



# **International aviation emissions to 2025: Can emissions be stabilised without restricting demand?**

Andrew Macintosh and Lailey Wallace

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### **CCLP Working Paper Series 2008/1 corresponding author:**

Andrew Macintosh  
Associate Director  
ANU CCLP  
Ph: 61 2 6125 3832  
Email: [macintosh@law.anu.edu.au](mailto:macintosh@law.anu.edu.au)

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## **Abstract**

International aviation is growing rapidly, resulting in rising aviation greenhouse gas emissions. Concerns about the growth trajectory of the industry and emissions have led to calls for additional measures to be introduced to restrict demand and prompt innovation. The aviation industry has rejected these suggestions, arguing that it is only a minor cause of global warming and that it has achieved admirable advances in the emission intensity of the aviation task since the early 1990s. This paper projects international civil aviation emissions to 2025 and analyses the emission intensity improvements that are necessary to offset rising international demand. The findings suggest international aviation carbon dioxide (CO<sub>2</sub>) emissions will increase by more than 110 per cent between 2005 and 2025 (from 416 Mt to between 876 – 1,013 Mt) and that it is highly unlikely that emissions could be stabilised at levels consistent with risk averse climate targets without restricting demand.

## 1. Introduction

Sixty years ago, civil aviation was an infant industry that was responsible for a tiny proportion of the transport task. Today it is an integral part of the world economy, accounting for approximately nine per cent of global GDP and carrying more than two billion passengers and 41 million tonnes of freight and mail each year (ICAO 2007a; Airbus 2007; UNSD 2008). Total world revenue traffic (international and domestic, passenger and cargo) on scheduled airlines in 2006 exceeded 510 billion revenue tonne kilometres (RTK)<sup>1</sup>, which included almost four trillion revenue passenger kilometres (RPK).<sup>2</sup> In the same year, total revenues of the scheduled airlines of the parties to the Convention on International Civil Aviation of December 1944 (Chicago Convention) topped US\$450 billion, more than 120 per cent above 1990 levels (ICAO 2007a).

The success of the aviation industry is poised to continue over the coming decades. Industry forecasts predict worldwide RPK will grow at an average rate of approximately five per cent per annum over the next 20 years (Boeing 2007; Airbus 2007). Cargo traffic, as measured in RTK, is expected to grow at around six per cent over the same period. If realised, these forecasts would see passenger (RPK) and cargo (RTK) traffic increase by 180 per cent and 220 per cent respectively between 2006 and 2026.

Continuing rapid growth in aviation would provide economic benefits and allow greater mobility amongst the world's population. However, these benefits would come at a cost, most notably a significant increase in aviation greenhouse gas emissions. While aviation is not currently one of the main drivers of global warming, the growth trajectory of the industry suggests it could become a significant factor over the coming decades. A report prepared by the Intergovernmental Panel on Climate Change (IPCC) in 1999 at the request of the International Civil Aviation Organization (ICAO) found that civil aviation carbon dioxide (CO<sub>2</sub>) emissions could rise by between 60 per cent and over 1,000 per cent between 1992 and 2050 (IPCC 1999). More recent research suggests that if strong global economic growth continues, aviation CO<sub>2</sub> emissions are likely to experience a greater than three-fold increase between 2000 and 2050 (Berghof *et al.* 2005; Horton 2006). Concerns about rapid growth in the industry and the associated threat to the climate system have prompted debate about the future of aviation.

The international market has been the focal point of a considerable amount of the discussion about aviation and climate change. This is partly due to the fact that international aviation is responsible for over 60 per cent of total aviation emissions. International flights are also the fastest growing segment of the aviation market. In addition, curbing the growth in international aviation emissions raises a number of difficult legal issues, particularly in relation to the ability of countries to unilaterally impose carbon prices on

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<sup>1</sup> A tonne kilometre is equal to one tonne of load (passenger or cargo) transported one kilometre.

<sup>2</sup> A passenger kilometre is equal to one passenger transported one kilometre.

foreign aircraft. The forecast trajectory of international traffic and concerns about emissions growth has led to calls for additional measures to be introduced to restrict demand and prompt innovation. The aviation industry has rejected these suggestions, arguing that it is only a minor cause of global warming and that it has achieved admirable advances in the emission intensity of the aviation task since the early 1990s.

This paper aims to add to the growing body of literature on aviation and climate change by projecting international civil aviation CO<sub>2</sub> emissions to 2025 and determining the emission intensity improvements that are necessary to offset rising international demand. The objective is to highlight the need for measures to be introduced to curb demand and prompt innovation if the international community wants to keep the increase in the global average surface temperature to less than 2°C. Data from the available climate models indicate that global greenhouse gas emissions will need to be dramatically reduced over the coming decades if this temperature target is to be achieved (Friedlingstein *et al.* 2006; Meehl *et al.* 2007). Sharp increases in emissions from any sector are inconsistent with this objective, including the aviation industry.

This paper is set out as follows. Section 2 provides an overview of aviation's climate impacts. Section 3 analyses recent trends in the aviation industry, focusing on the international market. Section 4 projects international civil aviation emissions over the period 2005 – 2025 using ICAO traffic data. Section 5 analyses the emission intensity improvements that are necessary to offset the projected increases in demand. Section 6 provides a conclusion.

## **2. Greenhouse gas emissions from aviation**

Aircraft emit a range of gases and particles which affect the atmosphere. In the context of climate change, the major emissions are CO<sub>2</sub>, nitrogen oxides (NO<sub>x</sub>),<sup>3</sup> water vapour (H<sub>2</sub>O), sulphur oxides (SO<sub>x</sub>) (which form sulphate particles) and soot (IPCC 1999).<sup>4</sup> A summary of the atmospheric impacts of these agents and estimates of their associated radiative forcings in 2000 is provided in Table 1. Radiative forcing is a measure of the impact of an agent on the energy balance of the earth's atmosphere. It is technically defined as the change in net irradiance at the tropopause (i.e. the boundary between the troposphere and stratosphere) and is measured in watts per square metre (W/m<sup>2</sup>) (IPCC 2001). A positive number indicates the agent has a warming effect, a negative number indicates a cooling agent.

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<sup>3</sup> Nitrogen oxides comprise nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>).

<sup>4</sup> The emissions differ depending on the stage in the operating cycle. At cruising altitude and during takeoff, the main emissions are CO<sub>2</sub> and NO<sub>x</sub>. While idle, the major non-CO<sub>2</sub> emissions are of hydrocarbons (HC), but significant amounts of NO<sub>x</sub> and carbon monoxide (CO) are also emitted. During the approach stage, there is a mixture of CO<sub>2</sub>, NO<sub>x</sub>, HC and CO (BTRE 2002).

**Table 1 Radiative forcing from aviation emissions in 2000**

Agent	Comment	Radiative forcing (mW/m <sup>2</sup> )*	Scientific understanding
CO <sub>2</sub>	CO <sub>2</sub> is a well-mixed, long-lived (5 – 200 years) greenhouse gas and its warming effects on the climate are relatively well understood.	+25	Good
NO <sub>x</sub> O <sub>3</sub> CH <sub>4</sub>	NO <sub>x</sub> emissions have warming and cooling effects. The warming arises because aviation NO <sub>x</sub> emissions result in the production of ozone (O <sub>3</sub> ) (a greenhouse gas) in the troposphere. The cooling effects arise because chemical reactions associated with NO <sub>x</sub> remove methane (CH <sub>4</sub> ) (a greenhouse gas) from the atmosphere.	+22 -10	Fair Fair
H <sub>2</sub> O H <sub>2</sub> O Contrails Cirrus	Aviation H <sub>2</sub> O emissions have three main impacts. H <sub>2</sub> O emitted from aircraft builds up in the lower stratosphere and traps infrared radiation, leading to warming. Aviation H <sub>2</sub> O emissions create contrails, which act like clouds and trap heat. Contrails created by aircraft can lead to the creation of cirrus clouds, which also leads to warming.	+2  +10  +30 (range +10 to +80)	Fair  Fair  Poor
SO <sub>x</sub>	SO <sub>x</sub> emissions lead to the formation of sulphur aerosols, which reflect solar radiation and thereby cool the atmosphere. They can also have indirect effects by altering cloud formation. The radiative forcing estimates only consider the direct effects.	-3.5	Fair
Soot	Soot can act as a warming agent by trapping and radiating heat. It can also have indirect warming effects by altering the albedo (reflectivity) of the earth's surface. The radiative forcing estimates only consider the direct effects.	+2.5	Fair
<b>Total (without cirrus cloud effects)</b>		+48	

Source: Sausen *et al.* (2005).

