Greenhouse Gas Emissions from Aviation

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Front page photo: contrails formed by water vapour emissions from an aircraft (photo courtesy of Parl Vater, all rights reserved)

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Table of Contents

Table of Graphs

Table of Tables

1 Introduction

Greenhouse gas emissions from aviation have been rising steadily in the past due to increased demand for air traffic despite efficiency increases through technological improvements and operative measures. Looking at CO_2 alone aviation is responsible for approximately 2.5% of global greenhouse gas emissions but the share is projected to rise up to 10% in a business as usual scenario of global emissions (IPCC 1999). The total impact of aviation on climate change is estimated to be two to five times higher than the effect of CO_2 alone due to emissions of NO_x and cloud formation. As a result, emissions from EU aviation could be responsible for 40% to over 100% of the allowable greenhouse gas emissions in 2050 if global warming is limited to 2°C, the goal set by the EU (T&E 2006).

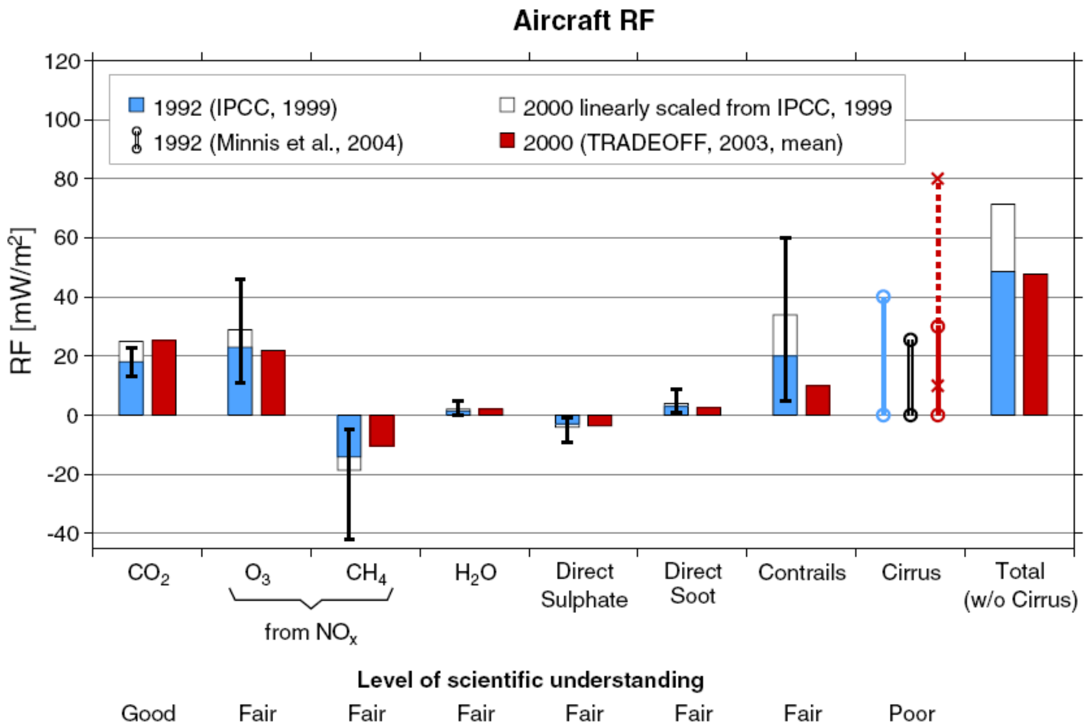
Emissions from international aviation and maritime transport, so called bunker fuels, are not covered under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. Instead, responsibility to reduce these emissions is handed to the International Civil Aviation Organisation (ICAO) and the International Maritime Organisation (IMO). There is little political will to reduce greenhouse gas emissions from aviation on an international level despite the growing trend and the projected impact on the climate in the next decades. As a consequence the Commission of the European Communities has proposed a Directive which would include aviation in an emissions trading scheme (EC 2006). The proposal foresees that all flights which depart and/or arrive at an EU airport will be covered by the scheme after an initial year which only covers intra-EU flights.

The purpose of this report is to compile reliable and transparent data on the effects of aviation on climate change. It compiles information on historic and projected emissions from government sources, science and business organisations. Chapter 2 discusses the climate impact of aviation in more detail. Historic CO_2 emissions from the sector are presented in chapter 3. Several different projections up to 2050 are presented in chapter 4.

2 Climate Change and Aviation

The impact of fossil fuel combustion on the climate is normally dominated by carbon dioxide (CO_2) emissions. The other two greenhouse gases emitted during fossil fuel combustion, methane (CH_4) and nitrogen dioxide (N_2O), together contribute less than 2% to the greenhouse gas emissions from EU fuel combustion as estimated under the Kyoto Protocol (EC 2006). This picture changes when looking at the aviation sector due to the altitude at which airplanes fly and emissions occur. Apart from emissions of direct greenhouse gases emissions of substances that produce or destroy greenhouse gases and emission of substances that trigger the generation of clouds have to be taken into account for a full assessment of the impact of aviation on climate (IPCC 1999). It is estimated that the overall contribution of aviation to global warming is 2 to 5 times higher than the radiative forcing[1] of its CO_2 emissions alone (Sausen 2005). The range reflects the uncertainty in the assessment of the radiative forcing of the indirect effects (Graph 1). Note that the total given in the graph does not include the effect of cirrus clouds as the level of scientific understanding is judged to be poor. The scientific understanding of the chemical and physical reactions in the atmosphere is best for CO_2 emissions. For all other effects the scientific knowledge of the underlying reactions is judged to be fair (Sausen 2005). Below is a compilation of the different effects of aviation on climate based upon the special IPCC report (IPCC 1999) with updates by Sausen et al (Sausen 2005) and a study by CE Delft and MNP (CE Delft 2007).

Graph 1 Radiative forcing of aviation in the years 1992 and 2000



Source: Sausen 2005.

2.1 Direct greenhouse gases

Emissions of the direct greenhouse gases CO_2 and H_2O scale linearly with the amount of fuel burnt and can be estimated with a good level of accuracy. Emissions of soot and their characteristics depend on engine characteristics and can only be estimated with large uncertainties.

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[1] Radiative forcing is a measure for the change of the earth's energy balance due to a change of greenhouse gas concentrations given in power per area (W/m^2). Radiative forcing depends on the concentration of a given gas in the atmosphere and can therefore vary over time. Estimates for radiative forcing for future years depend on scenarios on global greenhouse gas emissions from all sectors.

- **Carbon dioxide** has a warming effect on the climate and remains in the atmosphere for several decades. CO_2 emissions from aviation can be treated identically to those from other sectors as the gas remains long enough in the atmosphere to be well mixed independent of the source location.
- **Water vapour** has a warming effect on the climate and is generated from the Hydrogen contained in the kerosene. It remains only for a short period in the troposphere, the altitude at which most emissions from aviation occur. The quantity of water vapour emitted by aviation is small compared to the natural hydrological cycle and the effect on the climate is minor.
- **Soot particles** are produced in the combustion process and have a small warming effect on the climate as they absorb incoming sunlight and heat up the atmosphere.

2.2 Indirect greenhouse gases

NO_x and SO_2 emissions do not contribute to global warming directly but produce or destroy greenhouse gases, in particular ozone (O_3), methane and sulphate aerosols. SO_2 emissions can be estimated with good accuracy if the sulphur content of the fuel is known. Estimates on the formation of O_3 and the destruction of CH_4 vary strongly with the atmospheric models used.

- **Ozone** has a warming effect on the climate. The effect is higher at cruising altitude than on the ground due to longer lifetimes and greater radiative forcing in the troposphere. Ozone generation is increased through NO_x emissions from aviation.
- **Methane** is a greenhouse gas which is present in the atmosphere due to natural as well as human induced sources. Very little or no methane is emitted by airplanes but NO_x emissions initiate a destruction of CH_4 molecules and therefore have a cooling effect on the climate (negative radiative forcing). Overall the warming effect of NO_x emissions due to ozone formation is estimated to be higher than the cooling results due to methane destruction.
- **Sulphate aerosols** scatter incoming sunlight back to the atmosphere and lead to a cooling of the climate (negative radiative forcing). Sulphur contained in the kerosene oxidises to SO_2 during combustion out of which a fraction is converted to SO_4 in a further step.

2.3 Cloud formation

Additional to the effects discussed above soot particles, sulphate aerosols and water vapour may also lead to contrails and cirrus cloud formation. The impact of aviation emissions on cirrus cloud formation is not well understood but could be the most important effect.

- **Contrails** are formed through emissions of water and particles under certain atmospheric conditions and visible as white lines with the eye (see cover photo). The trails mainly consist of water already contained in the atmosphere and airplanes only triggered their formation. The effect of contrails is twofold: they cool the climate through increased backscatter of solar radiation but also trap heat on the earth which contributes to global warming. Overall contrails have a positive radiative forcing although significant uncertainties remain in the estimation of the magnitude. The formation of contrails is well understood and can be modelled if sufficient parameters on the atmospheric conditions are available.

- **Cirrus cloud** formation might be augmented through aviation induced contrails and cloud seeding through particles. Increased cirrus cloud formation contributes to global warming but exact quantifications are not yet possible. Estimates ranges from no or very little radiative forcing up to four times the forcing induced by CO_2 alone.

