Tyndall°Centre
for Climate Change Research

Aviation in a low-carbon EU: A research report by The Tyndall Centre, University of Manchester

Final Report

Prepared for Friends of the Earth

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Tyndall Centre for Climate Change Research

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1. Introduction

In 2004, Friends of the Earth published research carried out by the Tyndall Centre that investigated the implications of a growing EU aviation industry within the context of a region striving to tackle greenhouse gas emissions. The widely cited report (Bows et al., 2005) concluded that if the EU were to significantly curb its carbon dioxide emissions over the coming decades, the aviation sector would be responsible for a very large share of these emissions in the future, if little additional action were taken to curb aviation growth.

This report provides an update to the earlier analysis and incorporates a number of important refinements. Firstly, the research now includes the importance of cumulative emissions and carbon budgets as oppose to a smooth pathway to a certain percentage reduction in 2050. This builds on from work carried out for Friends of the Earth and the Co-op bank, 'Living within a carbon budget' (Bows et al., 2006).

Secondly, although the carbon budget chosen continues to be informed by the a 2°C temperature threshold target, the carbon dioxide concentration considered within this report is 450ppmv rather than 550ppmv reflecting, at least in part, how the science has moved on. Consequently, the carbon budget available is more limited than under a 550ppmv regime considered previously.

Thirdly, rather than assuming carbon emissions from the aviation industry will continue to rise, the analysis explores the impact of scenarios that aim to be consistent with a 450ppmv future through reductions in passenger growth rates, the more rapid introduction of new management practices and technologies and, in the long-term, alternative fuel sources.

Finally, this study considers the potential impact of including aviation within the EU's emission trading scheme (EU ETS), and the carbon prices required to bring about significant reductions in aviation emission growth.

1.1 EU climate policy

European nations are in broad agreement that individual States, and the EU as a whole, must tackle the problem of escalating carbon dioxide emissions arising from energy consumption. In response, several nations have set carbon reduction targets for future years. In theory at least, these targets are chosen to correspond with stabilising carbon dioxide equivalent (CO_2 eq.) or carbon dioxide alone (CO_2) concentrations at levels that are likely to avoid 'dangerous climate change'.

Although there is no scientific consensus for what is considered to be 'dangerous' in relation to climate change, it has been broadly accepted by the policy community that this relates to global mean surface temperatures not exceeding 2ºC above pre-industrial levels (Schellnhuber et al., 2005). The European Commission (the Commission) acknowledge in a recent Communication (COMM, 2007) that stabilising long-term greenhouse gas concentrations at around 450ppmv CO_2 eq. provides a 50% chance of ensuring global mean temperatures do not exceed the 2ºC threshold. However, its (arguably inadequate) policy response is to set an aspirational target of reducing greenhouse gas emissions by 60%-80% by 2050 from 1990 levels by apportioning global emissions to EU nations (COMM, 2007).

By selecting a target related to global CO_2 eq. concentrations, governments have, perhaps inadvertently, accepted that such targets must include all greenhouse gas-producing sectors. Furthermore, in aiming for a target percentage reduction by a particular date, they have neglected the crucial importance of cumulative emissions and carbon-cycle feedback mechanisms such as those illustrated by the IPCC's newly published range of global cumulative carbon dioxide emissions associated with a 450ppmv CO_2 stabilisation level [(IPCC, 2007): 17].

By addressing these two deficiencies in the targets, this analysis aims to quantify the contribution of the aviation industry to future EU climate change targets in relation to CO_2 alone. The arguments for focusing on CO_2 rather than the other five greenhouse gases and a need for more stringent emission reductions to meet the 2ºC target are presented alongside the main discussion of the approaches used in this study.

1.2 Aviation trends

The air transport market within the EU25 nations has continued to grow rapidly since the previous Friends of the Earth/Tyndall report was published (Bows et al., 2005). EU25 passenger numbers in 2005 exceeded 700 billion, with an 8.5% increase on the previous year's figures (de la Fuente Layos, 2007). This level of growth illustrates a resurgence of the industry following the events of September the 11^{th} 2001.

Inseparable from this resurgence is the continued high levels of growth in carbon dioxide emissions from the industry. Although nations are not required under Kyoto to publish their carbon dioxide emissions from international aviation within their national inventories, this data is submitted alongside as a memo. Combining the CO_2 emissions from domestic and international aviation provides an estimated CO_2 emission growth rate of 7% between 2003 and 2004 and 6% between 2004 and 2005. These rates of growth are similar to those produced by the industry since 1993, with the exception of the period affected by the events of September 11^{th} 2001 This rapid growth in emissions, coupled with limited opportunities for other than incremental improvements in fuel efficiency, at least in the short- to medium-term, gives rise to the concern that as EU nations strive to reduce its carbon dioxide emissions, aviation will be responsible for an increasing share of total emissions.

A further area of concern relates to non-CO_2 emissions from aircraft contributing to additional net heating of the atmosphere. NO_x emissions that form ozone and deplete methane, as well as soot and water vapour that form contrails and may lead to cirrus clouds each have an impact on the climate. However, there is much debate over the appropriate metric to account for these additional impacts.

Radiative forcing is often used to relate the CO_2 impact to the impact from NO_x and contrails through the use of an 'uplift factor'. The IPCC used such a factor in their special report on aviation (Penner et al., 1999), this factor has since been updated (Sausen et al., 2005). However, radiative forcing is a measure of historical impact and is arguably only useful when comparing well-mixed greenhouse gases. Neither NO_x or contrails are well-mixed, and for this and other reasons (section 2.1) therefore within this report, no uplift factor will be applied. That is not to say that these emissions are not important, merely that the use of the radiative forcing uplift factor is at best confusing, and at worse could lead to polices that are potentially damaging to the climate.

1.3 EU emissions trading scheme

The EU's emissions trading scheme (EU ETS) began in operation in January 2005, with the first phase of the scheme set to run until the end of 2007. The scheme initially involved some 12,000 installations covering energy activities that exceeded 20MW, as well as a number of process emission activities covering around 45% of the EU's carbon dioxide emissions. The second and expanded phase of the EU ETS is set to begin in 2008, and, in recognising the growing issue of emissions generated by the aviation industry, the EU are currently discussing including aviation within the scheme by 2011.

As a first stage, the proposal suggests including intra-EU flights only, extending this to all departures and arrivals from EU nations by 2012. The aim of including aviation within the scheme is to internalise some of the costs of the environmental impact of the aviation sector. However, a number of issues are yet to be fully addressed, in particular; the impact of including aviation in the ETS; the level of emissions rights to be purchased by the aviation industry given current emission growth rates; and the overall level of the EU ETS cap.

In addition to comparing the EU's growing aviation industry with an overall EU carbon budget, as an update to the previous Tyndall report, the analysis presented in this report develops scenarios that explore the inclusion of the aviation sector within the EU ETS.

2. EU carbon budgets & implications for aviation

If the EU is to make its fair contribution to a global mean surface temperature not exceeding the 2°C threshold, it is necessary to quantify the available carbon budget for the EU25 nations and explore the aviation sector's contribution to the climate change debate. This section explores the relationship between global temperature changes, atmospheric concentrations of greenhouse gases, and the mitigation action required by the EU25 when the emissions burden is apportioned. A resulting carbon budget and a range of trajectories is produced which illustrates the scale of action that will be required if the EU is to remain committed to its 2°C target. Aviation emission scenarios in relation to this carbon budget and pathway up to 2012 – the year in which aviation is to be fully included within the EU ETS – are presented.

2.1 Temperature and greenhouse gas concentrations

One of the key variables of interest to those involved in climate change mitigation and adaptation is the global mean temperature change due to the increase in greenhouse gas concentrations in the atmosphere. Understandably, there is both confusion and uncertainty as to the atmospheric concentration of greenhouse gases in the atmosphere and the likely resultant temperature change.

Some of this confusion stems from errors in the translation of the science into policy. For example, many UK policy documents refer to 550ppmv CO_2 alone being related to the 2°C threshold, when in fact the original work carried out by the UK's Royal Commission on Environmental Pollution (RCEP) essentially linked 550ppmv CO_2 eq to this temperature change (RCEP, 2000). Uncertainty, on the other hand, comes from the inherent range of outputs given by climate models in assessing the impact of altering the atmospheric concentration of CO_2 and other greenhouse gases, and the variety of model results available.