\* mW/m<sup>2</sup> means milliwatt, or 10<sup>-3</sup> watts.

The Intergovernmental Panel on Climate Change (IPCC) has estimated that the total radiative forcing associated with anthropogenic agents in 2005 was 1.6 W/m<sup>2</sup> (0.6 – 2.4 W/m<sup>2</sup>). This suggests aviation's contribution excluding cirrus cloud effects is in the order of three per cent. When cirrus cloud effects are included, aviation's contribution could be as high as 6 – 8 per cent. Hence, while aviation is not currently one of the main drivers of global warming, its effects are significant and should not be overlooked in policy processes.

A technical difficulty facing policy makers seeking to address aviation emissions is how to account for non-CO<sub>2</sub> emissions. The nature of most non-CO<sub>2</sub> emissions precludes the use of standard global warming potentials (GWPs) to convert non-CO<sub>2</sub> emissions into carbon dioxide equivalents (CO<sub>2</sub>-e). GWPs are a measure of the cumulative radiative forcing associated with a unit mass of the relevant direct greenhouse gas when compared to the same mass

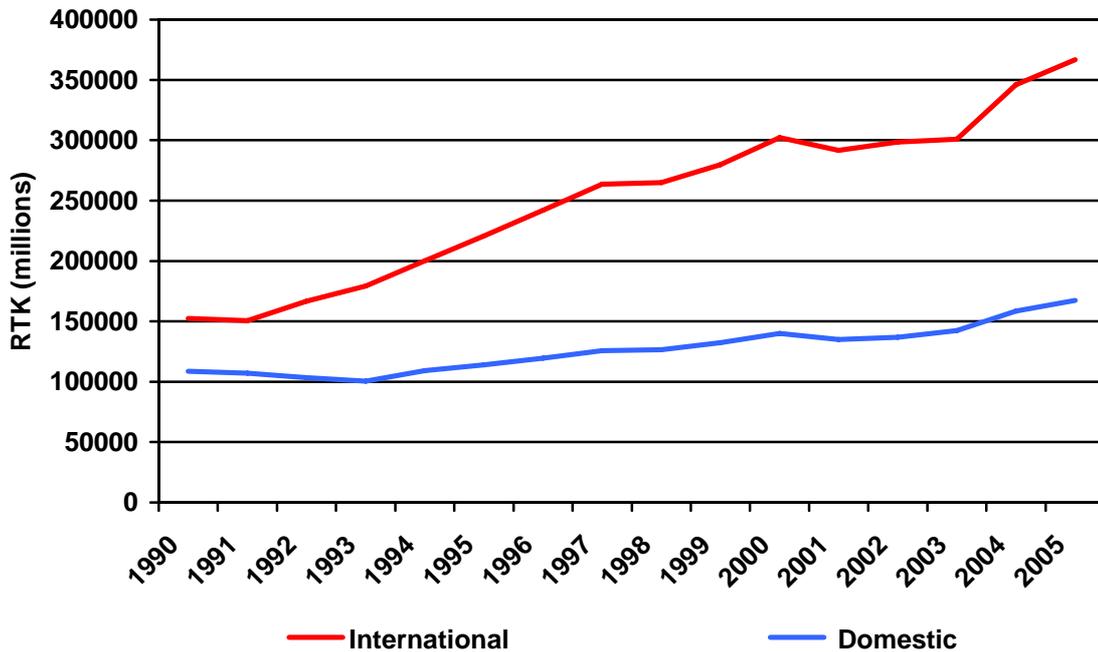
of CO<sub>2</sub> over a specified period (typically 100 years) (IPCC 2001). They are not calculated for H<sub>2</sub>O and indirect greenhouse gases like CO and NO<sub>x</sub> because of the variable nature of the relevant climate impacts (IPCC 2001; Forster *et al.* 2006). The absence of GWPs for H<sub>2</sub>O, NO<sub>x</sub> and CO emissions means it is very difficult to compare the impacts of a unit mass of these gases to those associated with a unit mass of direct greenhouse gases like CO<sub>2</sub>.

One proposed solution is to use a radiative forcing index (RFI) (i.e. the ratio between the total radiative forcing from aviation and the radiative forcing associated with aviation CO<sub>2</sub> emissions) to devise a metric (often called an 'uplift factor'), which is used to estimate aviation CO<sub>2</sub>-e emissions. To do so, CO<sub>2</sub> emissions from aviation are multiplied by the uplift factor to provide an estimate of the total impact of aviation emissions in CO<sub>2</sub>-e. There is debate about the appropriateness of uplift factors and their use in policy processes. Questions have also been raised about what uplift factor should be applied. Recent studies indicate that the appropriate uplift factor could range between 1.7 and 5.1 times aviation CO<sub>2</sub> emissions depending on the timescales of the analysis (Sausen *et al.* 2005; Forster *et al.* 2005). If the purpose is to provide an approximation of CO<sub>2</sub>-e using a 100-year timeframe, an uplift factor of 1.7 appears to be the best estimate, although it is subject to considerable uncertainty.

### **3. Recent trends in aviation traffic and emissions**

The aviation industry has grown rapidly in recent decades. Between 1990 and 2006, total scheduled world RTK increased by 119 per cent, with scheduled passenger (RPK) and cargo (RTK) traffic rising by 108 per cent and 140 per cent respectively. The major driver of global traffic growth has been international services. Between 1990 and 2005, total international RTK increased by 141 per cent. In comparison, total domestic RTK rose by only 54 per cent (see Figure 1).

**Figure 1 Total international and domestic revenue tonne kilometres (RTK), 1990 to 2005**



Source: Author estimates based on ICAO (1991 – 2007) and IATA (2000 – 2007).

The increase in aviation traffic over the past 20 years has been accompanied by dramatic improvements in the emission intensity of the aviation task. Data from the International Air Transport Association (IATA) suggest that system-wide fuel efficiency of scheduled IATA member services (i.e. international and domestic, passenger and cargo) declined from 51.3 to 39.4 litres per RTK (L/RTK) between 1994 and 2006; a 23 per cent improvement (IATA 2000 – 2007).<sup>5</sup> Airbus has published data indicating that the fuel efficiency of the world passenger fleet improved by approximately 35 per cent between 1990 and 2007, falling from 7.3 to 4.7 L/100 RPK (Airbus 2007).

The fuel efficiency and emission intensity of the international task has followed the global trend. Over the period 1990 – 2005, the emission intensity of the international task fell by 40 per cent (191 to 113 kg CO<sub>2</sub>/100 RTK).<sup>6</sup> These changes are attributable to three factors: beneficial changes in air traffic management (ATM); improvements in aircraft and engine design;<sup>7</sup> and

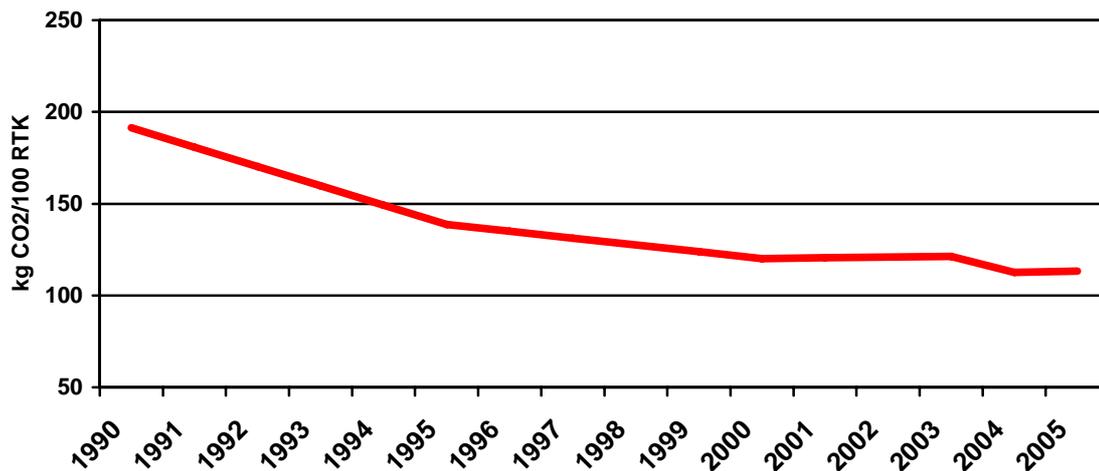
<sup>5</sup> These data were derived from returns made by approximately 55 per cent of IATA member airlines, who were responsible for around 70 per cent of total global RTK over the relevant period.