3 Historic Emissions of CO_2, SO_2 and NO_x

The most comprehensive public source for CO_2, SO_2 and NO_x emissions from aviation for EU Member States are the national greenhouse gas inventory reports under the UNFCCC and its Kyoto Protocol. Under these treaties industrialised countries, so called Annex I countries, have to prepare annual reports on the emissions of all greenhouse gases covered by the Convention and the Protocol. Although emissions from international aviation are not included in the national totals they are reported as memo items and available for all years starting 1990. Reporting is based on fuel sold and differentiated between domestic and international aviation.

An alternative source could be the database assembled by Eurocontrol on all flights of its member countries since 1996. The main purpose of the data is the collection of route charges and air traffic management but it also provides an excellent basis for modelling emissions from aviation. Eurocontrol has developed an application which is able to do so but the data is not publicly available.

3.1 Estimation methods and uncertainties

Several different methodologies for the estimation of CO_2, SO_2 and NO_x emissions from aviation are used in Member States (Table 1). In the simplest methodology given in the IPCC good practice guidance (Tier 1) total fuel supplied to aircrafts is multiplied by emission factors for the three gases (IPCC 2000a). Emissions of CO_2 and SO_2 only depend on the carbon and sulphur content of the fuel and can be estimated accurately using this methodology assuming that the respective contents are known. NO_x emissions on the other hand vary between flight stages. More advanced methodologies take this into account and estimate emissions for landing and take-off cycles (LTO) separately from the cruise stage. Emissions and fuel consumption during LTO are estimated either based on total number of LTOs and emission factors for an average fleet (Tier 2a) or on the number of LTOs per aircraft type and respective emission factors (Tier 2b). The difference between total fuel sold and fuel use during LTO is used to estimate cruise emissions. Some Member States use more advanced models to calculate emissions for each individual flight (Tier 3). The total quantity of fuel supplied to airplanes is normally taken from national statistics; emission factors are either country specific or taken from the IPCC Guidelines (IPCC 1996) or the EMEP/CORINAIR Guidebook (EEA 2006). Emissions of water and soot as well as the formation of contrails and clouds are not reported under the UNFCCC and are not further considered in this chapter.

The uncertainties for the estimation of total CO_2 emissions from the aviation sector are considered to be low. Emissions mainly depend on total fuel sales which are usually included in national energy statistics with good accuracy. The main difficulty faced by Parties is the separation between domestic and international aviation. In general, all flights departing and arriving in one country should be reported under domestic aviation whereas flights arriving in a different country should be reported as international bunker fuels.[2] National statistics might not differentiate between the two categories or use different definitions for the split. While this does not affect to total estimate of emissions from the sector it can lead to significant errors in the data given for domestic and international aviation. A comparison of emission estimates for the year 2000 from national inventory reports with Eurocontrol estimates based on a detailed model using air traffic management data showed that values agree within 10% for most countries for the sector as a whole. Estimates for domestic aviation alone on the other hand differed by up to 200% in several countries (ETC/ACC 2004). In the most recent EC GHG inventory report, uncertainty of CO_2 emissions from domestic aviation is estimated to be 20% for the EU-15 (EC 2006). For NO_x and SO_2 confidence levels are lower due to higher uncertainties in the emission factor (NO_x) and the sulphur content of the kerosene (SO_2).

[2] Special rules exist for stops solely for refuelling or when passengers are only dropped off/ picked up at the beginning or end of a long distance flight. These cases have little relevance in the EU as most countries are too small to justify several stops in them for one flight.

Table 1 *Methods, activity data and emission factors used for the estimation of emissions from aviation*

	Method applied	Activity Data	Emission Factor
Austria	country specific	national statistics	country specific
Belgium	Corinair, model	national statistics	Corinair
Cyprus	-	-	-
Czech Republic	Tier 1	national statistics	Default
Denmark	Corinair	national statistics	Corinair
Estonia	Tier 1	national statistics	Default
Finland	Tier 2b	national statistics	country specific
France	Tier 2b	national statistics	country specific
Germany	Tier 1	national statistics, associations	country specific
Greece	Tier 2a	national statistics, associations	Corinair
Hungary	-	-	-
Ireland	Tier 2a	national statistics	country specific
Italy	Tier 1, Tier 2a	national statistics	country specific
Latvia	Tier 1	queries	Default
Lithuania	Tier 2	national statistics	country specific
Luxembourg	Corinair, Default	-	Corinair, Default
Malta	-	-	-
Netherlands	Tier 2	national statistics	country specific
Poland	model	national statistics, associations	Default
Portugal	Tier 2b	national statistics, associations	Corinair
Slovakia	Tier 2a	associations, queries, nat. stat.	Corinair
Slovenia	Tier 1	national statistics	Default
Spain	Tier 2a	national statistics	Default
Sweden	Tier 1	national statistics	country specific
United Kingdom	Tier 3	national statistics, associations	country specific

Source: *EC 2006.*

3.2 Historic emissions and growth rates

Emissions of CO_2, NO_x and SO_2 as reported by EU Member States are presented in Table 2 to Table 4 and Graph 2 to Graph 3. Between 1990 and 2004 CO_2 emissions from the EU aviation sector have risen by 73% (Table 2). Six countries (UK, Germany, France, Spain, Italy and the Netherlands) are responsible for 82% of the total emissions. The old 15 Member States are responsible for over 95% of the sector's fuel consumption. Emissions from aviation have risen annually on average by 4% in the same period despite a noticeable decline after the attacks of 11 September 2001. Emissions from the aviation sector in the new Member States reached 1990 levels in 2004 but the data shows large annual fluctuations which might be due to incomplete or inaccurate estimates in some countries and not representing real growth rates. Emissions of NO_x and SO_2 show the same trend and distribution across Member States as for CO_2.

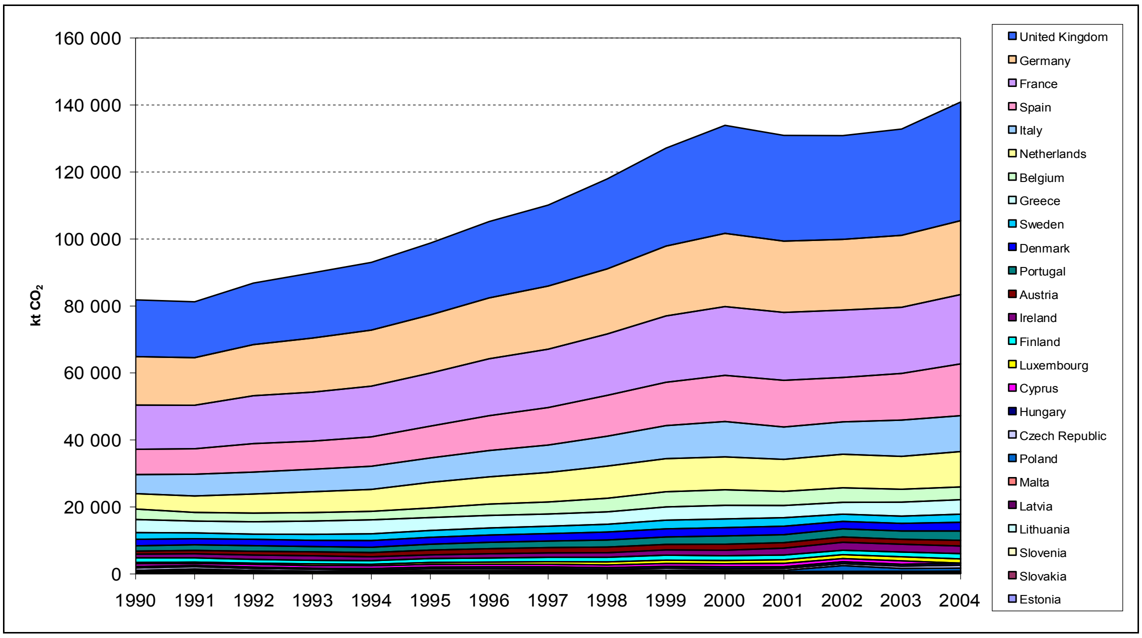
Table 2 *CO_2 emissions from aviation in EU Member States 1990-2004*

	Emissions [kt CO_2]			
	1990	1995	2000	2004
Austria	918	1 385	1 757	1 724
Belgium	3 108	2 895	4 665	3 825
Cyprus[a]	745	820	898	1 017
Czech Republic	766	499	447	889
Denmark	1 979	2 066	2 504	2 575
Estonia	103	52	65	89
Finland	1 369	1 130	1 408	1 584
France	13 158	15 818	20 534	20 715
Germany	14 487	17 359	21 861	22 040
Greece	3 902	3 819	4 062	4 333
Hungary	475	524	641	609
Ireland	1 118	1 148	1 662	2 223
Italy	5 713	7 304	10 551	10 736
Latvia	221	78	83	149
Lithuania	418	128	81	120
Luxembourg	399	574	972	1 290
Malta	207	333	335	343
Netherlands	4 582	7 625	9 790	10 544
Poland[b]	317	308	358	854
Portugal	1 555	1 764	2 495	2 775
Slovakia	51	65	69	103
Slovenia	82	60	74	62
Spain	7 567	9 519	13 811	15 421
Sweden	2 009	2 060	2 570	2 439
United Kingdom	16 946	21 459	32 212	35 426
EU 10	3 386	2 867	3 051	4 235
EU 15	78 811	95 925	130 856	137 653
EU 25	82 196	98 792	133 907	141 888

Notes: NE: not estimated
[a] Incomplete dataset. 2003 emissions instead of 2004 emissions used.
[b] Incomplete dataset. 1991 emissions instead of 1990 emissions used.