The methods used in this analysis are consistent with those presented in 'Living within a carbon budget' (Bows et al., 2006), and relate an atmospheric concentration of CO_2 alone with the 2°C temperature threshold, based on work presented at the Department for the Environment Food and Rural Affairs (DEFRA) conference in Exeter in 2005.

As noted in Section 1, the analysis focuses on CO_2 alone rather than other greenhouse gases expressed as CO_2 equivalent. The reasons for this are as follows:

I. The global cumulative carbon *budget* has a more significant impact on climate change than greenhouse gas emission *pathways*. The latest IPCC document presents a new range of global cumulative CO_2 emissions that can be released between the years 2000 and 2100 consistent with a 450ppmv CO_2 concentration. This new range incorporates complex interactions that aim to quantify the impact of including carbon-cycle feedbacks in studies. This level of sophistication has not been applied when assessing the feedback impacts of the other greenhouse gases.

II. The carbon-cycle feedback/cumulative budget work mentioned above has been carried out in relation to carbon alone, and not directly considered other greenhouse gases.

III. Policy messages for climate change, energy and aviation can be drawn from a CO_2 alone study due to its dominance in relation to energy emissions. The inclusion of other greenhouse gases in the analysis is, therefore, not only unnecessary, but would risk adding a level of complexity that would itself confuse the issues and associated policy messages.

IV. Within the EU, non CO_2 greenhouse gas emissions have been following similar trends to CO_2 emissions in the previous 5 years. This report assumes this will continue to be the case. Furthermore, given that policy measures to address CO_2 will likely differ considerably from those related to the other greenhouse gases, they are treated separately here.

As noted in Section 1, in employing the carbon budget methodology, the stabilisation level of 450ppmv CO_2 is chosen. However, according to the results of Meinshasuan (Meinshausen, 2006), this stabilisation level, if equivalent to 500ppmv CO_2 eq. has an approximate 70% chance of exceeding the 2°C level. A legitimate question, then, is why isn't a lower stabilisation target addressed within this work to minimise the chance of exceeding the 2°C threshold? The answer takes into account what can be considered to be realistic in relation to a global timescale for action and can be justified as follows:

The current level of CO_2 in the atmosphere is now in excess 380ppmv, and for CO_2 eq. around 430ppmv. Aiming for a 450ppmv CO_2 eq. concentration would give a 50% chance of not exceeding the 2°C level according to the Meinshausen work. In other words, a much better chance of not exceeding the 2°C threshold than stabilising at 450ppmv CO_2 alone (which would be closer to 500ppmv CO_2 eq.).

The concentration of CO_2 eq. in the atmosphere is increasing at roughly 3ppmv per year, and in the previous 3 years, there has been an increased rate of growth in the emissions from fossil fuel use. Consequently, at current rates of growth, it would take only 7 years from 2005 (the latest date for which concentration data is available) for concentrations to rise from 430ppmv CO_2 eq. to 450ppmv CO_2 eq.

Currently the largest growth in emissions generated by energy consumption is being driven by industrialising nations such as China and India. These nations have no commitments to reduce or slow down the rate of increase in their emissions. It would seem highly unlikely, then, that these nations will be able to curb growth rates significantly in such a short time-frame to allow global concentrations to stabilise at 450ppmv CO_2 eq. In addition, US emissions are continuing to rise, as are those from the EU; this is despite policies being in place to mitigate emissions and commitments to Kyoto. Therefore, in the absence of a radical and almost immediate departure from current trends, achieving 450ppmv CO_2 eq. can be considered to be, at best, extremely unlikely and, more reasonably, unachievable given the practical constraints.

An important point to note in relation to this argument relates to the impact of 'overshooting' the stabilisation target. Some studies have assessed the possibility of overshooting the desired target stabilisation concentration, to allow delayed action to result in the same temperature increase. Overshooting scenarios allow the concentration of greenhouse gases to temporarily exceed the ultimately desired stabilisation level. Uncertainties relating to the scale of impact of, even temporarily, exceeding a particular stabilisation level (or the ease of reducing that level back down again) are significant and would require a considerable amount of further research into a number of areas including:

a) the possible trajectories that nations could take to overshoot;
b) the policies required to set nations down such a path; and
c) the impact of a temporarily high greenhouse gas concentration, particularly on feedbacks.

Clearly, a small study such as this can not address such issues and scenarios within the available timescales and budgets.

2.2 EU carbon budget

2.2.1 General principles

As noted in Section 1, the EU has adopted a target of global mean surface temperatures not exceeding a 2°C rise above pre-industrial levels (COMM, 2007). To achieve this, the EU has set an aspirational target of reducing its greenhouse gas emissions by 60%-80% by 2050 from 1990 levels (COMM, 2007).

This target was originally associated with the objective of stabilising atmospheric CO_2 eq. at below 550ppmv. However, recent studies illustrate that the 450ppmv stabilisation level will provide a significantly higher probability of not exceeding this 2°C threshold than would 550ppmv. It has been estimated that 450ppmv CO_2 eq. offers an approximate 46% chance of not exceeding the 2°C threshold (i.e. a 54% failure probability), whereas 550ppmv CO_2 gives only a 29% chance (i.e. a 71% failure probability) (Meinshausen, 2006). There are therefore a number of important issues to be addressed in relation to the EU's climate change target and in turn how such targets relate to the aviation industry.

The first point to be considered is the ultimate aim of the target – i.e. for temperatures to not exceed the 2°C threshold. This threshold is associated with atmospheric CO_2 eq. levels relating to different probabilities of exceeding 2°C. This type of methodology therefore assumes that all greenhouse gas-producing sectors are included, as the atmosphere does not 'see' what is or is not accounted for.

The Kyoto Protocol, and the UK's carbon reduction target both omitted international aviation and shipping from their targets. For the EU, it is ambiguous as to whether or not these sectors are or are not included. If these sectors currently contributed insignificant amounts of greenhouse gases (and this situation was unlikely to change), it might be reasonable to omit them. However, this analysis (and others) strongly indicates that this is not the case for the aviation sector. This implies that, in order to institute climate policy that is both proportionate and sufficient to address the issues, there is a need to account for the emissions from international sectors (such as aviation) that are, or may in the future represent, a significant proportion of a nation's total emissions.

Secondly, in considering how best to develop a carbon trajectory in line with a 2°C target, it is important not to become overly focussed on choosing a convenient percentage reduction by particular dates into the future as is often the case (DEFRA, 2006), (UNFCCC, 1997). Here, scientific analysis shows that it is the cumulative emissions that are more influential in reaching a desired atmospheric greenhouse gas concentration rather than the emission pathway taken (Jones et al., 2006; Matthews, 2006; Matthews, 2005). This is a point that, although very significant, seems to have been overlooked by governments.

Accordingly, delaying action to mitigate emissions requires more stringent measures to avoid exceeding the 2°C threshold than is generally recognised (Stern, 2006; Bows et al., 2006). The danger of failing to adequately account for the cumulative emissions issue in policymaking is that the resulting policies will be overly focused on the longer-term issues (and hence address energy supply), when in fact it is the short-to-medium term (and hence energy demand) that is of crucial importance [(Bows et al., 2006): 20]. Clearly, a policy that is out of balance with the variables which it seeks to regulate will not be an efficient policy and may fail in its objectives.

The third point relates to carbon-cycle feedbacks. These feedback mechanisms have only recently and still partially, been incorporated in climate change emission budget studies, and are shown to have a very significant effect on the carbon budgets available. This has been illustrated this year by the IPCC [(IPCC, 2007): 17]. Carbon budgets that include feedback mechanisms can be some 20% smaller than those that omit feedbacks (Matthews, 2005).

2.2.2 Deriving an appropriate cumulative carbon budget for the EU

In order to derive a cumulative carbon budget for the EU for the study, it is necessary to apportion the global cumulative CO_2 emissions to nations. For this study the Contraction & Convergence (Meyer, 2000) model has been modified to include world bunker fuels, and then run using the cumulative carbon range ('Low' and 'High' in Table 1) recently published by the IPCC (IPCC, 2007) for 450ppmv CO_2.

Table 1 outlines the both global cumulative carbon range and those emissions apportioned to the EU.[1]

[1] The range in the figures is due to results from different models with varying levels of carbon cycle feedbacks.