<sup>6</sup> Some of the observed change in the emission intensity of the international task may be due to data errors that are attributable to the poor quality of aviation statistics, particularly in the early 1990s. However, there is considerable evidence supporting a sharp improvement in fuel efficiency and emission intensity over this period. For example, data from ICAO indicate that the fuel efficiency of the scheduled international task (excluding operations of airlines registered in the Commonwealth of Independent States) fell from 53.5 L/100 RTK in 1985 to 36.1 L/100 RTK in 2005, a 33 per cent improvement (ICAO 2007b).

<sup>7</sup> ATM and aircraft and engine design improvements have reduced fuel burn per available seat kilometre by approximately 70 per cent since the 1960s (IPCC 1999; ICAO 2007c).

a significant increase in passenger and weight load factors (i.e. aircraft are using more of their capacity). As shown in Figure 2, the greatest advances in the emission intensity of the international aviation task were experienced in the 1990s when the average annual rate of improvement was almost 4.5 per cent. Since 2000, the rate of improvement has fallen to 1.2 per cent, suggesting the opportunities for gains are diminishing.

**Figure 2 Emission intensity of total international aviation, 1990 to 2005, kg CO<sub>2</sub>/100 RTK**



Source: Author estimates based on IEA (2007a), ICAO (1991 – 2007) and IATA (2000 – 2007).

Despite the improvements in emission intensity of the task, aviation CO<sub>2</sub> emissions have increased considerably since the early 1990s. Although there are differences in the estimates, the weight of evidence suggests that total global civil aviation CO<sub>2</sub> emissions rose from approximately 400 Mt in 1990 to at least 650 Mt in 2004 (IPCC 1999; Kim *et al.* 2005; IEA 2007b; 2007c). Data published by the International Energy Agency (IEA) indicate that international aviation CO<sub>2</sub> emissions increased by 33 per cent over this period, from 292 Mt to 390 Mt (IEA 2007a).<sup>8</sup> Global fossil CO<sub>2</sub> emissions (i.e. emissions from fossil fuel combustion, cement manufacture and gas flaring) in 2004 were approximately 29,029 Mt (7,910 Mt C) (Marland *et al.* 2007), suggesting that aviation constituted approximately 2.2 per cent of the world total, with international aviation emissions comprising 1.3 per cent.

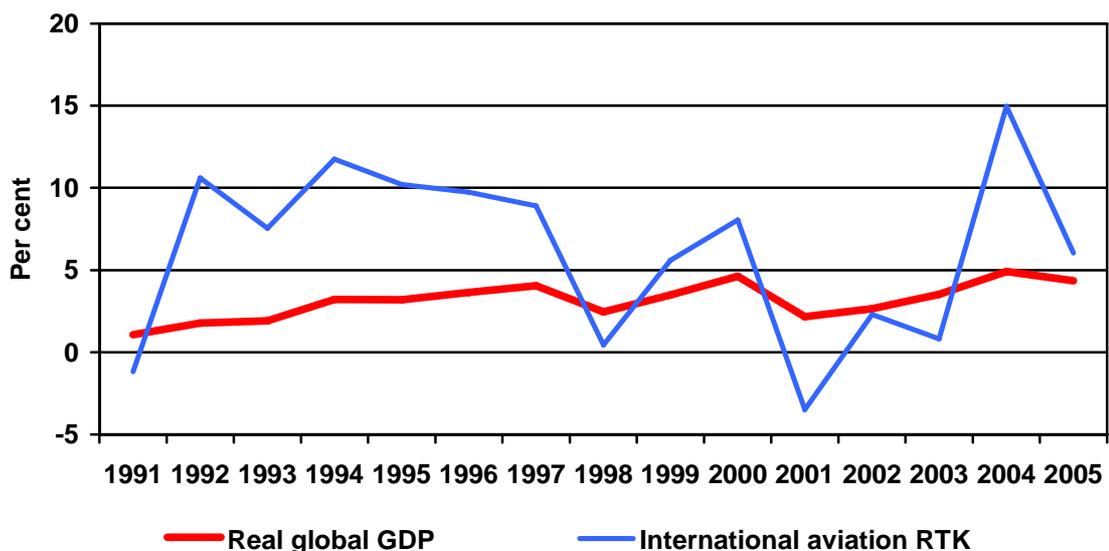
Aviation demand is set to experience rapid growth over the next 20 years. ICAO's most recent forecast suggests that the total scheduled passenger task (RPK) will grow at an average rate of 4.6 per annum between 2005 and 2025, with scheduled international RPK growing at 5.3 per cent per annum over the same period. Scheduled freight services are also expected to increase considerably, with overall freight RTK growing at 6.6 per cent per annum and

<sup>8</sup> The IEA estimates are subject to a degree of uncertainty due to reporting problems (IEA 2007a; den Elzen *et al.* 2007).

international freight RTK growing at 6.9 per cent per annum. Boeing and Airbus have forecast similar rates of traffic growth (Boeing 2007; Airbus 2007).

An expectation of strong economic growth is the main underlying driver of the aviation traffic projections. Aviation traffic is usually highly responsive to economic growth rates; with increases in economic activity prompting greater than proportional increases in traffic (i.e. demand is income elastic).<sup>9</sup> Where this relationship does not hold, the cause can typically be traced to unforeseen market shocks. These market dynamics are evident in the trends in international aviation since 1990 (see Figure 3). International traffic growth rates have generally been responsive to global GDP over this period. Significant divergences between the two were witnessed in response to a number of external shocks, including the East Asian Financial Crisis in 1997-98, the September 11 terrorist attacks in 2001 (which coincided with the global economic slowdown in 2001-02) and the SARS (Severe Acute Respiratory Syndrome) outbreak that began in November 2002.

**Figure 3 Annual growth rate of international aviation traffic (RTK) versus annual real growth rate of global GDP (at PPP), 1990 to 2005**



Source: Author estimates based on Datastream International Database (2008), ICAO (1991 – 2007) and IATA (2000 – 2007).

Over the coming decades, strong global economic growth is expected to lead to considerable growth in aviation demand. To offset the emission increases caused by rising demand, there would have to be radical improvements in the emission intensity of the aviation task. The available evidence suggests this is unlikely. The IPCC's special report on aviation (IPCC 1999) included projections based on estimates of traffic demand prepared by ICAO's Forecasting and Economic Analysis Subgroup (FESG) and economic growth rate data from the IPCC's IS92a, IS92e and IS92c emission scenarios. The

<sup>9</sup> This conclusion is supported by a considerable body of research. For further discussion, see Macintosh and Downie (2007).

scenarios based on technological assumptions that are consistent with the current design philosophy suggest global civil aviation CO<sub>2</sub> emissions will rise from approximately 415 Mt in 1992 to between 1440 – 2302 Mt in 2050 (excluding the less likely, low growth Fc1 scenario). Several subsequent reports have produced similar findings. Details of selected results from the IPCC report and two subsequent papers are provided in Table 2.