Source: *EC 2006.*

Graph 2 *CO_2 emissions from aviation in EU Member States 1990-2004*



Source: *EC 2006.*

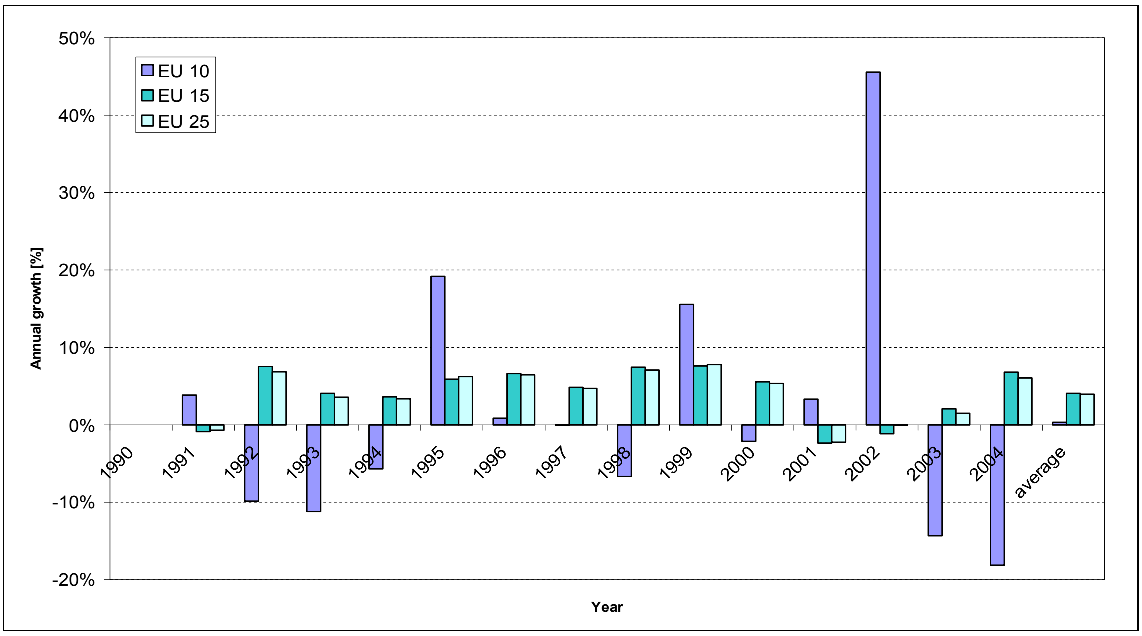
Table 3 Annual growth rates of CO_2 emissions from aviation 1990-2004

	Annual Growth Rates [%]			
	1990-1994	1995-1999	2000-2004	1990-2004
Austria	7.8%	4.0%	-0.5%	4.6%
Belgium	-5.0%	11.9%	-4.8%	1.5%
Cyprus[a]	0.1%	0.4%	4.3%	2.4%
Czech Republic	-14.9%	5.7%	18.8%	1.1%
Denmark	0.4%	4.5%	0.7%	1.9%
Estonia	-8.7%	6.6%	8.0%	-1.1%
Finland	-6.2%	6.3%	3.0%	1.0%
France	3.6%	5.8%	0.2%	3.3%
Germany	3.7%	4.7%	0.2%	3.0%
Greece	1.7%	0.8%	1.6%	0.8%
Hungary	2.9%	3.3%	-1.3%	1.8%
Ireland	1.0%	9.1%	7.5%	5.0%
Italy	4.8%	7.9%	0.4%	4.6%
Latvia	-22.9%	4.0%	15.8%	-2.8%
Lithuania	-26.1%	-10.6%	10.4%	-8.5%
Luxembourg	6.1%	15.5%	7.3%	8.7%
Malta	12.6%	1.3%	0.6%	3.7%
Netherlands	9.5%	6.7%	1.9%	6.1%
Poland[b]	NE	2.9%	24.3%	7.9%
Portugal	0.9%	5.6%	2.7%	4.2%
Slovakia	NE	0.0%	10.7%	5.7%
Slovenia	-9.1%	2.1%	-4.3%	-2.0%
Spain	3.7%	7.9%	2.8%	5.2%
Sweden	-0.6%	5.8%	-1.3%	1.4%
United Kingdom	4.5%	8.0%	2.4%	5.4%
EU 10	-8.2%	2.1%	8.5%	1.6%
EU 15	3.5%	6.6%	1.3%	4.1%
EU 25	3.1%	6.5%	1.5%	4.0%

Notes: NE: not estimated
[a] Incomplete dataset. 2003 emissions instead of 2004 emissions used.
[b] Incomplete dataset. 1991 emissions instead of 1990 emissions used.

Source: EC 2006.

Graph 3 Annual growth rates of CO_2 emissions from aviation 1990-2004.



Source: EC 2006.

Table 4 *Emissions of NO_x and SO_2 from aviation in EU Member States 1990-2004*

	NO_x [kt NO_x]				SO_2 [kt SO_2]			
	1990	1995	2000	2004	1990	1995	2000	2004
Austria	2.8	4.4	5.6	5.5	0.29	0.44	0.56	0.55
Belgium	1.0	1.3	2.7	3.7	0.09	0.11	0.22	0.30
Cyprus	3.4	3.7	3.5	0.0	0.05	0.05	0.05	0.00
Czech Republic	4.8	3.1	2.8	1.0	0.48	0.31	0.28	0.06
Denmark	8.1	8.5	10.2	11.0	0.63	0.66	0.80	0.82
Estonia	0.4	5.8	6.9	9.4	0.00	0.00	0.00	0.00
Finland	3.9	3.2	4.1	4.1	0.33	0.28	0.36	0.41
France	32.5	39.7	50.9	50.9	4.18	5.02	6.52	6.58
Germany	63.2	85.9	97.1	97.9	4.90	2.18	2.77	2.80
Greece	18.1	18.9	20.4	22.1	1.33	1.33	1.43	1.52
Hungary[a]	NO/NE	0.2	0.3	0.3	NO/NE	0.01	0.02	0.02
Ireland	3.5	3.2	4.5	5.2	0.35	0.36	0.52	0.70
Italy	27.5	34.5	56.5	62.0	1.88	2.36	3.86	4.23
Latvia	0.8	0.3	0.3	0.5	0.07	0.02	0.03	0.05
Lithuania	NO/NE	NO/NE	NO/NE	NO/NE	NO/NE	NO/NE	NO/NE	NO/NE
Luxembourg	0.2	NO/NE	NO/NE	NO/NE	0.01	NO/NE	NO/NE	NO/NE
Malta[a]	0.0	1.4	1.4	0.0	0.00	0.01	0.01	0.00
Netherlands[b]	1.9	2.4	3.1	3.3	0.16	0.19	0.24	0.15
Poland	0.0	0.0	0.0	0.2	0.00	0.00	0.00	0.00
Portugal	6.4	7.3	10.5	11.4	0.40	0.46	0.65	0.72
Slovakia[b]	0.0	0.0	0.0	0.0	0.01	0.00	0.01	0.01
Slovenia	NO/NE	NO/NE	NO/NE	NO/NE	NO/NE	NO/NE	NO/NE	NO/NE
Spain	32.4	44.3	63.6	71.4	2.40	3.02	4.38	4.90
Sweden	8.1	8.5	11.3	10.8	0.64	0.66	0.82	0.78
United Kingdom	80.1	98.4	145.4	157.9	3.23	5.45	7.36	9.22
EU 10	9.4	14.4	15.2	11.4	0.6	0.4	0.4	0.1
EU 15	290.0	360.5	485.9	517.3	20.8	22.5	30.5	33.7
EU 25	299.4	374.8	501.1	528.6	21.4	22.9	30.9	33.8

Notes: NO/NE: not occuring or not estimated
[a] Emissions from international flights only
[b] Emissions from domistic flights only

