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 Organisation (ICAO) and the International Maritime Organisation (IMO), respectively".

In 1996 the Subsidiary Body for Scientific and Technological Advice (SBSTA) of UNFCCC elaborated eight options for allocating responsibilities for greenhouse gas emissions from international aviation and marine shipping. In the first option international emissions are not allocated to individual countries but remain in the international sphere. In the other seven options a variety of criteria are employed for allocating international emissions to individual countries.

In order to facilitate the debate on the allocation issue at the meetings of UNFCCC, SBSTA and ICAO's Committee on Aviation Environmental Protection (CAEP), the Dutch Civil Aviation Authority (RLD) commissioned the present study to assess the distributional consequences for 23 individual countries of each of the UNFCCC/SBSTA CO_2 emissions allocation options. The study has been executed by a consortium consisting of Resource Analysis (RA) and the Centre for Energy Conservation and Environmental Technology (CE).

Aim and focus of the study

The *aim* of the study is to provide insight into how the eight options identified by UNFCCC/SBSTA for national allocation of international aviation and marine emissions of the greenhouse gas carbon dioxide (CO_2) translate into assigned amounts accruing to individual countries.
The *focus* of this study is mainly on *international* aviation because:
- the marine sector has not addressed the issue of greenhouse gas emissions to the same extent as the aviation sector;
- the average annual increase in marine bunkers is about 0.8% while for aviation this figure was about 3.3% in the period 1970-1995; this makes the allocation of international aviation emissions relatively more urgent;

- the insufficiency and inconsistency of statistics on international marine bunker fuels is greater than in the case of the aviation sector.

Methodology

The eight allocation options defined by SBSTA and considered in the present study are:

1 No allocation.
2 Allocation of global bunker sales and associated emissions to Parties in proportion to their national emissions.
3 Allocation to Parties according to the country where the bunker fuel is sold.
4 Allocation to Parties according to the nationality of the transport operator.
5 Allocation to Parties according to the country of destination or departure of aircraft or vessel.
6 Allocation to Parties according to the country of destination or departure of passengers or cargo.
7 Allocation to Parties according to the country of origin of passengers or owner of cargo.
8 Allocation to the Party of all emissions generated in its national space.

The emissions of the following 23 countries have been specifically considered: the countries of the European Union (15), Switzerland, Norway, USA, Canada, Russia, Brazil, Japan and Australia. For each of the eight allocation options and each of these countries, the nationally allocated international aviation CO_2 emission is presented

- in absolute terms,
- as a percentage of global international aviation emissions, and
- as a percentage of the country's total national emissions.

The results are presented in parallel format for the base year (1990-1992) and the year 2010, a horizon deemed representative for the first commitment period (2008-2012) within which the Kyoto targets are to be met. In order to forecast global CO_2 emissions from international aviation in 2010 use was made of the AERO modelling system.
In the case of international marine emissions only three allocation options were analysed: options 1,2 and 3. Results are presented for the base year 1990.

Conclusions

The results of this study lead to the following conclusions:

1 The statistics available for calculating the consequences of the eight emission allocation options defined by UNFCCC (1996) are characterised by insufficiency, incompleteness and non-uniformity across countries. The principal reason is that the CO_2 emissions from international bunker fuels reported to UNFCCC in National Communications and those reported in international statistics (IEA, UN, ICAO, IMO) are inconsistent with regard to definitions and methodologies and contain major gaps. For example: (i) In the second National Communications of some countries no distinction is made between domestic and international CO_2 emissions from aviation and shipping and (ii) the international fuel bunker statistics of non-Annex I countries are incomplete. The lack and inconsistency of available data means that no reliable estimate can be made of the aggregate, i.e. global CO_2 emissions caused by international aviation and shipping, a crucial statistic for adequately estimating the consequences of all allocation options.

2 This study provides an indication of the distributional consequences for 23 countries of eight options for allocating international aviation CO_2 emissions. Because of the lack of sufficient and reliable data, however, these results may be subject to change as better information becomes available.

3 Because of the inadequacy of international bunker fuel statistics and because additional information (on RTK, number of flight departures and arrivals, etc.) showing consistency with fuel use data are required for some allocation options, in this study it was opted to use the AERO modelling system for such calculations. This approach allows for consistent presentation of the consequences of the eight allocation options and for mutual *comparison* within reasonable margins of uncertainty, in line with the objective of the study. Evidently, AERO-MS is not an officially recognised data source meeting the guidelines of the IPCC. At the present time, however, the 'official' fuel use data provided by the National Communications are inadequate for the objectives of this study.

4 The total CO_2 emissions from international aviation computed by AERO-MS are close to international fuel bunker statistics: 153 Mtonne CO_2, compared with 155 Mtonne CO_2 according to AERO, based on fuel consumption in the base year.

5 In 1992 about 60% of global CO_2 emissions from aviation were related to *international* aviation activities. In absolute terms global CO_2 emissions from *international* aviation then totalled 243 Mtonne, representing 1.1% of all global anthropogenic CO_2 emissions. These emissions are not included in the reduction targets agreed in the Kyoto protocol.

6 The contribution of *international* aviation to global CO_2 emissions is expected to rise to about 1.8% in 2010 as a result of substantial growth of international air transport and CO_2 emission reductions in other sectors compared to 1992.

7 **Option 1** (no allocation) represents a maintenance of the status quo, i.e. reporting international aviation and marine emissions in a separate category. Under this option these emissions would still be considered in relation to article 2.2 of the Kyoto Protocol which states that "the Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine fuels".