**Table 2 Civil aviation projections to 2050**

<b>Authors</b>	<b>Comment</b>	<b>Base year estimate (Mt CO<sub>2</sub>)</b>	<b>2050 estimate (Mt CO<sub>2</sub>)</b>
IPCC (1999)	The IPCC special report on aviation included details of several scenarios. The range here relates to the mid (Fa1) and high (Fe1) growth scenarios.	415 (year 1992)	1,440 – 2,302
Berghof <i>et al.</i> (2005)	The European Union's 'CONSAVE 2050' project estimated global aviation emissions using assumptions similar to those in the IPCC's A1, A2 and B1 scenarios. The range here relates to the three most likely scenarios (ULS, RPP and FW).	470 (year 2000)	955 – 2442
Owen and Lee (2006)	Projections calculated using the FAST model based on FESG data to 2020 then IPCC growth data from the A1 and B2 scenarios for 2020 to 2050. The data cover scheduled traffic only, which partially explains the low historical emission estimates.	482 (year 2005)	1,996 – 2,971

Aviation's contribution to global warming should not be exaggerated. Compared to activities such as electricity generation and agriculture, it is a minor contributor. However, sharp increases in emissions from any sector are inconsistent with risk averse climate targets and arguably the objective of avoiding dangerous climate change.

Article 2 of the UNFCCC states that the objective of the convention is the 'stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. Based on the available science and informed by value judgments, many individuals and institutions have suggested that the threshold for dangerous climate change is an increase in the average surface temperature of between 1.7 – 2.5°C above pre-industrial levels.<sup>10</sup> To have a reasonable chance of preventing global warming exceeding a 2°C threshold, which is the most commonly cited target, the atmospheric concentration of greenhouse

<sup>10</sup> European Parliament (2005; 2007); Hanson *et al.* (2007a; 2007b); Scientific Expert Group on Climate Change (2007); and German Advisory Council on Global Change (2007).

gases would have to be stabilised at less than 450 ppm CO<sub>2</sub>-e. Meeting this stabilisation target would require dramatic action. Global carbon emissions would have to be reduced by in excess of 60 per cent on 2000 levels by 2050 (IPCC 2007). The latest generation of climate models that account for climate-carbon cycle feedbacks suggest the required emission reductions may be greater than previously believed and that significant emission reductions may be necessary by 2030 just to keep the atmospheric concentrations of CO<sub>2</sub> below 450 ppm (i.e. 550 ppm CO<sub>2</sub>-e) (Friedlingstein *et al.* 2006; Meehl *et al.* 2007).

If there is a desire on behalf of policy makers to keep increases in the average global surface temperature below 2.0 – 2.5°C above pre-industrial levels, steps will need to be taken in the near future to curb aviation emissions. International aviation emissions are of particular concern because of the speed at which demand is increasing and the political and legal issues hindering the introduction of effective abatement measures.

#### **4. International aviation emission projections**

##### *Emission projections*

The reason for the concern about international civil aviation can be demonstrated by projecting international emissions over the period 2005 – 2025. To do this, the following equation was used.

$$E_n = RTK_n \times EI_n$$

Where

$E_n$  = t CO<sub>2</sub> emissions in year n.

$RTK_n$  = projected revenue tonne kilometres in year n.

$EI_n$  = emission intensity of the international aviation task in year n, measured in t CO<sub>2</sub> per RTK.

Two scenarios were developed using the above equation: S1 and S2. Details of S1 and S2 are provided in Table 3.

**Table 3 Traffic and emission intensity assumptions for S1 and S2**

Scenario	Traffic growth assumptions	Emission intensity assumptions
S1	<p>Scheduled passenger and freight RTK grow in accordance with ICAO forecasts for the period 2005 – 2025. The ICAO growth rates are:</p> <ul style="list-style-type: none"> <li>• Scheduled passenger growth rate = 5.3%/yr</li> <li>• Scheduled freight growth rate = 6.9%/yr</li> </ul> <p>Scheduled mail RTK grows in accordance with the average over the previous decade (i.e. 2.2%/yr) for the period 2006 – 2015, then the rate falls to 2.0%/yr between 2016 – 2025.</p> <p>Based on historic trends, non-scheduled passenger and cargo RTK is assumed to grow by 1.5%/yr over the period 2006 – 2015, and by 1.0%/yr between 2016 – 2025.</p>	<p>International fleet emission intensity improves in line with UK DTI assumptions:</p> <ul style="list-style-type: none"> <li>• 1.3%/yr between 2006 – 2010;</li> <li>• 1.0%/yr between 2011 – 2020;</li> <li>and</li> <li>• 0.5%/yr between 2021 – 2025.*</li> </ul>
S2	As for S1.	<p>International fleet emission intensity improves in line with the IATA target of a 25 per cent improvement between 2005 and 2020 (i.e. 1.9%/yr). Between 2021 and 2025, the fleet emission intensity improves by 1.0%/yr.</p>

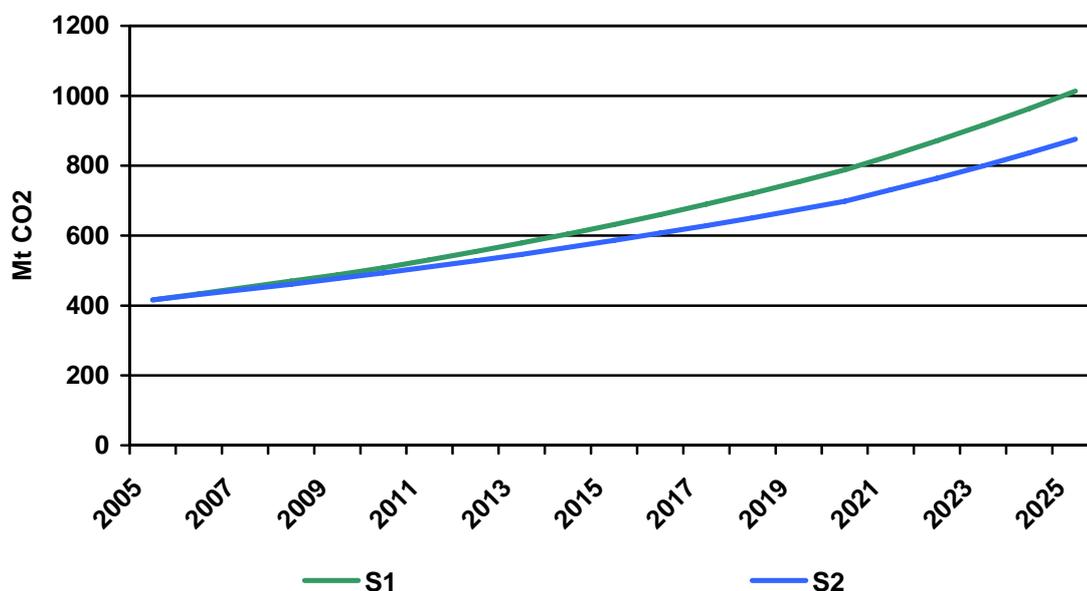
\* These emission intensity improvement rates are derived from the United Kingdom Department of Trade and Industry (UK DTI) fleet fuel efficiency improvement estimates discussed in IPCC (1999).

The traffic data for 2005 and 2006 were obtained from ICAO (2007a) and IATA (2006; 2007), with the exception of the non-scheduled cargo data for 2006, for which data were not available. The 2006 non-scheduled cargo estimate was derived in accordance with the assumptions discussed in Table 3. The emission intensity for the base year (2005) was derived using the IEA's estimate of international aviation emissions (IEA 2007a). There is considerable uncertainty associated with international traffic, fuel and emission statistics, including those published by the IEA. The weaknesses in the available databases are well known and are discussed at length elsewhere.<sup>11</sup> Key problems include the reporting of non-scheduled traffic and the allocation of fuel between domestic, international and military uses. These issues add further uncertainty to the emission projections.

<sup>11</sup> See den Elzen *et al.* (2007).