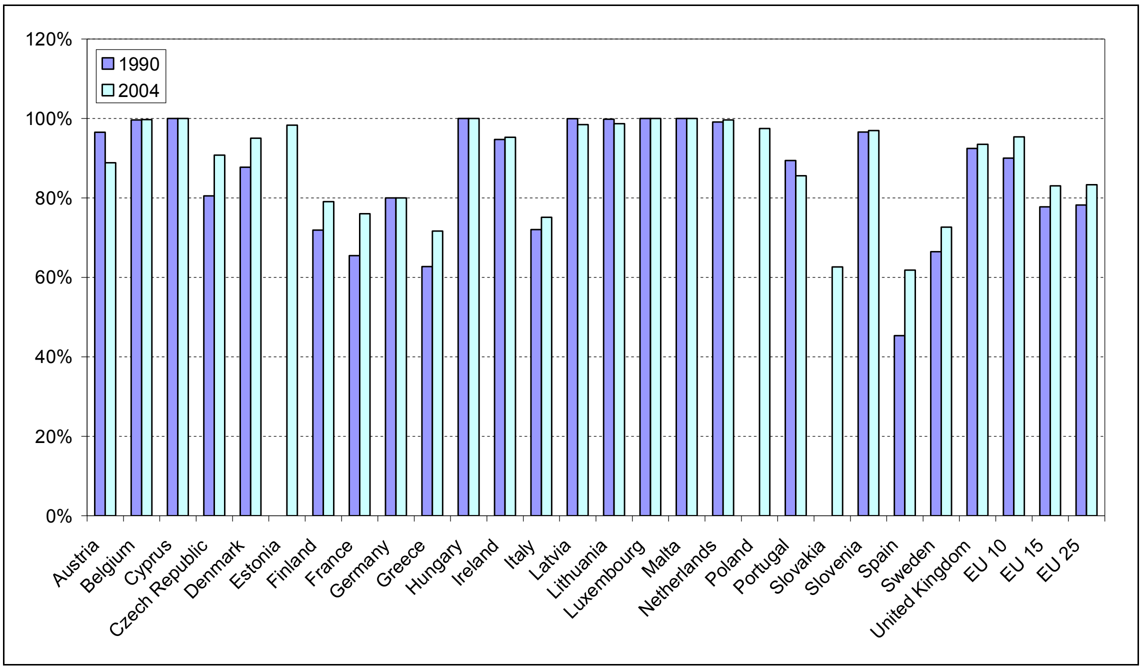
Source: *EC 2006.*

3.3 Domestic and international CO_2 emissions from aviation

Only emissions from domestic aviation are covered under the quantified emission reduction commitment under the Kyoto Protocol. Data included in the national inventory reports shows that international flights are responsible for about 80% of total fuel consumption from aviation for the EU as a whole (Graph 4). The share is lowest in larger countries whereas international aviation is responsible for over 95% of the emissions in most small Member States with no or very little domestic flights.

A more detailed assessment of the number of departures and CO_2 emissions for all flights leaving an EU airport has been undertaken by Eurocontrol for the year 2004 (Eurocontrol 2005). Emissions are estimated using a detailed model based on data gathered for route charges and air traffic management. The database does not include operational military flights and small airplanes and total emissions for 2004 are therefore somewhat lower than the values reported in national inventory reports. Of all flights departing from an EU airport almost 85% remain in the EU representing approximately 40% of total CO_2 emissions from aviation (Table 5). The numbers of long haul flights to North America and the Far East only have a share of 2.2% and 1.1% respectively but are responsible for 34% of total CO_2 emissions.

Graph 4 *Share of international aviation on total fuel consumption in 1990 and 2004*



Source: *EC 2006.*

Table 5 *Number of departures and CO_2 emissions of flights taking of from EU airports by destination region in 2004*

Flight destination region	Departures		CO_2 emissions	
	[1 000]	[%]	[kt]	[%]
EU 25	5 847	84.4%	52 328	39.9%
EU UPR	93	1.3%	4 157	3.2%
Europe (rest)	493	7.1%	7 370	5.6%
Africa	113	1.6%	6 570	5.0%
North America	152	2.2%	24 957	19.0%
Central America	21	0.3%	4 079	3.1%
South America	17	0.3%	3 882	3.0%
Middle East	109	1.6%	8 000	6.1%
Far East	73	1.1%	19 541	14.9%
Unknown	14	0.2%	249	0.2%
Total	6 931	100%	131 147	100%
Notes:	UPR: Ultra Peripheral Regions			

Source: *Eurocontrol 2005.*

Taking into account both information sources it can be concluded that approximately 20% of CO_2 emissions from aviation are due to domestic aviation, another 20% due to flights between EU Member States and 60% are caused by flights leaving the EU. The Commission proposal for the inclusion of aviation in an emission trading scheme fore-sees that all flights entering the EU are covered as well. In this case and assuming that arriving flights use the same quantity of kerosene as departing flights on the same route approximately 75% of the emission would originate from flights leaving or entering the EU while intra-EU and domestic aviation each would be responsible for just over 10%. Note that the data sets use different bases for estimating emissions (fuel sales vs. modelled emissions over given routes). The two approaches should produce the similar results under the assumptions that planes only take the necessary fuel for the next flight strip onboard and that emissions are independent of the direction a route is flown. In reality both assumptions are not entirely true.

3.4 Allocation of emissions from international aviation

Different possibilities have been discussed for the allocation of emissions from international aviation to Parties under the UNFCCC. Methodological difficulties as well as a lack of political will by some Parties led to the decision, that emissions from bunker fuels should not be covered under the Kyoto Protocol. Since then data availability and modelling capability has increased considerably. The Subsidiary Body for Scientific and Technological Advice developed and discussed 8 options for the allocation of bunker fuel emissions (UNFCCC 1996a). Out of these three were not favoured (UNFCCC 1996b). The remaining options are

- Option 1: no allocation,
- Option 3: allocation by fuel sold,
- Option 4: allocation by nationality of aircraft carrier,
- Option 5: allocation by country of departure and/or destination of aircraft and
- Option 6: allocation by country of departure and/or destination of passenger or cargo.

An analysis of the effects of the different allocation options on EU Member States was carried out by the Centre for Air Transport and the Environment of the Manchester Metropolitan University (MMU 2005a). The analysis was conducted using the FAST model which is based on data for movements of aircraft types between city pairs for certain years. Fuel consumption is calculated based on an aircraft performance model and the distance between the city pairs (MMU 2005a). For the EU as a whole total allocation does not depend strongly on the option chosen but the differences for individual member States can be considerable (Table 6). Option 3b is based on fuel sales as reported in national inventory reports. This dataset is not consistent with the calculated fuel consumption in the model. The FAST model is based on scheduled flights only and does not include charter and military flights. As a result, the model underestimates total emissions but provides a good indication for the relative differences between the different allocation options.

Table 6 *Allocation of 2000 emissions from international aviation to EU Member States by allocation option*

	Emissions [kt CO_2]					
	Domestic	Option 3a	Option 3b	Option 4	Option 5	Option 6
Austria	51	1 368	1 675	1 954	1 373	1 337
Belgium	-	2 847	3 907	94	2 787	2 740
Cyprus	8	415	-	295	414	429
Czech Republic	5	387	439	488	387	341
Denmark	126	1 810	2 348	334	1 808	1 571
Estonia		41	-	59	41	43
Finland	416	831	1 027	1 266	818	759
France	2 697	11 667	14 361	13 776	11 646	11 623
Germany	1 748	14 780	17 582	17 871	14 753	14 890
Greece	440	1 324	2 954	1 066	1 328	1 380
Hungary	-	440	634	555	440	392
Ireland	60	1 020	1 566	1 631	1 046	995
Italy	2 695	5 705	8 689	5 060	5 692	5 458
Latvia	-	52	51	54	52	39
Lithuania	5	57	-	71	57	50
Luxembourg	-	581	1 051	1 442	566	493
Maita	-	187	-	250	187	183
Netherlands	15	6 877	10 067	7 915	6 863	6 727
Poland	44	468	336	576	468	440
Portugal	328	1 294	972	1 172	1 290	1 333
Slovakia	5	21		21	21	17
Slovenia	-	58	-	87	58	43
Spain	3 131	5 668	8 314	4 534	5 682	5 683
Sweden	837	1 426	1 926	3 235	1 402	1 256
United Kingdom	1 714	20 151	29 412	20 463	20 264	20 564
EU25 Total	14 323	79 475	107 311	84 270	79 444	78 785
Annex I Total	175 489	169 722	200 799	174 620	169 553	169 306
Global total	213 885	265 616		265 616	265 616	265 616
Notes:	Option 3a: modelled departures; Option 3b: UNFCCC data; Option 4: no data available for 1990					

Source: *MMU 2005a.*

4 Projected Emissions for Aviation

Projections and forecasts of the development of the aviation industry are conducted for different purposes and based on different indicators. Developers of climate models focus on emissions and radiative forcing from the sector and try to model long time periods. Companies are more interested in the growth of passenger or freight kilometres or the development of airline fleet size and composition in the medium term. Projections are based on assumptions about future developments and are not able to capture unexpected changes or singular events, e.g. the attacks on the World Trade Centre in New York which had a clear impact on the growth of air travel for two years (Graph 2). Uncertainties increase with time horizons and it is not possible to develop or select a single best projection. This is taken into account by developing different scenarios using different sets of assumptions to show possible future developments and the potential range of emissions. This chapter therefore does not include one projection but presents several independent forecasts.

4.1 Projections from scientific bodies

IPCC special report on aviation and the global atmosphere

For the IPCC special report on aviation and the global atmosphere several different scenarios of future emissions of air transport were analysed. The assessment includes CO_2 and NO_x emissions as well as radiative forcing from CO_2, CH_4, H_2O, contrails and aerosols for the years 1992, 2015 and 2050. Based on these figures an interpolation was made for the time period 1990 to 2050. Different scenarios reflect different assumptions on economic growth, technological development and demand for air traffic. All models considered take into account, that the aviation market is gradually maturing and will eventually grow in line with GDP growth. The results of the different scenarios show a wide range with a projected increase of CO_2 emissions from aviation between 60% and 900% for the year 2050 (Table 7). NO_x emissions are estimated to lie between two and five times of their 1990 value by 2050 (Table 8).