8 **Option 2** (allocation proportional to national emissions) leads to national allocations that do not appear to reflect the respective volumes of international aviation activities. This is because this option does not relate emissions to a specific aviation activity such as bunker fuel sales or aircraft or passenger movements.

9 **Option 3** (allocation by country of aviation fuel sales) shows that countries with a relatively well developed aviation industry (in terms of number of departing flights) would be allocated a comparatively large share of global international emissions. Cases in point are Greece, Portugal and Spain, where relatively intense use is made of aviation services by tourists. Other examples of countries with a relatively well-developed aviation industry include Australia (with its peripheral location) and the Netherlands (with its relatively large share of transfer passengers).

10 **Option 4** (allocation by airline nationality). For lack of data this option was operationalised by allocating emissions proportionally to the total annual Revenue Tonne Kilometres (RTK) of the airlines of the country in question. This study shows that substantially more CO_2 emissions are allocated to the 23 countries under this option than under most others. This can be explained by the fact that the airlines of some of these countries service relatively more flight stages arriving and departing from overseas airports. Another notable difference is that under this option 'holi-

day' countries like Spain, Greece and Portugal are allocated less aviation emissions than in options 3, 5 and 6. This seems consistent with the facts, for a substantial share of international aviation to and from these countries consists of charter services operated by foreign airlines.

11 **Option 5** (allocation by country of aircraft departure/destination) The results for option 5 are very similar to those of option 3 (based on fuel sales). The differences follow from slight differences in average flight length (and associated emissions) of departing versus arriving flights in any given country. Under this option 50% of the emissions associated with departing flights and 50% of those associated with arriving flights are allocated to the country in question, while under option 3 all the emissions associated with departing international flights are allocated. As in the case of option 3, under this option countries with a relatively well-developed aviation industry (in terms of number of arrivals and departures) would be allocated a relatively large share of international aviation emissions.

12 **Option 6** (allocation by country of RTK departure/destination). The results of this option are similar to those of option 5 (and thus to those of option 3). While option 5 allocates emissions proportionally according to the country's share of *aircraft* departures/arrivals, option 6 does so on the basis of *RTK* departures/arrivals, i,e. the country's share in global international RTKs. The slight differences between the results for options 5 and 6 are due to inter-country differences in average fuel use characteristics and load factors on flights to and from countries.

13 **Option 7** (allocation by nationality of pax/cargo owner). This option could not be assessed in its original specification for lack of appropriate statistical data. As an approximation emissions were allocated proportionally to GNP for the purpose of this study.

14 **Option 8** (allocation of emissions generated in national airspace). Under this option 53% of emissions from international aviation remain unallocated. These are the emissions occurring outside the airspace of individual countries, i.e. above seas and oceans. Consequently, only about 30% of global international aviation emissions are allocated to the group of 23 countries.

15 With regard to international **marine** emissions, for which allocation options 1, 2 and 3 were examined, the following conclusions can be drawn. For option 1 (no allocation) and 2 (proportional to national emissions) the same conclusions can be drawn as for aviation emissions. The conclusions with respect to option 3, however, are remarkable: based on bunker fuel sales, two countries are allocated by far the largest share of total international marine CO_2 emissions: the USA with 24% and the Netherlands with 9%. The shares of the other countries are substantially lower. This study also shows the large measure of inter-country variation resulting when marine bunker emissions are expressed as a percentage of *national* anthropogenic CO_2 emissions. This varies from 20% for the Netherlands, 11 % for Belgium and 9% for Greece to zero for landlocked countries such as Austria, Luxembourg and Switzerland. Major refinery activities located near important marine shipping routes and ports explain the high shares for the first three countries. These results show also that the 'bunkering' phenomenon is far more extensive in the marine sector than in the aviation sector.

References

DNV, 1999	Methods used to Collect Data, Estimate and Report Emissions from International Bunker Fuels (Final Draft), June 1999.
IEA, 1992	Energy Statistics of OECD countries 1980-1990, OECD/IEA, Paris.
IEA, 1993	Oil and Gas Information 1993, IEA (1994) Paris.
IEA, 1997	Energy Statistics of OECD and non-OECD countries 1971-1995, OECD/IEA, Paris.
IEA, 1998	CO_2 emissions from fuel combustion, OECD/IEA, Paris.
IPCC, 1997	Revised 1996 IPCC Guidelines for National Greenhouse Gas Emission Inventories.
IPCC, 1999	Aviation and the Global Atmosphere, IPCC. 1999.
Olivier and Peters,	International Marine and Aviation bunker fuel: trends, ranking of
1999	countries and comparison with national CO2 emissions, Bilthoven, Netherlands.
RLD, 2000	Aviation Emissions and Evaluation of Reduction Options (AERO), Volume I: Description of the AERO Modelling System, RLD. 2000 (in prep.)
UN, 1994	Energy statistic yearbook, No. E/F.94.XVII.9, UN (1992), New York.
UNFCCC, 1996	FCCC/SBSTA/1996/9/Add.2
UNFCCC, 1997	Kyoto Protocol to the United Nations Framework Convention on Climate Change. UNFCCC, Bonn. Doc. N. FCCC/CP/1997/L/7/Add.1.
UNFCCC. 1998	FCCC/CP/1998/Add.2
Wit, R.C.N. (1996)	How to Control Greenhouse Gas Emissions from International Aviation? Options for Allocation, Centre for Energy Conservation and Environmental Technology (CE), Delft.
World Bank, 1994	World Tables 1994, World Bank. 1994.
World Bank, 1999	Global Economic Prospects - Report 2000, World Bank, 1999