The results for S1 and S2 are shown in Figure 4. Indices of projected CO<sub>2</sub> emissions at five-year intervals are provided in Table 4. Under S1, international aviation CO<sub>2</sub> emissions rise from 416 Mt in 2005 to 1,013 Mt in 2025. Under S2, emissions increase to 876 Mt in 2025.

**Figure 4 International civil aviation CO<sub>2</sub> emissions, 2005 – 2025**



**Table 4 International civil aviation CO<sub>2</sub> emissions, 1995 – 2025, indices of growth**

	1995	2000	2005	2010	2015	2020	2025
S1	84	87	100*	122	152	190	244
S2	84	87	100*	119	141	168	211

\* Base year (2005) estimate = 415.65 Mt CO<sub>2</sub>.

The above projections of international civil aviation CO<sub>2</sub> emissions do not fully account for the impacts of aviation emissions on the climate system. As discussed in Section 2, aviation non-CO<sub>2</sub> emissions (particularly NO<sub>x</sub> and H<sub>2</sub>O) have important climate impacts and are believed to account for 50 – 80 per cent of the current warming associated with aviation. If an uplift factor of 1.7 is used to estimate total CO<sub>2</sub>-e emissions, the emission intensity model suggests international aviation emissions will be between 1,488 – 1,722 Mt in 2025. While the use of uplift factors is controversial, these figures illustrate the potential magnitude of the total climate impacts associated with international aviation.

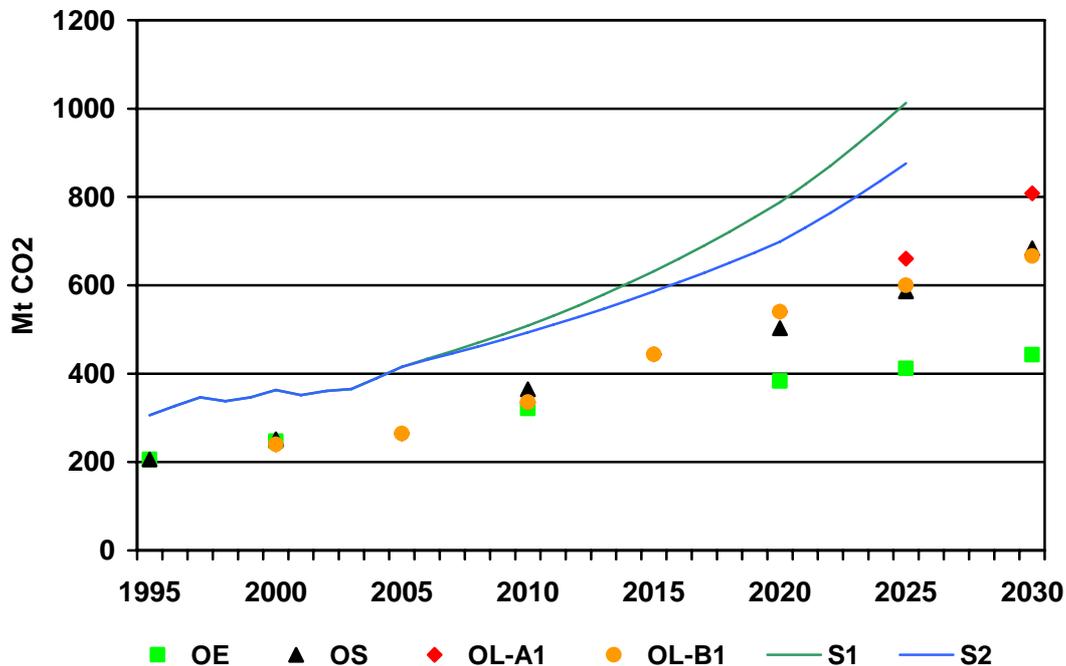
#### *Comparison with previous projections*

The results for S1 and S2 from the emission intensity model are at the higher end of previous international aviation emission projections. Olsthoorn (2001) projected that international aviation CO<sub>2</sub> emissions will be 86 – 144 per cent

above 1995 levels by 2020 (or 383 – 503 Mt) and 187 – 513 per cent above 1995 levels by 2050 (591 – 1263 Mt) if carbon is not priced. These results suggest that by 2025, emissions will be approximately 100 – 190 per cent above 1995 levels (~410 to 600 Mt CO<sub>2</sub>). In comparison, the emission intensity model predicts that emissions will be 150 – 190 per cent above 1995 levels in 2025 (876 – 1,013 Mt CO<sub>2</sub>). The results from Olsthoorn's (2001) low and high emission growth scenarios (the Ecological and Schumpter scenarios (marked 'OE' and 'OS' respectively)) are shown in Figure 5, along side the results from the emission intensity model. Much of the difference in absolute numbers is attributable to Olsthoorn's (2001) lower estimate of emissions in 1995 (206 Mt CO<sub>2</sub> compared to the latest IEA estimate of 306 Mt CO<sub>2</sub>). In relation to the proportional increases, the emission intensity model results overlap the upper end of the range in Olsthoorn (2001). The higher estimates from the emission intensity model are due mainly to differences in economic growth rates, which are a major determinant of aviation demand. The scenarios in Olsthoorn (2001) assumed annual global real GDP growth of 1.6 – 3.1 per cent. The ICAO traffic forecast used in the emission intensity model assumed real GDP growth of 3.5 per cent to 2025.

Owen and Lee (2006) provide another source of comparison. The report, which was prepared for the UK Department of Environment, Food and Rural Affairs (DEFRA), projected scheduled domestic and international aviation CO<sub>2</sub> emissions over the period 2000 – 2050. The traffic forecasts prepared by the FESG for the sixth meeting of ICAO's Committee on Aviation Environmental Protection (CAEP/6) were used as the basis for the projections to 2020 (Wickrama *et al.* 2003). Traffic forecasts for 2020 – 2050 were developed using a non-linear Verhulst logistic model derived from the historical relationship between aviation traffic and GDP between 1960 and 1995. The model was applied using the GDP growth rates from the IPCC's A1 and B2 SRES scenarios. The results suggest that scheduled international aviation CO<sub>2</sub> emissions will increase from approximately 240 Mt in 2000, rising to 264 Mt in 2005, then 540 Mt in 2020 and to between 666 – 808 Mt in 2030. These results suggest scheduled international aviation CO<sub>2</sub> emissions will be approximately 600 – 675 Mt in 2025 (~150 to 180 per cent above 2000 levels). The emission intensity model indicates that emissions will be 141 – 179 per cent above 2000 levels in 2025. The results from Owen and Lee's (2006) A1 and B1 scenarios are marked on Figure 5 as 'OL-A1' and 'OL-B1' respectively. The differences between the Owen and Lee (2006) projections and those from the current study are primarily due to a lower base year fuel efficiency estimate in Owen and Lee (2006) and differences in scope (i.e. Owen and Lee (2006) exclude non-scheduled traffic, which is likely to lower their estimates by approximately 10 per cent).

**Figure 5 Comparison of results from emission intensity model to those from international aviation emission studies, 1995 – 2030, Mt CO<sub>2</sub>**