Table 7 IPCC projections for the development of global and aviation CO_2 emissions up to 2050 (1990 = 100)

		1990	2000	2015	2025	2050
IS92a	Fossil Fuel (all sectors)	100	120	153	178	220
	CO2 Emissions (all sectors)	100	113	143	163	193
Aviation Scenarios	Fa1	100	127	190	214	276
	Fa2	100	127	190	217	285
	Fc1	100	127	190	180	157
	Fe1	100	127	190	260	435
	Eab	100	122	173	315	669
	Edh	100	152	262	469	988
	Fa1H	100	127	190	234	326

Source: IPCC 1999.

Table 8 IPCC projections for the development of global and aviation NO_x emissions up to 2050 (1990 = 100)

		1990	2000	2015	2025	2050
IS92a	Energy (all sectors)	100	120	149	167	212
	Biomass Burn (all sectors)	100	103	107	110	120
Aviation Scenarios	Fa1	100	140	215	255	360
	Fa2	100	140	215	235	280
	Fc1	100	140	215	210	200
	Fe1	100	140	215	320	570
	Eab	100	110	145	215	395
	Edh	100	140	215	320	580

Source: IPCC 1999.

Manchester Metropolitan University projections

Lee and Owen (MMU 2005b) updated the 1999 IPCC calculations using newer scenarios for GDP growth and more recent forecasts for the increase of global aviation. Regional traffic forecasts and load factors from ICAO have been used together with assumptions on fuel efficiency increases to model CO_2 emissions from aviation until 2020 using the FAST model. To model emissions between 2020 and 2050 GDP projections from two IPCC reference scenarios (IPCC 2000b) have been used to estimate the growth in revenue passenger kilometres. The projected relative increase of CO_2 emissions and annual growth rates until 2050 for the two scenarios are shown in Table 9 to Table 12. Absolute emission figures are given in Annex I.

Table 9 Projected annual growth rates of CO_2 emissions from aviation for EU Member States 2005-2050

	Annual emission growth rates [%]									
	FESG/CAEP-6[a]				SRES A1[b]			SRES B2[c]		
	2005	2010	2015	2020	2030	2040	2050	2030	2040	2050
Austria	-	4.1%	2.9%	2.3%	5.3%	3.2%	3.3%	4.2%	3.6%	0.8%
Belgium	-	4.0%	3.5%	1.7%	5.1%	3.4%	3.5%	4.4%	3.8%	1.0%
Cyprus	-	5.0%	7.1%	5.6%	4.5%	3.2%	3.3%	4.2%	3.6%	0.8%
Czech Republ	-	3.5%	3.0%	0.8%	4.6%	3.3%	3.3%	4.3%	3.7%	0.8%
Denmark	-	4.4%	5.5%	3.0%	5.0%	3.2%	3.3%	4.3%	3.7%	0.8%
Estonia	-	3.7%	2.2%	0.6%	4.5%	3.2%	3.2%	4.2%	3.6%	0.8%
Finland	-	3.8%	2.3%	3.4%	5.0%	3.2%	3.3%	4.2%	3.6%	0.8%
France	-	4.5%	4.6%	2.9%	5.5%	3.4%	3.5%	4.4%	3.8%	1.0%
Germany	-	4.8%	5.2%	2.2%	5.4%	3.3%	3.4%	4.4%	3.8%	0.9%
Greece	-	4.2%	4.2%	1.4%	4.7%	3.2%	3.3%	4.2%	3.6%	0.8%
Hungary	-	3.9%	3.3%	0.6%	4.9%	3.2%	3.3%	4.3%	3.6%	0.8%
Ireland	-	4.3%	4.5%	1.6%	4.8%	3.3%	3.4%	4.3%	3.7%	0.9%
Italy	-	4.3%	4.2%	2.1%	5.1%	3.3%	3.4%	4.3%	3.7%	0.9%
Latvia	-	3.6%	3.1%	0.9%	4.5%	3.2%	3.3%	4.2%	3.6%	0.8%
Lithuania	-	3.4%	2.7%	0.2%	4.5%	3.2%	3.2%	4.2%	3.5%	0.7%
Luxembourg	-	5.3%	6.0%	4.0%	6.0%	3.5%	3.6%	4.6%	3.9%	1.1%
Malta	-	3.4%	2.8%	0.8%	4.5%	3.2%	3.3%	4.3%	3.6%	0.8%
Netherlands	-	5.0%	5.1%	2.7%	5.9%	3.4%	3.5%	4.5%	3.9%	1.0%
Poland	-	3.8%	3.3%	1.1%	4.6%	3.2%	3.3%	4.2%	3.6%	0.8%
Portugal	-	5.0%	6.6%	5.7%	4.5%	3.2%	3.3%	4.2%	3.6%	0.8%
Slovakia	-	4.2%	4.3%	1.5%	4.4%	3.1%	3.3%	4.2%	3.6%	0.8%
Slovenia	-	3.5%	4.8%	-1.5%	4.5%	3.2%	4.0%	4.6%	3.6%	1.6%
Spain	-	4.6%	5.1%	2.5%	4.7%	3.2%	3.3%	4.3%	3.7%	0.8%
Sweden	-	4.3%	4.3%	1.6%	4.4%	3.2%	3.2%	4.2%	3.6%	0.7%
UK	-	5.2%	5.8%	2.4%	5.6%	3.5%	3.5%	4.5%	3.9%	1.0%
EU10	-	3.9%	3.9%	1.8%	4.6%	3.2%	3.3%	4.3%	3.6%	0.8%
EU15	-	4.7%	5.0%	2.5%	5.3%	3.4%	3.4%	4.4%	3.8%	0.9%
EU25	-	4.7%	5.0%	2.5%	5.3%	3.4%	3.4%	4.4%	3.8%	0.9%

Notes:
[a] Based ICAO FESG/CAEP-6 Traffic and Fleet Forecast Sub-Group scenarios
[b] Based on IPCC reference scenario SRES A1 (high economic growth)
[c] Based on IPCC reference scenario SRES B2 (low economic growth)

Source: MMU 2005b.

Table 10 *Projected increase of CO_2 emissions from aviation for EU 15 Member States 2005-2050*

		Relative emission growth [2005=100]									
		FESG/CAEP-6[a]				SRES A1[b]			SRES B2[c]		
		2005	2010	2015	2020	2030	2040	2050	2030	2040	2050
Austria	dom	100	122	145	163	242	332	454	200	285	305
	int	100	122	141	158	267	366	506	220	315	340
	total	**100**	**122**	**141**	**158**	**266**	**365**	**504**	**219**	**313**	**339**
Belgium	dom	-	-	-	-	-	-	-	-	-	-
	int	100	121	145	157	258	361	509	213	310	342
	total	**100**	**121**	**145**	**157**	**258**	**361**	**509**	**213**	**310**	**342**
Denmark	dom	100	124	155	171	254	347	476	210	298	320
	int	100	124	163	191	316	436	605	261	374	407
	total	**100**	**124**	**162**	**188**	**308**	**424**	**588**	**254**	**364**	**395**
Finland	dom	100	121	142	156	232	317	435	192	272	292
	int	100	120	133	160	265	364	504	219	313	339
	total	**100**	**120**	**135**	**159**	**258**	**355**	**490**	**213**	**305**	**329**
France	dom	100	126	165	209	311	424	582	257	364	391
	int	100	124	154	173	306	429	607	253	369	408
	total	**100**	**125**	**156**	**180**	**307**	**428**	**602**	**253**	**368**	**405**
Germany	dom	100	119	135	147	219	299	410	181	257	276
	int	100	127	166	186	318	442	621	262	380	417
	total	**100**	**126**	**163**	**182**	**307**	**427**	**598**	**253**	**367**	**402**
Greece	dom	100	119	135	144	215	293	402	177	252	270
	int	100	124	156	167	269	369	509	222	317	342
	total	**100**	**123**	**151**	**162**	**256**	**351**	**485**	**212**	**302**	**326**
Ireland	dom	100	125	157	200	297	405	557	245	348	374
	int	100	123	153	163	263	364	507	217	313	341
	total	**100**	**123**	**154**	**166**	**266**	**367**	**511**	**219**	**315**	**343**
Italy	dom	100	120	141	156	233	318	437	193	274	294
	int	100	125	156	173	294	409	573	242	351	385
	total	**100**	**124**	**152**	**168**	**277**	**383**	**535**	**228**	**329**	**359**
Luxembourg	dom	-	-	-	-	-	-	-	-	-	-
	int	100	129	173	210	377	532	759	311	457	510
	total	**100**	**129**	**173**	**210**	**377**	**532**	**759**	**311**	**457**	**510**
Netherlands	dom	100	123	147	167	250	340	467	207	293	313
	int	100	127	163	186	331	465	657	273	399	442
	total	**100**	**127**	**163**	**186**	**331**	**464**	**656**	**273**	**399**	**441**
Portugal	dom	100	132	197	309	461	628	862	380	539	579
	int	100	126	171	213	334	458	633	276	394	426
	total	**100**	**127**	**176**	**231**	**358**	**491**	**677**	**295**	**421**	**455**
Spain	dom	100	124	156	179	266	363	499	220	312	335
	int	100	126	164	183	298	412	573	246	354	385
	total	**100**	**125**	**161**	**181**	**287**	**395**	**546**	**237**	**339**	**367**
Sweden	dom	100	123	151	165	246	336	461	203	288	310
	int	100	123	153	164	259	355	489	214	305	329
	total	**100**	**123**	**152**	**164**	**253**	**346**	**477**	**209**	**297**	**320**
UK	dom	100	125	160	183	272	371	510	225	319	343
	int	100	129	172	194	340	479	680	281	412	457
	total	**100**	**129**	**171**	**193**	**334**	**469**	**664**	**275**	**403**	**446**