Table 1: Global and EU cumulative carbon budgets

Scenario	**Global cumulative emissions[2] $GtCO_2$ (GtC) (1990-2100)**	**EU cumulative emissions $GtCO_2$ (GtC) (1990-2100)**
450 Low	1431 (390)	160 (43.5)
450 High	2257 (615)	212 (57.8)

Such an analysis provides us with cumulative carbon budgets for the EU, but it is also desirable to be able to understand the impact of this budget on the EU's pathway to a low-carbon future. This is achieved by firstly considering those emissions released, but not yet recorded, for the years 2000-2005, then incorporating current EU emission trends, and finally by constraining the pathway to remain within budget.

In undertaking this analysis, the importance of using empirical data for the period between 2000-2005 cannot be overstated. When considering the cumulative carbon budget, nations emitting at high levels today are 'spending' their budgets very rapidly. As such, those emissions occurring between 2000 and 2005, and also for the short term future, will have a significant impact on the range of pathways available into the longer term. For example, in the case of the '450 High' scenario in Table 1, the emissions represent ~14% of the total budget in just 4 of the 50 years (i.e. 14% spent over only 8% of the timescale). In other words, we are spending our carbon budget very rapidly.

In terms of how this equates with emissions over time, two emission scenarios for the two cumulative emission ranges are presented in Figure 1. From the figure it can be seen that the higher the cumulative target, the easier it is to manoeuvre in later years.

Clearly, the converse is true for lower cumulative targets. Hence any policy aiming for levels at or lower than '450 Low' must both stabilise emissions in the shorter term (as a matter of some urgency) and maintain significant year-on-year reductions for three decades, in order to allow sufficient 'room for manoeuvre'. Both profiles have a convergence date of 2050, in line with the year used within the influential RCEP report (RCEP, 2000).

[2] Not including forestry

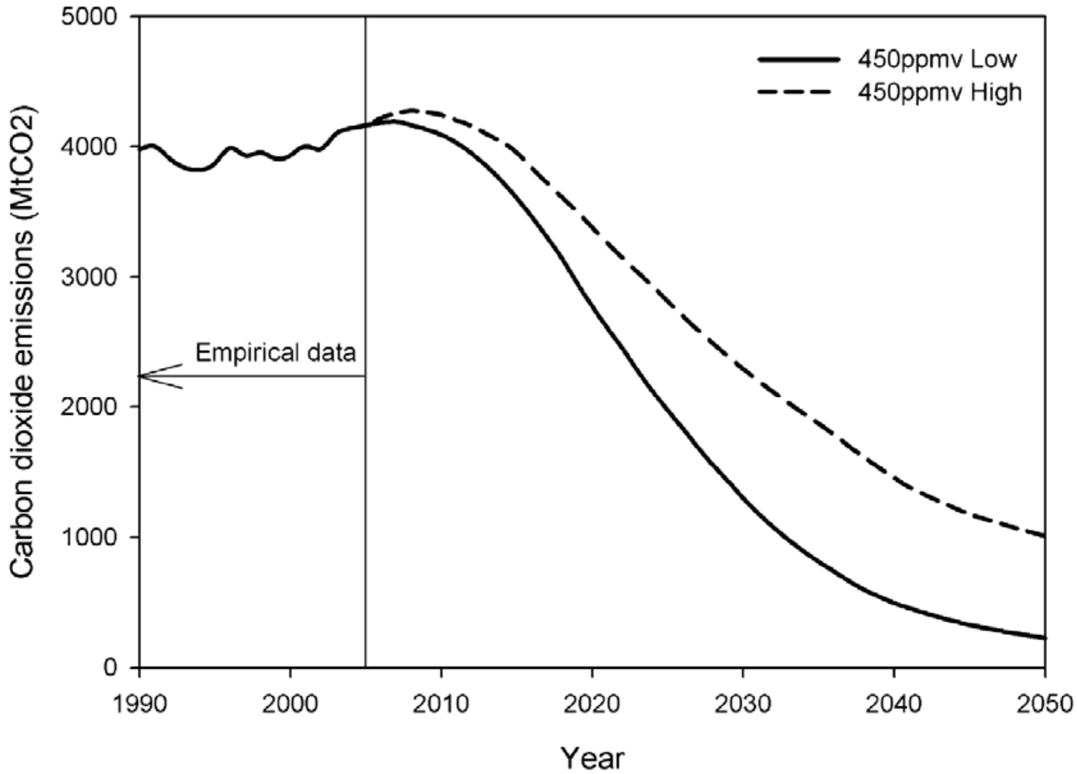

Figure 1: 450ppmv cumulative carbon dioxide emission profiles for the EU25

2.3 Historical aviation CO2 and passenger trends

It has been widely publicised that the aviation sector's emissions are growing more rapidly than any other sector in the UK. This is however also true for the EU25, where even the UK which has the largest aviation industry in Europe, has yet to see economic maturity. Figure 2 presents the CO_2 emissions from the aviation sector in the EU25 from 1993 to 2005 using the data submitted to the UNFCCC in 2007.

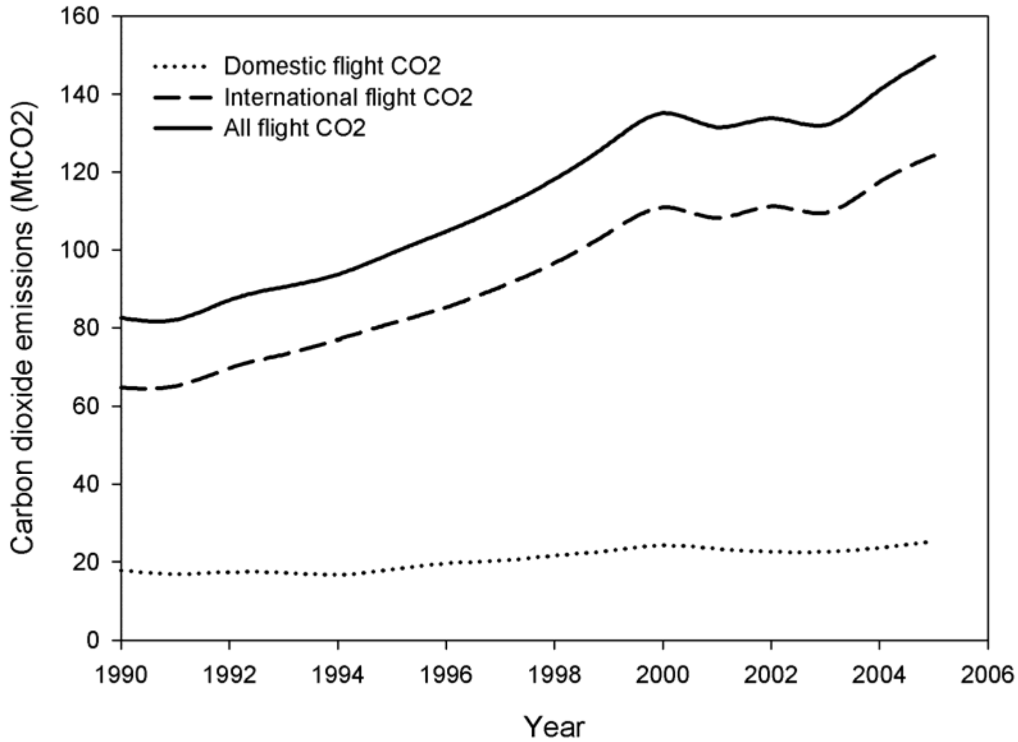

Figure 2: CO_2 emissions from the EU25's aviation sectors, from data submitted to the UNFCCC in 2007. The data incorporates an estimate for Greece and Malta in 2005 due to an absence of data. Although not all of the EU25 were in the EU from 1990, all of the nations have been included in the totals from the outset.

It is clear from Figure 2 that the emissions from international flights dominate. CO_2 emissions from domestic flights have increased at an average of 2.5% per year since 1990 according to this dataset. The corresponding figure for international flights is 4.5%. However, the events of September 11th 2001 had a marked impact on the growth rate of the aviation sector, as is clear from the data presented between 2001 and 2003. If the period between 1990 and 2000 is assessed, domestic aviation's annually averaged CO_2 growth was 3.2%, with international air travel at 5.6%. This period also incorporated the first gulf war, which understandably impacted on the industry. From 2003 to 2004, and 2004 to 2005, the total amount of CO_2 from the EU25's aviation industries increased by 7% and 6% respectively. This increase in emissions reflects the number of passengers travelling by air from the EU. Although data for passenger numbers for the whole of the EU25 is available only for 2004 to 2005, typical rates of growth can be gleaned from individual nations' statistics. Figure 3 illustrates passenger growth in three contrasting exemplar nations: UK, Poland and Spain.