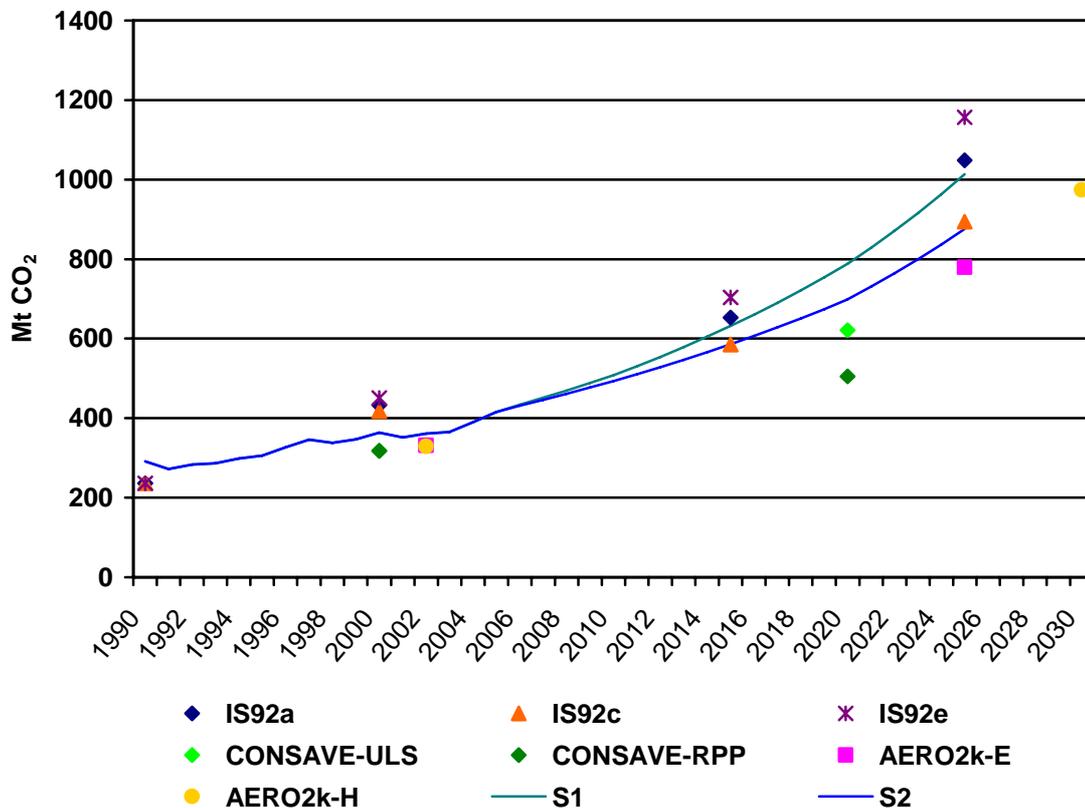


As discussed in Section 3, a number of long-range global aviation emission projections have been prepared. Vedantham and Oppenheimer (1998) projected global aviation emissions over the period 1990 – 2100 and provided interim results for 2025. Berghof *et al.* (2005) (the ‘CONSAVE’ project) conducted a similar exercise for the period 2000 – 2050, providing interim results for 2020. As part of the AERO2k project, Evers *et al.* (2004) projected global aviation emissions between 2002 and 2025, while Horton (2006) projected global emissions between 2002 and 2030 using the AERO2k database and FESG traffic forecasts. Figure 6 compares the results from the emission intensity model to selected adjusted results from Vedantham and Oppenheimer (1998), Evers *et al.* (2004), Horton (2006) and Berghof *et al.* (2005). The international component of the global estimates from these studies was estimated by assuming that international civil aviation CO<sub>2</sub> emissions are proportional to the international share of global scheduled traffic. The international/domestic traffic shares were devised using the ICAO (2007b) traffic forecasts.<sup>12</sup>

<sup>12</sup> Scheduled traffic forecasts for passenger and freight were compiled for the period 2005 – 2025 using ICAO traffic forecasts (ICAO 2007b). The global mail task was assumed to grow in accordance with the growth rates outlined in Table 3. Global civil emissions in Vedantham and Oppenheimer (1998), Evers *et al.* (2004) and Berghof *et al.* (2005) were estimated by subtracting an estimate of military emissions from the global total. For Vedantham and Oppenheimer (1998), the estimates of military emissions were derived using the nominal growth rates adopted in the study. Evers *et al.* (2004) provide separate estimates of military

From Vedantham and Oppenheimer (1998), only the base-demand level projections for the IS92a (IPCC base case), IS92c (low growth) and IS92e (high growth) scenarios are shown (marked 'IS92a' etc.). Their high-demand projections were excluded because they currently appear to be less plausible than the base-demand projections. From Berghof *et al.* (2005), only the Unlimited Skies (ULS) and Regulatory Push and Pull (RPP) scenarios are shown (marked as 'CONSAVE-ULS' and 'CONSAVE-RPP'). The other two scenarios from Berghof *et al.* (2005) (Fractured World (FW)<sup>13</sup> and Down to Earth (DtE)<sup>14</sup>) were considered less likely. From Horton (2006), only the Case 3 (or base case) outcomes are shown (marked 'AERO2k-H') because Cases 1 and 2 were founded on less probable technological assumptions, while Cases 4 and 5 were dependent on the imposition of carbon prices. The results from Eyers *et al.* (2004) are marked as 'AERO2k-E'.

**Figure 6 Comparison of results from emission intensity model to those from global aviation emission studies, 1990 – 2030, Mt CO<sub>2</sub>**



As Figure 6 shows, the results of the current study for 2025 align well with the base case (IS92a) and low growth (IS92c) scenarios from Vedantham and Oppenheimer (1998), while being noticeably higher than those from Eyers *et*

emissions. Berghof *et al.* (2005) used the Eyers *et al.* (2004) estimate of military emissions in 2002.

<sup>13</sup> FW assumed security concerns and a move away from global integration obstruct traffic growth.

<sup>14</sup> DtE assumed there is an aggressive push for greater environmental protection.

*al.* (2004) and Berghof *et al.* (2005).<sup>15</sup> The trajectory of S1 and S2 also suggests emissions will be above the Horton (2006) projections in 2030. The differences between the results of the current study and those from Eyers *et al.* (2004), Horton (2006) and Berghof *et al.* (2005) are attributable to a combination of a higher base year estimate in the current study, coverage (i.e. the current study includes scheduled and non-scheduled traffic) and higher traffic growth rates.

International aviation demand is growing faster than many previously forecast. ICAO's 2007 traffic analysis suggest the strong growth will continue over the next two decades. If these predictions are realised, international aviation emissions are likely to be at the upper end of current projections.

## **5. Can international emissions be stabilised without cutting demand?**

The results from the emission intensity model indicate that international aviation CO<sub>2</sub> emissions are likely to be more than 110 per cent above 2005 levels by 2025. Given the ambitious nature of the IATA target of improving the fuel efficiency of the fleet by 25 per cent by 2020 (and the fact that the IATA target has only been adopted by IATA member airlines),<sup>16</sup> the more probable outcome is an increase in international aviation emissions of greater than 140 per cent by 2025. If the international community agrees to pursue risk averse climate objectives (e.g. atmospheric greenhouse gas concentration targets below 550 ppm CO<sub>2</sub>-e), new measures will be required to control international aviation emissions. As discussed, the extent of the emission cuts that are necessary to achieve targets below 550 ppm CO<sub>2</sub>-e means that no sector will be able to dramatically increase their emissions without jeopardising the overall objective.

Calls for the introduction of mandatory measures to address aviation emissions have met with industry resistance. This is not extraordinary; most emission-intensive industries have resisted mandatory measures to curb greenhouse gas emissions. In responding to proposals for mandatory measures, the industry has relied heavily on the improvements in the emission intensity of the aviation task as a means of deflecting criticism. Yet history has shown that demand growth generally outstrips emission intensity gains. Whether this trend continues in the future is unknown. However, the available evidence suggests the chances of stabilising aviation emissions without restricting demand are diminutive.

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<sup>15</sup> In reality, the international proportion of the estimates of global aviation emissions is likely to be lower than indicated in Figure 6. This is a product of the fact that domestic aviation tends to have higher emission intensity than international aviation due to the nature of the domestic task (i.e. shorter routes) and the domestic fleet.

<sup>16</sup> IATA members are estimated to account for approximately 96 per cent of international scheduled RPKs (IATA 2007). Hence, airline coverage is likely to be less of an issue than the ambitious nature of the target.

To demonstrate this, two hypothetical scenarios (S3 and S4) were developed using the traffic forecasts outlined in Table 3.