Notes:
[a] Based ICAO FESG/CAEP-6 Traffic and Fleet Forecast Sub-Group scenarios
[b] Based on IPCC reference scenario SRES A1 (high economic growth)
[c] Based on IPCC reference scenario SRES B2 (low economic growth)

Source: *MMU 2005b.*

Table 11 *Projected increase of CO_2 emissions from aviation for EU 10 Member States 2005-2050*

		Relative emission growth [2005=100]									
			FESG/CAEP-6[a]			SRES A1[b]			SRES B2[c]		
		2005	2010	2015	2020	2030	2040	2050	2030	2040	2050
Cyprus	dom	100	150	225	300	450	600	825	375	525	550
	int	100	128	180	236	367	504	696	303	433	468
	total	**100**	**128**	**180**	**237**	**368**	**505**	**697**	**304**	**434**	**469**
Czech Republic	dom	100	120	160	180	260	360	500	220	300	340
	int	100	119	137	142	223	308	427	184	264	287
	total	**100**	**119**	**137**	**143**	**224**	**308**	**428**	**185**	**265**	**288**
Estonia	dom	-	-	-	-	-	-	-	-	-	-
	int	100	120	134	138	214	292	400	176	250	270
	total	**100**	**120**	**134**	**138**	**214**	**292**	**400**	**176**	**250**	**270**
Hungary	dom	-	-	-	-	-	-	-	-	-	-
	int	100	121	142	147	238	327	452	196	280	303
	total	**100**	**121**	**142**	**147**	**238**	**327**	**452**	**196**	**280**	**303**
Latvia	dom	-	-	-	-	-	-	-	-	-	-
	int	100	119	139	145	226	310	427	187	266	287
	total	**100**	**119**	**139**	**145**	**226**	**310**	**427**	**187**	**266**	**287**
Lithuania	dom	100	120	160	160	260	340	460	220	300	300
	int	100	118	133	135	209	286	392	173	245	264
	total	**100**	**118**	**135**	**137**	**213**	**290**	**397**	**176**	**249**	**266**
Malta	dom	-	-	-	-	-	-	-	-	-	-
	int	100	118	136	142	220	303	419	182	260	281
	total	**100**	**118**	**136**	**142**	**220**	**303**	**419**	**182**	**260**	**281**
Poland	dom	100	122	145	162	242	331	454	200	285	305
	int	100	120	141	148	233	320	443	193	275	298
	total	**100**	**120**	**141**	**150**	**235**	**322**	**445**	**194**	**276**	**299**
Slovakia	dom	100	117	133	150	217	283	400	183	250	267
	int	100	124	155	166	259	352	486	210	303	328
	total	**100**	**123**	**151**	**163**	**251**	**340**	**471**	**206**	**294**	**317**
Slovenia	dom	-	-	-	-	-	-	-	-	-	-
	int	100	119	136	139	216	295	405	178	253	272
	total	**100**	**119**	**150**	**139**	**216**	**295**	**439**	**178**	**253**	**295**

Notes: [a] Based ICAO FESG/CAEP-6 Traffic and Fleet Forecast Sub-Group scenarios
[b] Based on IPCC reference scenario SRES A1 (high economic growth)
[c] Based on IPCC reference scenario SRES B2 (low economic growth)

Source: *MMU 2005b.*

Table 12 *Projected increase of CO_2 emissions from aviation for the EU 2005-2050*

		Relative emission growth [2005=100]									
			FESG/CAEP-6[a]			SRES A1[b]			SRES B2[c]		
		2005	2010	2015	2020	2030	2040	2050	2030	2040	2050
EU10	dom	100	122	160	168	252	342	496	209	295	333
	int	100	121	147	161	253	348	481	209	298	323
	total	**100**	**121**	**147**	**161**	**253**	**347**	**481**	**209**	**298**	**323**
EU15	dom	100	123	153	177	264	360	494	218	309	332
	int	100	126	162	183	314	438	617	259	376	415
	total	**100**	**126**	**161**	**182**	**306**	**426**	**597**	**252**	**366**	**401**
EU25	dom	100	123	153	177	264	360	494	218	309	332
	int	100	126	162	182	312	436	614	258	374	412
	total	**100**	**126**	**161**	**181**	**305**	**424**	**595**	**251**	**364**	**400**

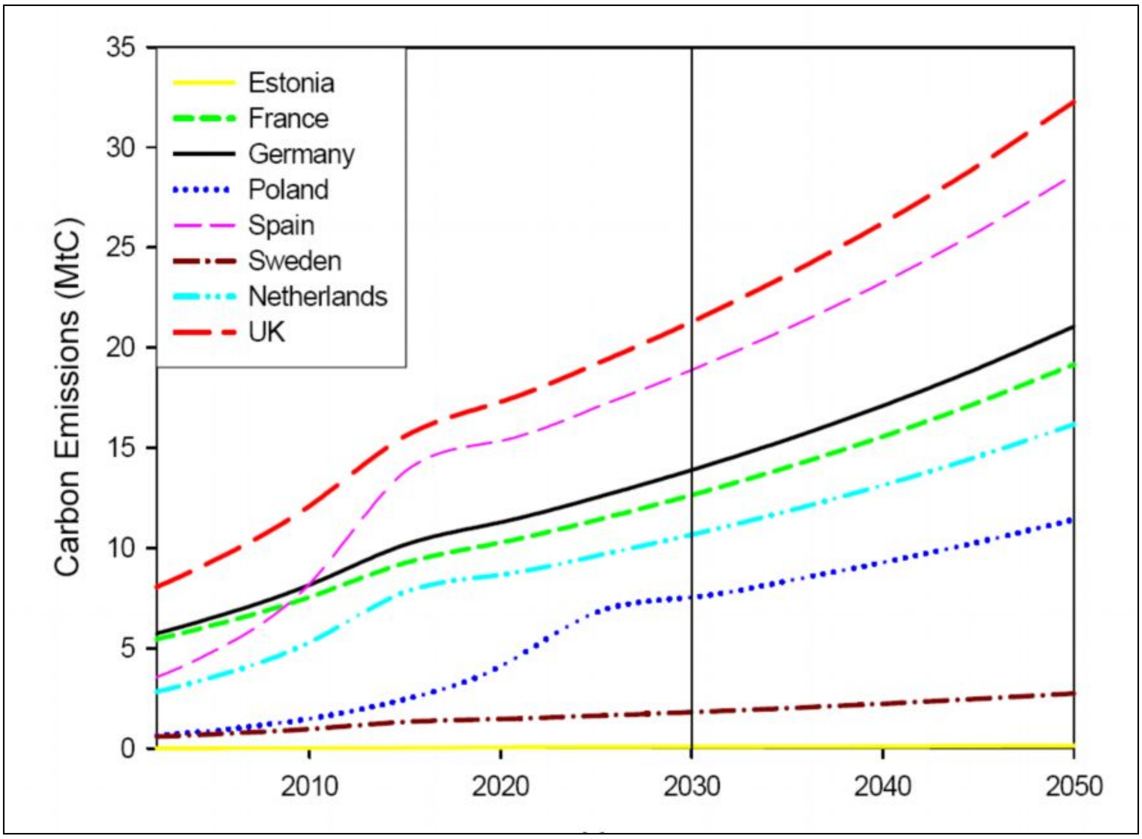
Notes: [a] Based ICAO FESG/CAEP-6 Traffic and Fleet Forecast Sub-Group scenarios
[b] Based on IPCC reference scenario SRES A1 (high economic growth)
[c] Based on IPCC reference scenario SRES B2 (low economic growth)

Source: *MMU 2005b.*

Tyndall growth scenarios

A different approach has been used in a study on growth scenarios for EU and UK aviation by the Tyndall Centre (Tyndall 2005). The forecast is based on passenger growth rates and the time period until 2050 is spilt in two periods. Current passenger growth rates are extrapolated until 2015 for EU 15 Member States and until 2025 for the new Member States reflecting the different maturity of the respective aviation markets. After this all national markets are assumed to grow with a lower rate until 2050 which is identical for all countries. To translate passenger growth rates into emission growth rates the estimates made in the 1999 IPCC special report on efficiency increase, airplane sizes and improved load management were used to take the evolving market into account. The combined effect of these measures is estimated to reduce emission growth by 1.2% per year (Tyndall 2005). Graph 5 shows the results of the analysis for selected EU Member States.