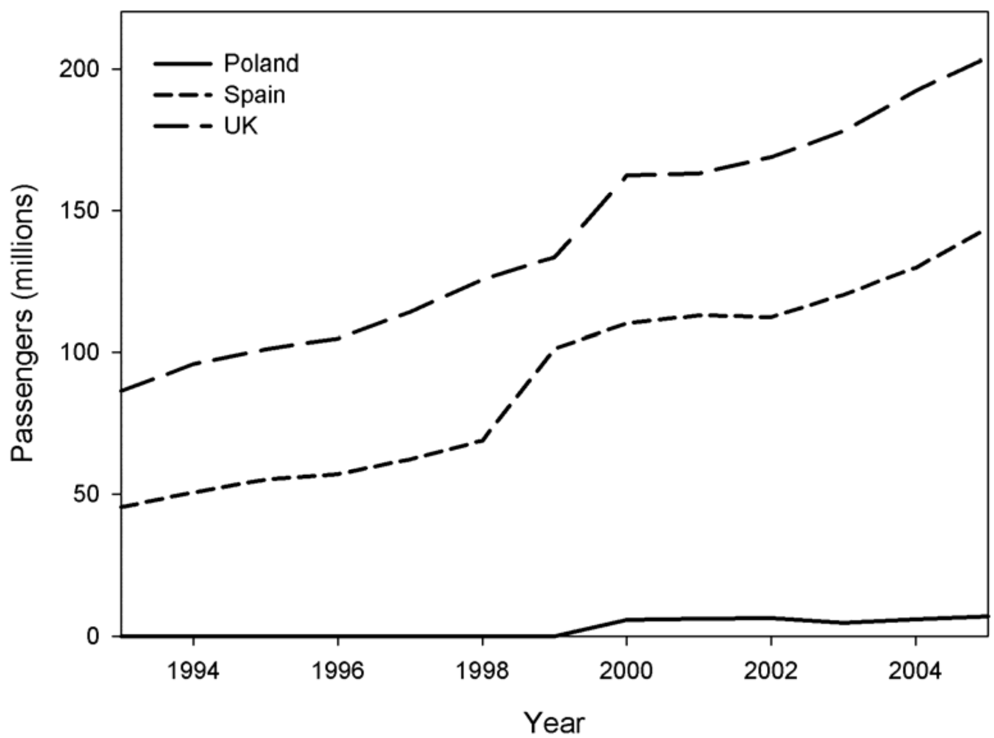

Figure 3: Passenger number data from three exemplar nations within the EU25.

None of the nations illustrated in Figure 3 are at the extremes of the industry's passenger growth range. Here, the UK's passenger numbers increased by an annual average of 7% between 1993 and 2005, and at a similar level between 2003 and 2005. Spain's respective figures were 10% and 9%, whereas Poland grew at an annual average rate of 21% between 2003 and 2005.

Although it is expected that passenger number growth will have a close relationship with the corresponding CO_2 emission growth, the link is not evident from the data. Figure 4 illustrates this point. Comparing the passenger growth and emission growth trends of the UK and Spain, the relationship between passenger and emission growth is somewhat different. In the UK, although passenger numbers increased by around 7% per year between 1993 and 2005, the corresponding CO_2 emissions grew at around 6% on average. For Spain, despite a 10% per annum increase in passenger numbers between 1993 and 2005, its CO_2 emissions as reported to the UNFCCC only increased at 6% per year. The fact that emissions are growing more rapidly per passenger for the UK could be attributable to a disproportionately higher growth in long-haul travel compared with medium and short haul. On the other hand, it could be an indication of deficiencies in the CO_2 estimates. Interestingly, despite a fast-growing aviation industry within Poland, emissions here were reported as decreasing from 1993 levels by 2005.

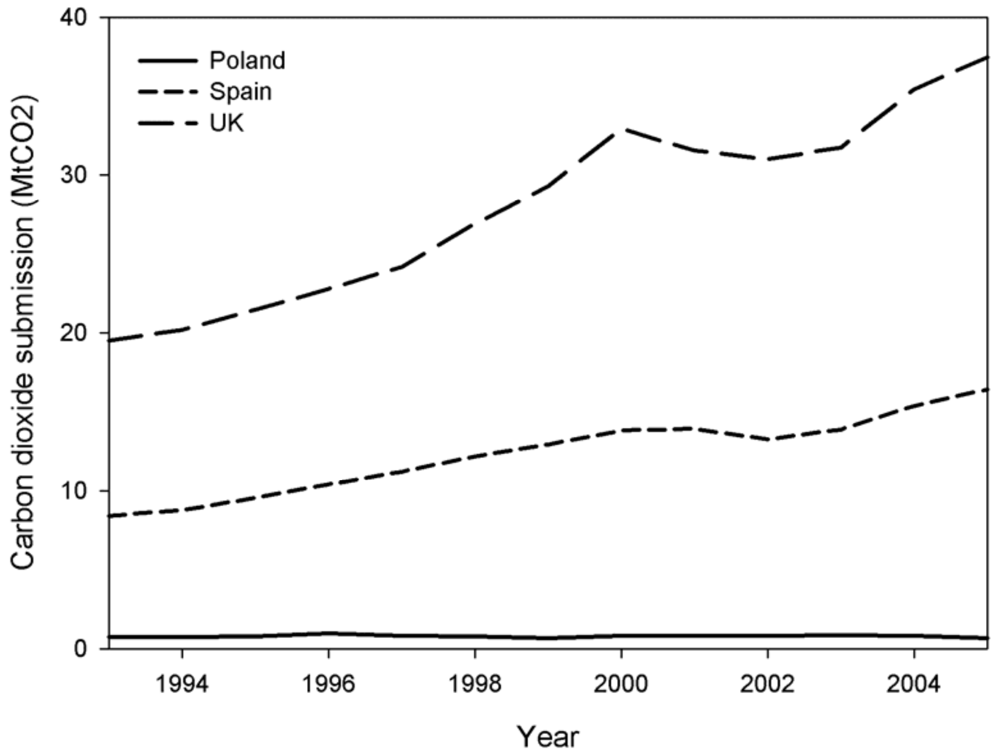

Figure 4: Carbon dioxide emissions from three exemplar nations within the EU25.

The analysis suggests significant discrepancies between data collection standards and robustness across the various EU nations; a situation that requires remedying as a matter of urgency if our understanding of the link between growth trends and emissions is to be improved. Taking the example of Poland, where growth in air travel is undeniable, the results imply that their decreasing CO_2 emissions from aviation are likely to be underestimating the impact of their industry.

2.4 Radiative forcing and non-greenhouse gas emissions

In addressing the aviation industry's impact on the climate, the issue of non-greenhouse gas emissions cannot be ignored. Aircraft release soot and water vapour that lead to the formation of contrails and possibly cirrus clouds, in addition to NOx emissions that form ozone, another greenhouse gas, and deplete methane. All of these emissions alter the radiative properties of the atmosphere either globally, when talking about well-mixed greenhouse gases, or at a local level in relation to contrails and cirrus clouds.

One metric that has been used to calculate the total impact on the climate of these emissions (in addition to CO_2) is radiative forcing. Radiative forcing compares the impact of these emissions relative to pre-industrial conditions. It calculates the total globally and annually averaged impact of anthropogenic emissions on the climate in terms of Watts per square metre (Wm^{-2}) in relation to an assumed zero Wm^{-2} in pre-industrial years (1750). For total global anthropogenic activities – i.e. from all sources, the figure stands at 1.6 Wm^{-2} (IPCC, 2007). If this metric is applied to the aviation sector, the emissions of CO_2, NO_x and contrails amount to a total radiative forcing impact in the year 2000 of around 0.048 Wm^{-2} (Sausen et al., 2005). This calculation does not include the radiative forcing of contrail-induced cirrus cloud due to very large uncertainties that remain in relation to their net impact.