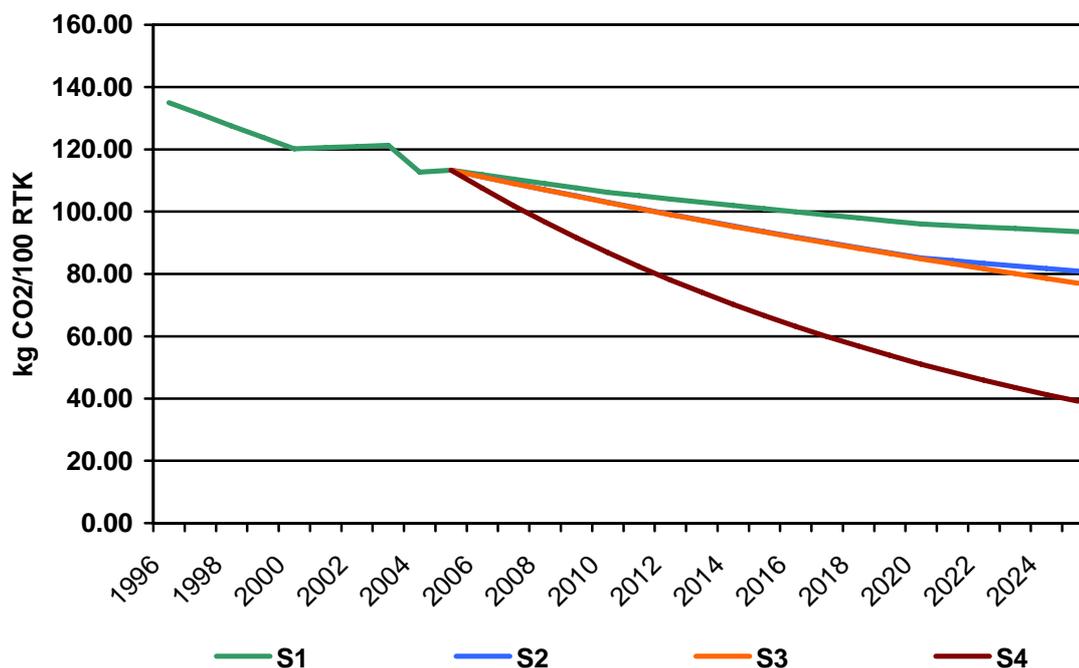
- S3 sought to answer the question: if demand is not restricted, by how much will the emission intensity of the task have to improve in order to keep international aviation CO<sub>2</sub> emissions below 831 Mt in 2025 (i.e. 100 per cent above 2005 levels).
- S4 was the same as S3, only the object was to determine by how much the emission intensity of the task would have to improve in order to stabilise international aviation CO<sub>2</sub> emissions at their 2005 levels by 2025 (i.e. 416 Mt).

The results are shown in Table 5 and are compared to those from S1 and S2. Figure 7 shows the emission intensities under S1 – S4 and compares these to the trends over the last decade (1996 – 2005).

**Table 5 Emission intensity improvements to keep international aviation emissions below targets, 2005 – 2025**

	Emission intensity in 2005 (kg CO <sub>2</sub> /100 RTK)	Emission intensity 2025 (kg CO <sub>2</sub> /100 RTK)	Average annual improvement (%)	Total improvement 2005 – 2025 (%)
S1	113	94	1.0	18
S2	113	81	1.7	29
S3	113	77	1.9	32
S4	113	39	5.2	65

**Figure 7 Historic and projected emission intensity improvements 1996 – 2025**



As Table 5 and Figure 7 illustrate, the task faced by the aviation industry if it proposes stabilising emissions without restricting demand is daunting. Without the imposition of carbon prices on international flights to suppress demand, it seems unlikely that international aviation emissions will be able to be kept below 850 Mt CO<sub>2</sub> by 2025 (i.e. more than 100 per cent above 2005 levels). International aviation CO<sub>2</sub> emissions are only likely to stay below this level if one or more of the following events occur: a prolonged global economic slowdown; an international shock, such as a major international conflict or pandemic; or the emergence and rapid deployment of new emission saving technology. On current evidence, the latter seems unlikely. While more efficient aircraft are currently being rolled out (e.g. A380 and B787), the fuel efficiency gains associated with the latest generation of aircraft are unlikely to be sufficient to offset the increases in international demand. Moreover, international aircraft have relatively long commercial lifetimes (typically 15 – 35 years) (ICAO 2007c). Without aggressive policy measures to promote the deployment of state of the art technology, the slow rate of turnover in the fleet will hinder progress on curbing emissions growth.

## 6. Conclusion

The international aviation industry is facing increasing pressure to curb growth in its greenhouse gas emissions. To date, it has been able to deflect calls for the imposition of effective abatement measures, successfully arguing that it is only a minor cause of global warming and that it has achieved admirable advances in the emission intensity of the aviation task since the early 1990s. The cause of the industry has been aided by a lack of political

will and legal disputes about the rights of nations to unilaterally impose carbon prices on foreign aircraft.

Frustrated at the lack of action, the European Union (EU) has proposed extending its emissions trading scheme to international aviation in 2012 (EC 2006; CEU 2007). This proposal has been met with near universal opposition from non-EU countries. At this point, it is unclear whether the EU will go ahead with its scheme and defy the international community. However, its willingness to propose the scheme is a sign of the intensity of the pressure for more action to be taken to contain the growth in emissions.

The basis for the EU's concerns has been highlighted in this article. Projections based on ICAO's 2007 traffic forecast suggest international aviation CO<sub>2</sub> emissions will increase by between 111 and 144 per cent between 2005 and 2025 (i.e. from 416 Mt to between 876 – 1,013 Mt). These projections are at the upper end of previous estimates, primarily because of an increase in forecast economic growth, higher base year emission estimates and broader coverage. It should also be emphasised that they are confined to CO<sub>2</sub> emissions and do not account for emissions of other gases and particles like H<sub>2</sub>O and NO<sub>x</sub>. If an uplift factor of 1.7 is used to estimate total CO<sub>2</sub>-e emissions, the emission intensity model suggests international aviation emissions will be between 1,488 – 1,722 Mt in 2025.

Stabilising international aviation emissions at levels consistent with risk averse climate targets without restricting demand will be extremely difficult. To prevent emissions from increasing by more than 100 per cent between 2005 and 2025, the emission intensity of the international task would have to fall by 32 per cent, requiring an average annual decrease of 1.9 per cent. To stabilise emissions at 2005 levels, the emission intensity of the task would have to be improved by 65 per cent, necessitating an average annual decrease of 5.2 per cent. With current technology, emission intensity improvements of this magnitude appear unlikely.

Further action on international aviation emissions will be required if the international community wants to keep the increase in the global average surface temperature to less than 2°C. Under current policy settings, emissions are likely to increase significantly unless there is a major global economic downturn or other shock to the aviation market.

## References

Airbus 2007, *Flying by Nature: Global Market Forecast 2007 – 2026*, Airbus, France.

Berghof, R., A. Schmitt, C. Eyers, K. Haag, J. Middel, M. Hepting, A. Grübler, R. Hancox 2005, *CONSAVE 2050 - Constrained Scenarios on Aviation and Emissions*, Project funded by the European Commission, Germany.

Boeing 2007, *Current Market Outlook 2007*, Boeing, United States.

Bureau of Transport and Regional Economics (BTRE) 2002, *Greenhouse gas emissions from transport: Australian trends to 2020*, Report 107, Commonwealth of Australia, November, Canberra.

Council of the European Union (CEU) 2007, *Proposal for a Directive of the European Parliament and of the Council amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community*, Interinstitutional File 2006/0304 (COD), Doc. No. 16855/07, CEU, 21 December, Belgium.

Datastream International Database 2008, *World GDP (Real US\$ at PPP)*, Thomson Datastream.

den Elzen, M., J. Olivier and M. Berk 2007, *An analysis of options for including international aviation and marine emissions in a post-2012 climate mitigation regime*, Netherlands Environmental Assessment Agency, The Netherlands.

European Commission (EC) 2006, *Directive of the European Parliament and of the Council amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community*, COM(2006) 818 Final, 2006/0304(COD), EC, Belgium.

European Parliament 2005, *European Parliament Resolution on "Winning the Battle Against Global Climate Change"*, A6-0312/2005 (available at: [http://ec.europa.eu/environment/climat/future\\_action.htm](http://ec.europa.eu/environment/climat/future_action.htm) (21 September 2007)).