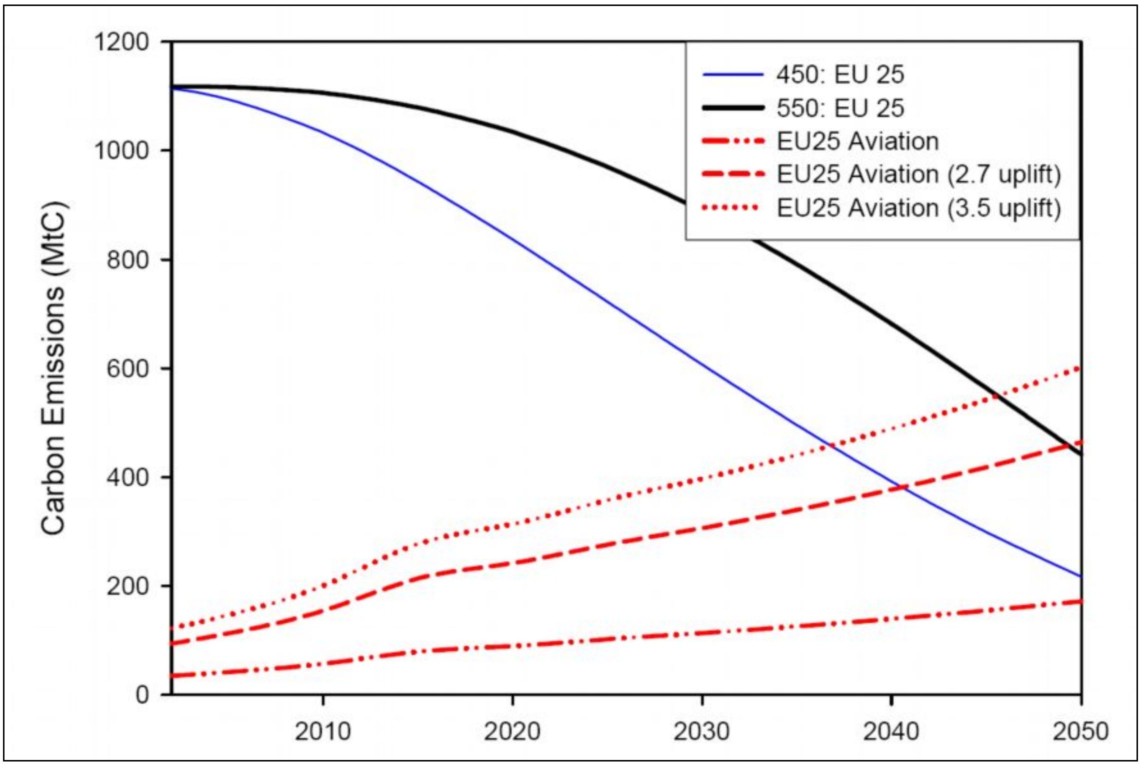
Graph 5 Carbon emissions from the aviation industry for selected European nations



Source: Tyndall 2005.

In a second step the projected emissions from the aviation sector were compared to two different contraction and convergence scenarios for worldwide greenhouse gas emissions. Under these scenarios industrialised countries need to reduce their greenhouse gas emissions between 60% and 80% up to 2050 to allow developing countries some but also limited room for emission increases. The difference between the two scenarios is the level at which greenhouse gas concentrations should stabilise in the atmosphere. Graph 6 shows that the share of emissions from the aviation sector alone could require the full allowable CO_2 budget if left unchecked in the lower scenario. If the CO_2 emissions are multiplied with a factor to take the indirect effects of aviation on the climate into account the share of aviation on global warming further increases.

Graph 6 Contraction and Convergence Profiles for EU 25 Compared with Aviation Forecasts



Source: Tyndall 2005.

4.2 Forecasts from the aviation industry

Several companies in the aviation sector publish projections on revenue passenger kilometres (RPK) for the next 20 years disaggregated by region. These values are used to assess the future market for airplanes and emissions of greenhouse gases or fuel consumption are normally not included in the analyses. Table 13 gives an overview over different projections published by the industry. In general forecasted growth rates are rather close between the different data sets with only few large discrepancies. Especially the average growth rate for the entire market is at our close to 5% per year in all studies and studied time horizons. A growth of RPK does not directly translate into a growth of CO_2 emissions as in general new airplane get more efficient and larger airplanes consume less fuel per passenger kilometre than small ones. IPCC estimated that the annual decrease of emissions due to such effects amount to about 1.2%, i.e. the worldwide emissions from aviation are expected to grow by about 4% per year until 2025.

Airbus estimates that by 2025 15% of the revenue passenger kilometres will be generated by domestic US flights followed by intra-EU flights (9%), domestic flights in China and flights between the EU and the US (both 7%) (Airbus 2006).

Table 13 Annual average growth forecasts of revenue passenger kilometres by region

Region	1998-2008				1998-2018				2005-2025	
	Airbus	Boeing	Rolls Royce[a]	Avitas[b]	Airbus	Boeing	Rolls Royce[a]	Avitas[b]	Airbus	Boeing
Intra North America	2.9%	3.0%	3.3%	2.5%	2.7%	2.9%	3.0%	2.5%	2.7%	3.6%
Intra Europe	5.7%	4.5%	4.7%	3.7%	5.5%	4.3%	3.9%	4.2%	4.1%	3.5%
Europe - North America	5.3%	3.8%	4.2%	5.2%	5.0%	3.7%	3.7%	4.6%	4.3%	4.5%
Africa - Europe	4.4%	5.0%	5.6%	7.3%	4.2%	4.8%	5.1%	7.5%	4.6%	5.0%
C America - N America	5.3%	4.1%	5.7%	4.1%	5.0%	4.0%	5.1%	3.8%	4.3%	4.9%
Intra China	8.8%	10.2%	12.9%	-	8.4%	9.3%	10.9%	-	8.2%	6.4%
C America - Europe	5.3%	4.1%	5.8%	4.2%	5.0%	4.0%	5.2%	4.9%	5.8%	5.1%
Intra South America	4.6%	7.0%	5.2%	12.0%	4.6%	6.9%	5.0%	11.7%	6.0%	6.9%
Total World	5.1%	4.7%	5.5%	5.2%	5.0%	4.7%	5.1%	5.0%	4.8%	4.9%

Notes: [a] forecasts are for 1997- 2007 and 1997 - 2017; regional segmentations differs in some cases
[b] forecasts are for 1999-2009 and 1999-2019

Source: Anker 2000, Airbus 2006, Boeing 2006.

4.3 Projections included in National Communications

Only few countries publish national projections for the development of the aviation sector. Data on the expected increase of aviation emissions for the next 15 to 25 years is included in six 4[th] national communications under the UNFCCC from EU Member States (Table 14). The projections made by the Czech Republic, Denmark and France are well annual below the business forecast for Europe as a whole and the detailed projections by Lee/Owen.

Table 14 Member State's projections

	Emissions [kt CO_2]							Annual growth rate	
	1990	2000	2005	2010	2015	2020	2030	1990-2010	2010-2020
Czech Republic	627	349	613	752	859	940		0.9%	1.4%
Denmark	2 001	2 533	2 406	2 604	2 823	3 082	3 508	1.3%	1.5%
France	13 000			21 800	24 450	27 100		2.6%	2.5%
Netherlands	4 552		11 200	12 800	13 600	14 400		5.3%	3.9%
Portugal[a]	167	367		462		625		5.2%	4.5%
Sweden[b]	1 354			2 708		3 250		3.5%	3.0%

Notes: [a] Emissions from domestic aviation only
[b] Emissions from interntional aivation only. Estimates for 2010 and 2020 based on growth data included in the Swedish 4[th] National Communication

Source: Member State's 4[th] National Communications under the UNFCCC and the Kyoto Protocol.