Whilst this metric has a clear role to play in the scientific analysis of climate change, it has limitations for developing current and future emission-reduction polices. Radiative forcing compares the impact of emissions from 1750 to date, to illustrate the impact of the different sectors on the overall temperature rise. When using it to look at future impacts, this measure is useful for policy adaptation, but it can lead to inappropriate policy messages if it is used to guide policy mitigation measures. This is where the cumulative approach is more useful. Furthermore, the metric could lead to unhelpful policy conclusions in certain situations. For example, if applied to shipping emissions, the policy conclusion may be to increase the sulphur emissions from ships to mitigate the warming caused by their release of CO_2 emissions. In addressing the impact of the aviation industry on the climate, both the radiative forcing approach and an approach addressing CO_2 alone provide clear indicators as to the significant impact the aviation sector will likely have on climate. In this study, cumulative emissions help identify the impact of the aviation industry on the climate (from the present to some date in the *future*) in combination with other sectors, and radiative forcing illustrates the overall contribution of the aviation industry to the *current* climate impact by considering the additional non-carbon components. Therefore, to be consistent with the cumulative carbon budget approach being taken here, the analysis of the aviation sector will address CO_2 alone.

2.5 Aviation emission scenarios from 2006 to 2012

As a first stage in developing aviation emission scenarios that can be a) compared with an overall EU25 carbon budget, and b) be analysed in relation to inclusion within the EU's Emission Trading Scheme, it is necessary to develop scenarios from today until the commencement date of the inclusion of aviation within the scheme.

For the purpose of this report, Phase 3 of the EU ETS is assumed to begin in the year 2012 and include all flights departing and arriving the EU.[3] In the absence of a clear link between passenger growth and CO_2 emissions growth, a number of assumptions must be made to make reasonable emission scenarios for the EU for the short term. Here a range of growth rates are required to reflect a range of possibilities and thus extend the scope of analysis. Some of the statistics used to provide a basis for the assumptions are summarised in Table 2.

[3] Currently, discussion about the EU ETS is ongoing in relation to the commencement date and coverage.

Table 2: Selected statistics relating to the EU25's aviation industry. The years most severely effected by the events of 11th September 2001 are not included within any of the trends extracted.

Period	Coverage	Source	Characteristic
2004-2005	EU25	Eurostat 2005	8.5% growth in passenger numbers
2003-2004	EU25	Eurostat 2004	8.8% growth in passenger numbers
2004-2005	EU15	Eurostat 2005	4.4% growth in flights
2003-2004	EU15	Eurostat 2005	5.0% growth in flights
2004-2005	EU25	UNFCCC	6% growth in CO_2 from aviation
2003-2004	EU25	UNFCCC	6.8% growth in CO_2 from aviation
1994-2000	EU25	UNFCCC	6.3% p.a. growth in CO_2 from aviation
1990-2000	EU15	UNFCCC	5.4% p.a. growth in CO_2 from aviation
2003-2005	EU25	UNFCCC	6.4% p.a. growth in CO_2 from aviation

Additional factors influencing the choice of scenarios include:

- the current continued success of the low-cost air model;
- access to a network of growing regional airports;
- the low-cost model extending in modified form to medium and longer haul routes such as those between the UK and the USA, a situation encouraged through the open-skies agreements; and
- no significant economic downturn between the 2005 data and today (2007).

From Table 2, it would appear that passenger number growth is somewhat higher than CO_2 growth, and that CO_2 growth is higher than flight growth. This would be consistent with an overall 1% - 2% improvement in the fuel efficiency of aircraft, and a general trend for passengers taking longer flights. However, a detailed analysis as to the specific nature of the differences is both beyond the scope of this study, and highly constrained by the consistency of data currently available across the EU25 nations.

For the years from 2006 to the end of 2011, recent and longer-term trend data significantly influences the choice of scenarios. According to the submissions to the UNFCCC, there has been a long-term trend of increasing CO_2 emissions from EU25 nations of the order of 6% per year. More recent emissions have also increased at 6% per year, once allowance is made for the period affected by the events of 11th September 2001. Reinforcing this 6% figure is Eurocontrol's forecast of strong growth for 2007-2008 (EUROCONTROL, 2007).

The range of scenarios considered for the period from 2006 to the end of 2011 uses 6% emission growth as a mid-range value, with 4% per year for the lower-range and 8% per year for the higher-range. Due to an absence of data in terms of passenger-km, it is difficult to relate fuel efficiency improvements to passenger-km growth rates. However, assuming no radical step changes in the short term, the scenarios all use a 1% per year improvement in fuel efficiency across the fleet for the period 2006 to the end of 2011.

One important distinction to make at this stage is the difference between the CO_2 emissions submitted to the UNFCCC for aviation in the EU25, and the emissions that will be included in the EU ETS analysis in Section 3 of this study. For the UNFCCC, domestic aviation's CO_2 is submitted separately from the CO_2 from international aviation. The latter broadly approximates to 50% of all flights to and from each nation within the EU to either another EU nation or an extra-EU nation. Therefore, the total domestic and international CO_2 for aviation submitted to the UNFCCC is an estimate of the CO_2 associated with all domestic flights within the EU25 and 50% of international flights to and from EU nations. Therefore, this UNFCCC data will give a baseline for 2005 of 149.6MtCO_2, 25.3MtCO_2 from domestic and 124.3MtCO_2 from international. However, to include aviation within the EU ETS, the Commission proposes CO_2 emissions from all departures and arrivals from and to EU nations are included. It is not appropriate to simply double the CO_2 emissions submitted to the UNFCCC to account for these additional flights, as double counting for domestic and intra-EU flights will occur. The method for calculating the alternative baseline is laid out on page 19. This EU ETS baseline will therefore be higher than the 2005 50% baseline of around 150MtCO_2 considered here, but not as high as two times this value. By applying the three different growth rates to the baseline figure of 150MtCO_2, the emissions by 2012 range from 189MtCO_2 to 236MtCO_2 as illustrated in Figure 5.

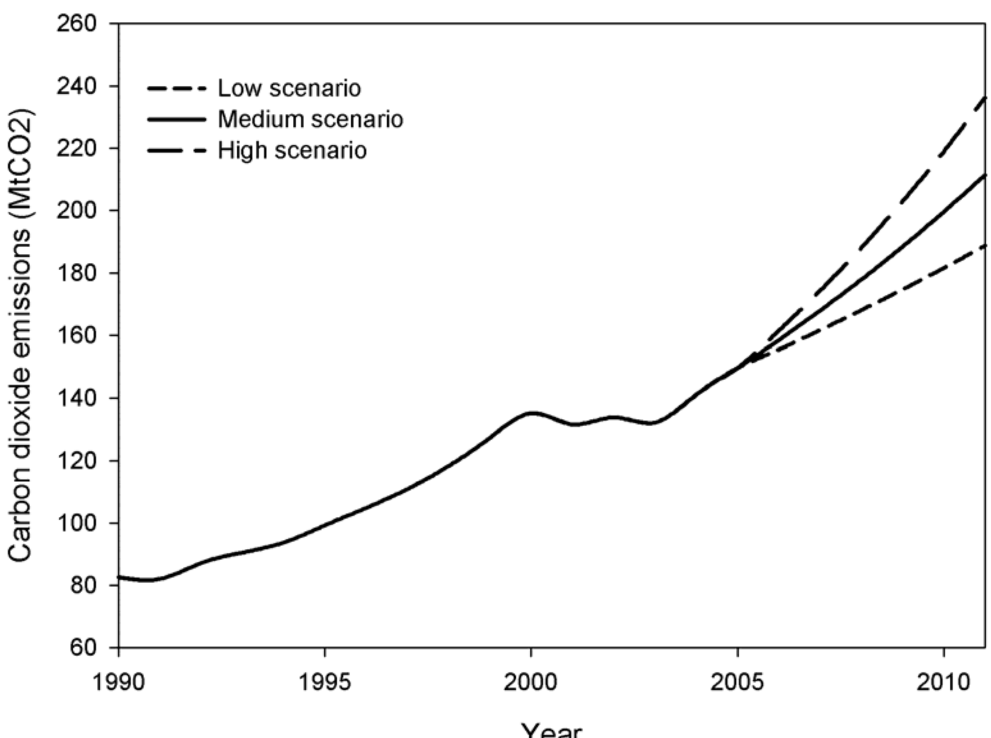

Figure 5: Data submitted to the UNFCCC for CO_2 emissions from EU25 nations aviation industries from 1990 to 2005, and three aviation emission scenarios from 2006 to 2011.