European Parliament 2007, *European Parliament Resolution on Climate Change*, B6-0045/2007, 14 February, Strasbourg (available at: [http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P6-TA-2007-0038+0+DOC+XML+V0//EN#def\\_1\\_1](http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P6-TA-2007-0038+0+DOC+XML+V0//EN#def_1_1) (21 September 2007)).

Eyers, C., P. Norman, J. Middel, M. Plohr, S. Michot, K. Atkinson and R. Christou 2004, *AERO2k Global Aviation Emissions Inventories for 2002 and 2025*, QINETIQ, Report to the European Commission, December, United Kingdom.

Forster, P., K. Shine and N. Stuber 2006, 'It is premature to include non-CO<sub>2</sub> effects of aviation in emission trading schemes', *Atmospheric Environment*, Vol. 40, pp. 1117 – 1121.

Friedlingstein, P., P. Cox, R. Betts, L. Bopp, W. von Bloh, V. Brovkin, P. Cadule, S. Doney, M. Eby, I. Fung, G. Bala, J. John, C. Jones, F. Joos, T. Kato, M. Kawamiya, W. Knorr, K. Lindsay, H. Matthews, T. Raddatz, P. Rayner, C. Reick, E. Roeckner, K. Schnitzler, R. Schnur, K. Strassmann, W. Weaver, C. Yoshikawa and N. Zeng 2006, 'Climate–Carbon Cycle Feedback Analysis: Results from the C4MIP Model Intercomparison', *Journal of Climate*, Vol. 19, 15 July, pp. 3337 – 3353.

German Advisory Council on Global Change (WBGU) 2007, *New impetus for climate policy: making the most of Germany's dual presidency*, Policy Paper No. 5, Germany (available at: [http://www.wbgu.de/wbgu\\_pp2007\\_engl.pdf](http://www.wbgu.de/wbgu_pp2007_engl.pdf) (21 September 2007)).

Hansen, J. *et al.* 2007a, 'Dangerous human-made interference with climate: a GISS modelE study', *Atmospheric Chemistry and Physics*, Vol. 7, pp. 2287 – 2312.

Hansen, J. *et al.* 2007b, 'Climate change and trace gases', *Philosophical Transactions of the Royal Society*, Vol. 365, pp. 1925 – 1954.

Horton, G. 2006, *Forecasts of CO<sub>2</sub> Emissions from Civil Aircraft for IPCC, QINETIQ*, November, United Kingdom.

Intergovernmental Panel on Climate Change (IPCC) 2007, *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H. Miller (eds.)], Cambridge University Press, United Kingdom and United States.

Intergovernmental Panel on Climate Change (IPCC) 1999, *Aviation and the Global Atmosphere, A Special Report of IPCC Working Group I and III* [Penner, J., D. Lister, D. Griggs, D. Dokken, M. McFarland (eds.)], Cambridge University Press, United Kingdom and United States.

Intergovernmental Panel on Climate Change (IPCC) 2001, *Climate Change 2001: The Scientific Basis, Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change* [Houghton, J., Y. Ding, D.J. Griggs, M. Noguer, P. van der Linden, X. Dai, K. Maskell, and C. Johnson (eds.)], Cambridge University Press, United Kingdom and United States.

International Air Transport Association (IATA) 2007, *World Air Transport Statistics*, IATA, Canada.

International Air Transport Association (IATA) 2006, *World Air Transport Statistics*, IATA, Canada.

International Air Transport Association (IATA) 2000 – 2007, *World Air Transport Statistics*, IATA, Canada.

International Civil Aviation Organization (ICAO) 2007a, *Annual Report of the Council 2006*, ICAO, Canada.

International Civil Aviation Organization (ICAO) 2007b, *Outlook for Air Transport to the Year 2025*, ICAO, Canada.

International Civil Aviation Organization (ICAO) 2007c, *ICAO Environmental Report 2007*, ICAO, Canada.

International Civil Aviation Organization (ICAO) 1991 – 2007, *Annual Reports of the Council*, ICAO, Canada.

International Energy Agency (IEA) 2007a, *CO<sub>2</sub> Emissions from Fossil Fuel Combustion 1971 – 2005*, 2007 Edition, IEA, France.

International Energy Agency (IEA) 2007b, *Energy Statistics of OECD Countries, 2004 – 2005*, 2007 Edition, IEA, France.

International Energy Agency (IEA) 2007c, *Energy Statistics of Non-OECD Countries, 2004 – 2005*, 2007 Edition, IEA, France.

Kim, B., G. Fleming, S. Balasubramanian, A. Malwitz, J. Lee, I. Waitz, K. Klima, M. Locke, C. Holsclaw, A. Morales, E. McQueen, W. Gillette 2005, *System for Assessing Aviation's Global Emissions (SAGE), Version 1.5, Global Aviation Emissions Inventories for 2000 through 2004*, United States Federal Aviation Administration, September, United States.

Macintosh, A. and C. Downie 2007, *A Flight Risk? Aviation and climate change in Australia*, Discussion Paper No. 94, The Australia Institute, Australia.

Marland, G., R. Andres and T. Boden 2007, *Global CO<sub>2</sub> Emissions from Fossil-Fuel Burning, Cement Manufacture, and Gas Flaring: 1751-2004*, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, United States.

Meehl, G., T. Stocker, W. Collins, P. Friedlingstein, A. Gaye, J. Gregory, A. Kitoh, R. Knutti, J. Murphy, A. Noda, S. Raper, I. Watterson, A. Weaver and Z.-C. Zhao 2007, 'Global Climate Projections' in IPCC, *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. Averyt, M. Tignor and H. Miller (eds.)], Cambridge University Press, United Kingdom and United States.

Olsthoorn, X. 2001, 'Carbon dioxide emissions from international aviation: 1950 – 2050', *Journal of Air Transport Management*, Vol. 7, pp. 87 – 93.

Owen, B. and D. Lee 2006, *Allocation of International Aviation Emissions from Scheduled Air Traffic – Future Cases, 2005 to 2050 (Report 3 of 3)*, Study on the Allocation of Emissions from International Aviation to the UK Inventory – CPEG7, Final Report to DEFRA Global Atmosphere Division, Manchester Metropolitan University, United Kingdom.

Royal Commission on Environmental Pollution (RCEP) 2002, *The Environmental Effects of Civil Aircraft in Flight*, Government of the United Kingdom, November, United Kingdom.

Sausen, R., I. Isaken, V. Grewe, D. Hauglustaine, D. Lee, G. Myhre, M. Kohler, G. Pitari, U. Schumann, F. Stordal and C. Zerefos 2005, 'Aviation radiative forcing in 2000: an update on IPCC (1999)', *Meteorologische Zeitschrift*, Vol. 14 (4), pp. 555 – 561.

Scientific Expert Group on Climate Change 2007, *Confronting Climate Change: Avoiding the Unmanageable and Managing the Unavoidable*, Scientific Expert Group Report on Climate Change and Sustainable Development, Prepared for the 15<sup>th</sup> Session of the United Nations Commission on Sustainable Development, United Nations Foundation and The Scientific Research Society, United States.

United Nations Statistics Division (UNSD) 2008, 'National Accounts Main Aggregates Database', <<http://unstats.un.org/unsd/snaama/Introduction.asp>> (7 April 2008).

Vedantham, A. and M. Oppenheimer 1998, 'Long-term scenarios for aviation: Demand and emissions of CO<sub>2</sub> and NO<sub>x</sub>', *Energy Policy*, Vol. 26(8), pp. 625 – 641.

Wickrama, U., D. Bedwell, L. Gray, S. Henderson, B. Olov-Nas, M. Pfeifer and C. Trautmann 2003, *Report of the FESG/CAEP6 Traffic and Fleet Forecast (forecasting sub-group of FESG)*, CAEP Secretariat, ICAO, Canada.

ANU Centre for Climate Law and Policy  
ANU College of Law  
The Australian National University  
Canberra ACT 0200  
Ph: 61 2 6125 3832

<http://law.anu.edu.au/CCLP/>