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Annex I

Table A- 1 CO_2 emissions from aviation from EU 15 Member States 2005-2050

		Emissions [kt CO_2]									
		FESG/CAEP-6[a]				SRES A1[b]			SRES B2[c]		
		2005	2010	2015	2020	2030	2040	2050	2030	2040	2050
	dom	92	112	133	150	223	305	418	184	262	281
Austria	int	1 920	2 351	2 713	3 033	5 125	7 033	9 720	4 229	6 042	6 532
	total	**2 012**	**2 463**	**2 846**	**3 183**	**5 348**	**7 338**	**10 138**	**4 413**	**6 304**	**6 813**
	dom	0	0	0	0	0	0	0	0	0	0
Belgium	int	2 857	3 471	4 129	4 484	7 381	10 314	14 529	6 089	8 859	9 763
	total	**2 857**	**3 471**	**4 129**	**4 484**	**7 381**	**10 314**	**14 529**	**6 089**	**8 859**	**9 763**
	dom	234	290	362	399	595	811	1 113	491	697	748
Denmark	int	1 519	1 885	2 479	2 900	4 801	6 618	9 190	3 961	5 685	6 176
	total	**1 753**	**2 175**	**2 841**	**3 299**	**5 396**	**7 429**	**10 303**	**4 452**	**6 382**	**6 924**
	dom	358	433	508	558	832	1 135	1 558	686	975	1 047
Finland	int	1 352	1 623	1 795	2 160	3 586	4 927	6 819	2 958	4 232	4 583
	total	**1 710**	**2 056**	**2 303**	**2 718**	**4 418**	**6 062**	**8 377**	**3 644**	**5 207**	**5 630**
	dom	2 796	3 513	4 612	5 830	8 698	11 863	16 286	7 176	10 190	10 944
France	int	11 397	14 179	17 532	19 744	34 906	48 937	69 174	28 797	42 037	46 485
	total	**14 193**	**17 692**	**22 144**	**25 574**	**43 604**	**60 800**	**85 460**	**35 973**	**52 227**	**57 429**
	dom	1 773	2 109	2 399	2 602	3 882	5 295	7 269	3 203	4 548	4 885
Germany	int	14 539	18 516	24 162	27 052	46 209	64 312	90 221	38 122	55 244	60 629
	total	**16 312**	**20 625**	**26 561**	**29 654**	**50 091**	**69 607**	**97 490**	**41 325**	**59 792**	**65 514**
	dom	460	547	619	663	989	1 348	1 851	816	1 158	1 244
Greece	int	1 563	1 944	2 441	2 612	4 197	5 760	7 961	3 463	4 948	5 349
	total	**2 023**	**2 491**	**3 060**	**3 275**	**5 186**	**7 108**	**9 812**	**4 279**	**6 106**	**6 593**
	dom	77	96	121	154	229	312	429	189	268	288
Ireland	int	1 091	1 345	1 672	1 783	2 873	3 973	5 536	2 370	3 413	3 720
	total	**1 168**	**1 441**	**1 793**	**1 937**	**3 102**	**4 285**	**5 965**	**2 559**	**3 681**	**4 008**
	dom	2 464	2 962	3 472	3 856	5 753	7 846	10 771	4 746	6 740	7 238
Italy	int	6 278	7 849	9 789	10 836	18 433	25 653	35 984	15 207	22 036	24 181
	total	**8 742**	**10 811**	**13 261**	**14 692**	**24 186**	**33 499**	**46 755**	**19 953**	**28 776**	**31 419**
	dom	0	0	0	0	0	0	0	0	0	0
Luxembourg	int	382	494	661	803	1 439	2 034	2 899	1 187	1 747	1 948
	total	**382**	**494**	**661**	**803**	**1 439**	**2 034**	**2 899**	**1 187**	**1 747**	**1 948**
	dom	30	37	44	50	75	102	140	62	88	94
Netherlands	int	6 389	8 138	10 422	11 907	21 156	29 683	41 990	17 454	25 498	28 218
	total	**6 419**	**8 175**	**10 466**	**11 957**	**21 231**	**29 785**	**42 130**	**17 516**	**25 586**	**28 312**
	dom	246	325	484	759	1 133	1 545	2 121	935	1 327	1 425
Portugal	int	1 049	1 326	1 789	2 234	3 503	4 807	6 644	2 890	4 129	4 465
	total	**1 295**	**1 651**	**2 273**	**2 993**	**4 636**	**6 352**	**8 765**	**3 825**	**5 456**	**5 890**
	dom	3 141	3 882	4 886	5 608	8 366	11 410	15 665	6 902	9 801	10 527
Spain	int	5 698	7 171	9 319	10 432	17 006	23 470	32 637	14 030	20 161	21 932
	total	**8 839**	**11 053**	**14 205**	**16 040**	**25 372**	**34 880**	**48 302**	**20 932**	**29 962**	**32 459**
	dom	1 084	1 334	1 637	1 788	2 668	3 639	4 995	2 201	3 126	3 357
Sweden	int	1 389	1 712	2 119	2 277	3 596	4 926	6 795	2 967	4 231	4 566
	total	**2 473**	**3 046**	**3 756**	**4 065**	**6 264**	**8 565**	**11 790**	**5 168**	**7 357**	**7 923**
	dom	2 479	3 102	3 977	4 526	6 752	9 209	12 643	5 570	7 911	8 496
UK	int	22 429	28 996	38 654	43 527	76 369	107 517	152 629	63 004	92 357	102 567
	total	**24 908**	**32 098**	**42 631**	**48 053**	**83 121**	**116 726**	**165 272**	**68 574**	**100 268**	**111 063**

Notes:
[a] Based ICAO FESG/CAEP-6 Traffic and Fleet Forecast Sub-Group scenarios
[b] Based on IPCC reference scenario SRES A1 (high economic growth)
[c] Based on IPCC reference scenario SRES B2 (low economic growth)

Source: MMU 2005b.

Table A- 2 CO_2 emissions from aviation from EU 10 Member States 2005-2050

		Emissions [kt CO_2]									
		FESG/CAEP-6[a]				SRES A1[b]			SRES B2[c]		
		2005	2010	2015	2020	2030	2040	2050	2030	2040	2050
Cyprus	dom	4	6	9	12	18	24	33	15	21	22
	int	363	463	653	857	1 334	1 829	2 526	1 101	1 571	1 698
	total	**367**	**469**	**662**	**869**	**1 352**	**1 853**	**2 559**	**1 116**	**1 592**	**1 720**
Czech Republic	dom	5	6	8	9	13	18	25	11	15	17
	int	390	463	535	555	870	1 200	1 667	718	1 031	1 120
	total	**395**	**469**	**543**	**564**	**883**	**1 218**	**1 692**	**729**	**1 046**	**1 137**
Estonia	dom	0	0	0	0	0	0	0	0	0	0
	int	50	60	67	69	107	146	200	88	125	135
	total	**50**	**60**	**67**	**69**	**107**	**146**	**200**	**88**	**125**	**135**
Hungary	dom	0	0	0	0	0	0	0	0	0	0
	int	460	558	655	675	1 094	1 502	2 078	903	1 290	1 396
	total	**460**	**558**	**655**	**675**	**1 094**	**1 502**	**2 078**	**903**	**1 290**	**1 396**
Latvia	dom	0	0	0	0	0	0	0	0	0	0
	int	62	74	86	90	140	192	265	116	165	178
	total	**62**	**74**	**86**	**90**	**140**	**192**	**265**	**116**	**165**	**178**
Lithuania	dom	5	6	8	8	13	17	23	11	15	15
	int	66	78	88	89	138	189	259	114	162	174
	total	**71**	**84**	**96**	**97**	**151**	**206**	**282**	**125**	**177**	**189**
Malta	dom	0	0	0	0	0	0	0	0	0	0
	int	159	188	216	225	350	481	666	289	413	447
	total	**159**	**188**	**216**	**225**	**350**	**481**	**666**	**289**	**413**	**447**
Poland	dom	65	79	94	105	157	215	295	130	185	198
	int	445	535	627	658	1 039	1 426	1 972	857	1 225	1 325
	total	**510**	**614**	**721**	**763**	**1 196**	**1 641**	**2 267**	**987**	**1 410**	**1 523**
Slovakia	dom	6	7	8	9	13	17	24	11	15	16
	int	29	36	45	48	75	102	141	61	88	95
	total	**35**	**43**	**53**	**57**	**88**	**119**	**165**	**72**	**103**	**111**
Slovenia	dom	0	0	9	0	0	0	22	0	0	15
	int	64	76	87	89	138	189	259	114	162	174
	total	**64**	**76**	**96**	**89**	**138**	**189**	**281**	**114**	**162**	**189**

Notes:
[a] Based ICAO FESG/CAEP-6 Traffic and Fleet Forecast Sub-Group scenarios
[b] Based on IPCC reference scenario SRES A1 (high economic growth)
[c] Based on IPCC reference scenario SRES B2 (low economic growth)

Source: MMU 2005b.

Table A- 3 CO_2 emissions from aviation from the EU 2005-2050

		Emissions [kt CO_2]									
		FESG/CAEP-6[a]				SRES A1[b]			SRES B2[c]		
		2005	2010	2015	2020	2030	2040	2050	2030	2040	2050
EU10	dom	85	104	136	143	214	291	422	178	251	283
	int	2 088	2 531	3 059	3 355	5 285	7 256	10 033	4 361	6 232	6 742
	total	**2 173**	**2 635**	**3 195**	**3 498**	**5 499**	**7 547**	**10 455**	**4 539**	**6 483**	**7 025**
EU15	dom	15 237	18 743	23 253	26 943	40 195	54 820	75 260	33 159	47 089	50 575
	int	79 852	100 999	129 675	145 784	250 580	349 966	492 728	206 727	300 621	331 113
	total	**95 089**	**119 742**	**152 928**	**172 727**	**290 775**	**404 786**	**567 988**	**239 886**	**347 710**	**381 688**
EU25	dom	15 322	18 847	23 389	27 086	40 409	55 111	75 682	33 337	47 340	50 858
	int	81 940	103 530	132 734	149 139	255 865	357 222	502 761	211 088	306 853	337 855
	total	**97 262**	**122 377**	**156 123**	**176 225**	**296 274**	**412 333**	**578 443**	**244 425**	**354 193**	**388 713**

Notes:
[a] Based ICAO FESG/CAEP-6 Traffic and Fleet Forecast Sub-Group scenarios
[b] Based on IPCC reference scenario SRES A1 (high economic growth)
[c] Based on IPCC reference scenario SRES B2 (low economic growth)

Source: MMU 2005b.