2.6 Aviation emissions in relation to a 450ppmv budget

Prior to considering the impact of the EU ETS on the aviation sector, or indeed the cost of joining the scheme under the various scenarios, it is useful to quantify the CO_2 emissions from the aviation sector from now until 2012 in relation to the overall 450ppmv EU25 carbon budget. Figure 5b illustrates the carbon budget presented earlier (in Figure 1), but in this case, including the 3 aviation emission scenarios. Although in the very short term, the aviation sector's emissions account for between 4 and 6% of the EU25's total permitted emissions. Post-2012, the situation alters considerably, with aviation emissions rapidly becoming a much more significant portion of the whole. This issue will be explored in more detail on page 24, however, the figure illustrates clearly that, in striving to mitigate CO_2 emissions from energy use, the EU's emission trajectory must change as a matter of urgency.

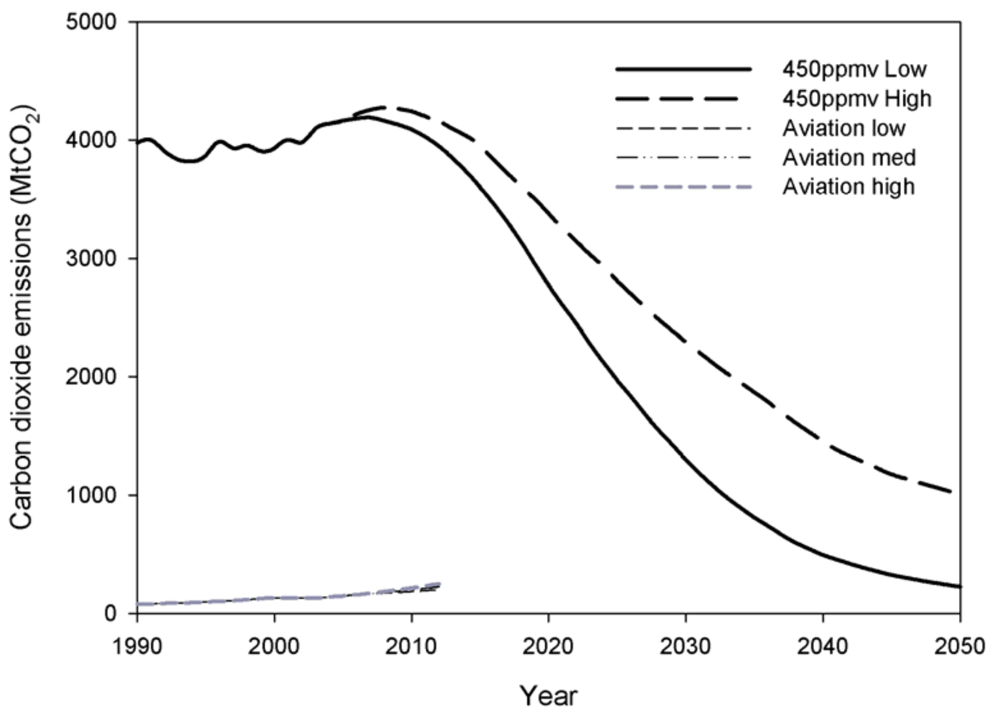

Figure 6: 450ppmv cumulative carbon dioxide emission profiles for the EU25 and the three aviation emissions scenarios.

3. Including aviation within the EU ETS

This section presents scenarios that explore the inclusion of aviation within the EU ETS, initially for the period up to 2012, and later between 2012 to 2050. To include aviation within the scheme, the Commission propose the baseline above which the industry must buy emission allowances be placed at the 2004-2006 level. In other words, any CO_2 emitted above the 2004-2006 level will need to be purchased by the industry from the market. However, the UK Government is also exploring the possibility of employing alternative baseline dates.

In this study, three different baselines are explored – one for 1990, one for 2000 and one for 2005. The first part of this section describes how these baselines were derived. The scenarios developed in the previous section are then compared with the baselines to illustrate the levels of emissions that will need to be purchased by the industry if all departing and arriving flights are included within the scheme.

The second half of this section begins by developing a suite of aviation scenarios from 2012 to 2050 commensurate with a world striving to live within the 450ppmv carbon budget. These scenarios incorporate a range of growth rates and assumptions related to fuel efficiency and, in the longer term, the inclusion of alternative low-carbon fuels. The cost of these different scenarios under a range of carbon allowance prices is also considered. In addition, some qualitative and quantitative analysis is undertaken to investigate what the impact might be on the cost of an air ticket for selected exemplar flights. Finally, the aviation scenarios are compared with the overall 450ppmv carbon budget for the EU25.

3.1 Short-term scenarios

3.1.1 Deriving baselines

Within the EU's discussions to include aviation within the Emissions Trading Scheme, it is proposed that emissions attributable to all flights within and between EU nations and, in addition, all emissions for flights (arriving and departing) between the EU and non-EU nations (COMM, 2007) will be included. Unfortunately, the data submitted to the UNFCCC for aviation activities does not differentiate between intra-EU flights and those flights between EU nations and non-EU nations. Other studies that have considered the inclusion of aviation within the EU ETS have therefore employed modelling techniques to produce the starting baseline (Wit et al., 2005; ICF Consulting, 2006; IATA, 2007).

Within the analysis presented here, where available, empirical data is used in preference to modelled data. However, it has proved necessary to use some of the model output calculated within the EU's own study 'Giving Wings to Emissions Trading' (Wit et al., 2005). Nevertheless, the method used to derive the baseline data is based on a considerable degree of empirical data, as explained below, and therefore provides a robust alternative assessment of the baselines to be considered.

Clearly, to estimate the CO_2 emissions from all EU departures and arrivals, the emissions from flights within the EU must be separated from those from international flights between the EU and non-EU nations. For the most recent baseline – 2005, this involves applying the empirical data relating to the aviation fuel submissions to the UNFCCC as a starting point. From this data, an estimate for the CO_2 emissions attributable to the EU25's domestic aviation (i.e. emissions relating to flights within each individual EU25 nation such as a flight from Manchester to London) can be made. Secondly, from the data submitted as a memo to the UNFCCC in relation to international aviation bunker fuels, it is possible to determine a value for the total EU25 bunker fuel CO_2 emissions attributable to aviation for non-domestic flights. Aggregating these figures from domestic and international aviation gives a resultant CO_2 estimate for all domestic flights and departures from EU nations.

To avoid double counting of emissions between EU nations, the intra-EU flight CO_2 (not including domestic flights) is removed from the international bunker figure[4]. The intra-EU CO_2 estimate is based on the modelled data within 'Giving Wings' document and extrapolated for one year given knowledge on the CO_2 trend. In addition, emissions from flights between the EU and ultra-peripheral EU regions, and to overseas EU countries and territories must also be subtracted from the international bunker figure. Subtracting these emissions from the total bunker figure gives a figure for 50% of CO_2 from flights between EU nations and non-EU nations.

To account for all arrivals and departures, this figure must be doubled. The final baseline figure can then be obtained by adding this figure to the domestic CO_2 UNFCCC emission figure and the intra-EU CO_2 modelled emission figure. The results using this method are presented in Table 3. Two further baselines, one for 1990 and one for 2000 are also calculated for this analysis. In these cases, the intra-EU data required was not available and trend data from the CO_2 emissions inventories submitted to the UNFCCC are used to estimate the intra-EU figures[5]. The results for these years are also presented in Table 3.

Table 3: CO_2 emissions from all flights that either depart or arrive in the EU

[4] Data within the Giving Wings document is calculated to 2004, therefore the 2005 intra-EU figure was extrapolated from the existing trend data from submissions to the UNFCCC in 2007

[5] It is not ideal to extrapolate trend data from either international or domestic submissions to the UNFCCC to intra-EU flights. However, clearly the change in emissions from these flights will reflect both trends, and is not likely to be considerably different from the international CO2 trends. As with all estimates, the figures for 1990 and 2000 are therefore meant as guides to the actual baseline data.

UNITS: $MtCO_2$		**1990**	**2000**	**2002**	**2003**	**2004**	**2005**
UNFCCC international aviation bunker CO_2[6]	Empirical	64.8	111.0	111.4	109.6	117.6	124.3
UNFCCC domestic aviation CO_2	Empirical	17.8	24.2	22.6	22.6	23.6	25.3
Intra EU flight CO_2 (EU to EU, not domestic)	Modelled	19.3	36.0	34.0	36.3	38.0	40.2
EU to EU ultra peripheral regions CO_2	Modelled	4.8	8.9	8.4	8.2	8.2	8.1
EU to EU overseas countries & territories CO_2	Modelled	0.5	0.9	0.8	1.0	0.9	0.9
Derived starting aviation CO_2 value	Derived from empirical and model data	**122.8**	**200.4**	**202.2**	**196.3**	**211.6**	**224.7**

3.1.2 Aviation emission scenarios relating to the EU ETS

In Section 2, three aviation scenarios were described relating to different possible growth rates between 2006 and 2012. These growth rates were applied to a baseline figure of $150MtCO_2$, which is an estimate of 50% of CO_2 emissions from all EU departures and arrivals. However, in considering aviation in relation to the EU ETS, as described above, all arrivals and departures are to be included. Accordingly, the growth rates presented in Section 2 are applied to the new EU ETS-specific baselines that were presented in Table 3. The resulting scenarios up to 2012 are illustrated in Figure 7.

[6] 2007 submission

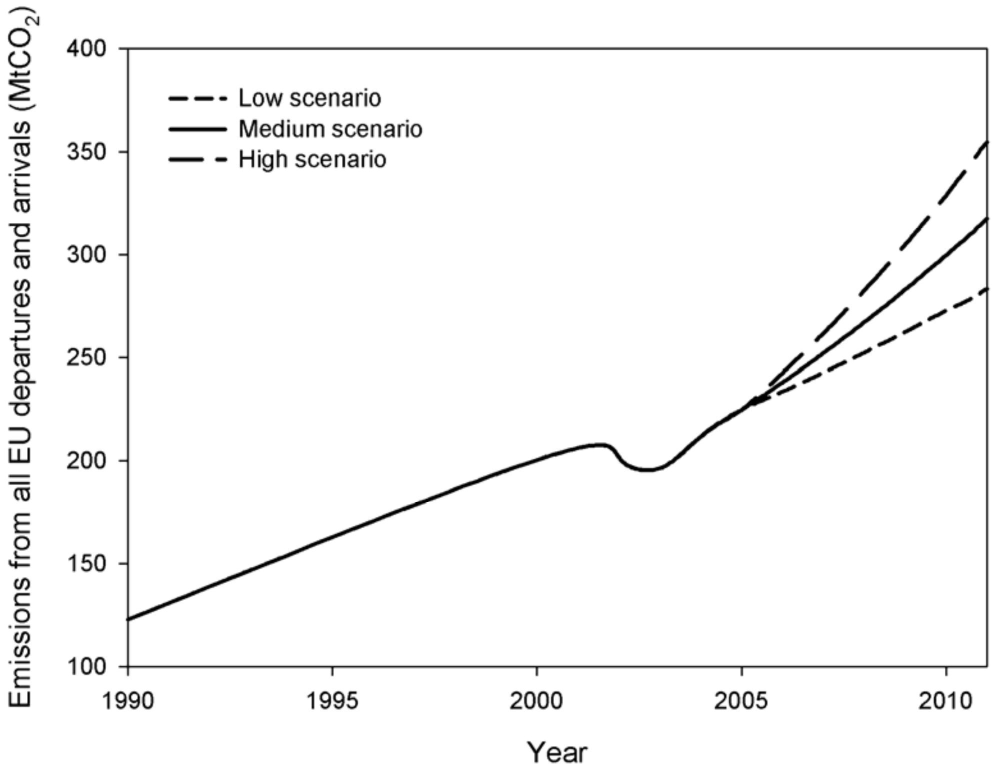

Figure 7: Aviation CO_2 emissions for all departures and arrivals under a range of growth rates. This range is the same as that applied to the UNFCCC data presented in Figure 5.

This figure is more stylised than Figure 5 due to an absence of data points between 1990 and 2000. Clearly, when the scenario growth rates are applied to a higher starting baseline, the final CO_2 emissions in 2012 will be somewhat higher than if only 50% of flights were included within the scheme. allows comparison between the CO_2 emissions in 2012 from using 50% of flights with the 'pure' UNFCCC data and the CO_2 emissions when all departures and arrivals are included.

In terms of how these growth rates compare with other studies, Tables 4 and 5 provide data from a range of sources for total emissions in the period up to 2012. Table 4 provides a comparison in terms of the resultant emissions at the end of 2011 and actual or implied growth rates over the timescales used in the studies. As can be seen from the table, studies vary in terms of the timescales and baselines used and also with nature of departure and destination covered, producing differences in resulting emissions.

Table 4: Comparison of emission growth rates between scenarios and studies

Study/Scenario	**Coverage**	**End of 2011 emissions ($MtCO_2$)**	**Implied annual emission growth rate**
Tyndall low	All flights to and from EU	284	4% from 2006 to 2012
Tyndall medium	All flights to and from EU	318	6% from 2006 to 2012
Tyndall high	All flights to and from EU	355	8% from 2006 to 2012
IATA	All flights	283.8	3.9% from 2005 to 2012
IATA	Intra-EU flights	71.4	3.5% from 2005 to 2012
EU Giving Wings	Intra-EU (including uplift multiplier)	71	4% annually from 2008 to 2012
EU Giving Wings	Flights from EU (CO_2 only)	178.5	4% annually from 2008 to 2012
EU Giving Wings	EU Airspace (CO_2 only)	156.5	4% annually from 2008 to 2012
DEFRA Option 1	Intra-EU (including uplift multiplier)	71	Unclear (report does not give baseline)
DEFRA Option 2	Flights from EU (CO_2 only)	178.5	Unclear (report does not give baseline)
DEFRA Option 3	EU Airspace (CO_2 only)	156.5	Unclear (report does not give baseline)

Clearly, in comparing like with like in terms of the geographical coverage (arrival and departure), the largest factor responsible for differences in estimates appears to be the rate of growth that is assumed in the studies. Table 5 provides the growth rates assumed in this analysis (to derive the low, medium and high growth) and also those used in the Commission's study. Here it can be seen that the Tyndall low and medium scenarios reflect the range of growth scenarios implied by studies such as that undertaken by the Commission, with the high scenario appropriately reflecting growth rates in excess of these (at the higher end of the spectrum).

Table 5: Comparison of emission growth rates between the EU Commission study and the Tyndall scenarios

Study	Coverage	Period	Annual average emission growth rate
Tyndall low scenario	All flights to and from the EU	2006-2012	4%
Tyndall med scenario	All flights to and from the EU	2006-2012	6%
Tyndall high scenario	All flights to and from the EU	2006-2012	8%
EU Commission	Intra EEA flights	2005-2010	5.1%
EU Commission	All departing flights from the EEA	2005-2010	5.2%
EU Commission	Intra EEA flights	2010-2015	3.9%
EU Commission	All departing flights from the EEA	2010-2015	3.9%
EU Commission	Intra EEA flights	2015-2020	3.1%
EU Commission	All departing flights from the EEA	2015-2020	3.3%

3.1.3 Baselines and 2012 allowances

Based on these scenarios, by the end of 2011, the aviation sectors emissions range between around 284 and 355 $MtCO_2$. Three baselines of 1990, 2000 and 2005 for aviation emissions are considered here, and Table 7 presents the allowances that need to be purchased in 2012 compared with the three baselines.

Table 6: Emissions allowances to be purchased in 2012 under the range of Tyndall scenarios

Baseline year	Emissions in baseline year ($MtCO_2$)	Emissions in 2012 ($MtCO_2$)	Emissions to be purchased ($MtCO_2$)
1990	123	284 - 355	161-232
2000	200	284 - 355	84-155
2005	225	284 - 355	59-130

Clearly the earlier the baseline year, the more allowances must be purchased by the industry. In fact, the aviation sector has grown so significantly since 1990 that the emissions allowances that would need to be purchased are in excess of the total amount of emissions released in 1990. The range is somewhat lower for the 2005 baseline, where between 59 and 130 million allowances must be purchased by the industry. The cost to the industry will depend on the price of carbon on the market. This will be discussed in the next section.

3.2 Medium-long term scenarios

In considering aviation emission scenarios for the medium (2017-2030) to long-term (2031-2050), not only must a range of assumptions be made in relation to the aviation industry, but attention must also be paid to overarching EU policy climate.

In aiming for a 450ppmv stabilisation level, it is assumed here that:

i. The EU adopts a comprehensive and scientifically literate basis for its climate policy derived from a cumulative carbon budget approach;
ii. It has a complete account of all sectors; and
iii. It uses a Contraction and Convergence regime (Meyer, 2000) with a convergence date of 2050 to apportion global cumulative emissions to the EU25.

For the aviation sector, three core scenarios commensurate with 450ppmv are considered alongside one illustrative scenario that is outside of the 450ppmv regime. Each of the scenarios are considered from 2012, with differing effects on the aviation sector.[7] Given that the core scenarios are required to be commensurate with the cumulative emissions budget for 450ppmv, it is clear that the sooner the EU responds, the less demanding will be the emissions pathway from that point onwards. To address the problem of growing emissions from the aviation sector, it is assumed that key short-term dates for EU action are 2012 – the date by which aviation is included in EU ETS, and 2017, giving the EU a decade to fully adopt the emission implications of its own targets.

3.2.1 Scenario assumptions

Future aviation emissions are subject to a number of factors:

- the rate of growth in the near term (i.e. now to 2012)
- the rate of growth in the short, medium to long-term (i.e. after 2012); and
- the rate of introduction of new technologies and operational measures that may act to improve the efficiency and carbon intensity of the industry compared to the present.

Accordingly, building on the three (low, medium, high) near term scenarios to 2012 (discussed in Section 2) we have sought to develop a series of scenarios that reflect the range of reasonable and optimistic possibilities for the short, medium and long-term post 2012. These scenarios have been called:

- Indigo;
- Aqua;
- Violet; and
- Emerald.

[7] Since there are already three scenarios from 2006 to 2012, this will result in nine scenarios overall in line with a 450ppmv future, and three additional scenarios outside of this remit.

In each case, the four scenarios are divided into three time periods after 2012 as follows:

Short-term	Start of 2012 to the start of 2017	5 years
Medium-term	Start of 2017 to the start of 2031	13 years
Long-term	Start of 2031 to the start of 2051	20 years

Three of the scenarios (Indigo, Aqua and Violet) are based on an assumption that the EU is committed to meaningful 450ppmv carbon budget, and that aviation will play its part in that process. Consequently, all these scenarios assume the significant reductions in the CO_2 emitted per passenger-km flown (CO_2/pax), as presented in Table 7; these combine to give a reduction in CO_2/pax for 2012 -2050 of 68.5%. The overarching context of this reduction in carbon intensity is society's explicit and genuine commitment to a 450ppmv pathway.

Table 7: CO_2/pax improvement per period

	Short	**Medium**	**Long**
Mean annual improvement in CO_2/pax	1.5%	2%	4%
Total improvement of the period	7% in 5 yrs	23% in 13yrs	56% in 20 yrs

It should be noted that there is some confusion in relation to the improvements that have been demonstrated historically by the aviation industry, and future fuel burn targets, such as those set by ACARE. For example, within the IPCC's special report on aviation, it is stated that aircraft fuel efficiency improvements have been of the order of 1-2% per year, with a 70% improvement from 1950-1997 [Section 7.2.4, (Penner et al., 1999)]. This measurement is in improvements to available seat kilometres per kg of fuel burnt for a new aircraft in 1997 compared with one in 1950. In the case of the ACARE target however, they are suggesting a 50% improvement in CO_2/seat km by 2020 for a new aircraft compared with one in 2000. This is equivalent to a 3.4% per year improvement in the amount if CO_2/seat km. Further points to note include:

- Seat kilometres are not equivalent to passenger kilometres as they do not take into account changes in the load-factor of the aircraft – i.e. how full it is.
- A 1% per year increase in the number of seat kilometres per kg of fuel burnt is not the same as a 1% decrease in the number of kg of fuel burnt per seat kilometre
- Improvements to the amount of CO_2 produced per passenger km is affected not only by improvements in fuel efficiency but also by switching to alternative fuels
- The percentage figures in Table 7 refer to the whole fleet of aircraft operating in and out of the EU, rather than a single new aircraft compared with one from an earlier year.

The Greener by Design study highlights a number of areas that could offer substantial improvements in terms of the fuel burn saved per seat km (for a new aircraft compared with an older one in the case of technological measures). (Green, 2005a). For example, in the short to medium-term, air traffic management improvements could offer an 8% reduction in fuel burn, open rotor engines of the type currently being discussed by Easyjet could improve fuel efficiency by some 12% and the use of lighter materials such as carbon-fibre could offer an additional 15-65% improvement. Indeed the latest *Dreamliner* aircraft produced by Boeing and due to begin operations in the coming few years could improve the fuel burnt per passenger by some 27% compared with comparative existing Boeing models, according to Boeing sources.

In the longer term, laminar flow-type aircraft designs could reduce fuel burn by over 50% and alternative fuels, although generally believed unlikely to be used across the fleet prior to 2030, could play a role to reduce aviation's CO_2 emissions, if the drive towards a low-carbon economy was strong enough. Even in the very short-term, small steps are being taken, for example, Virgin Atlantic plan to fly an aircraft propelled by biofuel in 2008. It is the timescale over which the gains in fuel efficiency and the incorporation of new low-carbon fuels into the mix can be achieved that is of key importance, as this has a knock-on affect on how quickly improvements are exhibited across the aircraft fleet.

In terms of these Tyndall scenarios, technological improvements in efficiency coupled with a variety of air traffic management and operational changes provide the principal components of the reducing CO_2/pax during the first two periods (2012-2017 and 2018-2030). Typical changes include continued incremental jet-engine improvements and the incorporation of rear-mounted open rotor engines particularly for shorter-haul flights. Airframe modifications to wing design to improve air flow and hence fuel burn and increasing amounts of materials used to reduce the weight of the aircraft. It is also assumed that there will be additional load-factor increases, and a series of efficiency gains across the air traffic management system through more direct routing, reduced taxiing, waiting and circling, and reduced use of the auxiliary power unit.

It is assumed that fuel switching is a minor component within the two earlier periods, but increases significantly in the third period (2031-2050). In this long-term period, fuel efficiency improvements across the fleet continue to be of the order of 2% per year, with the remaining 2% being derived from fuel switching to a low carbon fuel such as biofuel or hydrogen for example. If all of the fuel switching were to biofuel, the amounts implied would be in line with previous constraints set by Friends of the Earth for the amount of biofuel that can be used sustainably[8].

In considering these assumed efficiency savings and the introduction of low-carbon fuels, it must be noted that these reflect a situation where the aviation industry goes well beyond its achievements over the previous two decades. However, such significant improvements to the technical, operational and managerial efficiency of aviation are only considered possible when driven by a concerted effort on the part of the industry (and society) to deliver them. The incorporation of low-carbon fuels in the post-2030 period will, in addition to incremental technological and operational development, require a considerable amount of innovation and fleet-wide take-up.

[8] Constraints for the UK were set at around 20Mtoe per year from 2030 to 2050 within the Living within a Carbon Budget work. It is assumed here that similar amounts of biofuel per head across the EU are considered reasonable.

In terms of drivers for such a change, the three scenarios reflect a society who's focus is very different from that of today, for example: the news may finish with carbon reductions achieved and not FTSE movements etc, and GDP may be of secondary importance compared with carbon adaptation and mitigation progress. Within such a society, low-carbon innovation would receive very significant funding and policies would be in place to regulate low-carbon behaviour and operation within companies. The difference in emphasis of this world from ours is central to the scenarios within this report. Therefore it is worth reiterating that the carbon intensity improvements within the scenarios are well in excess of what has occurred within most fleets in recent times but are in keeping with what is possible (Green, 2005b) if the right suite of incentives were in place.

In terms of the other variables reflected in the scenarios, while the three scenarios (Indigo, Aqua and Violet) all have the same level of carbon intensity improvement, each differs in the rate of passenger growth. These factors combine to produce different emission changes between 2012 and 2050 which, in combination with the low, medium and high growth scenarios for the near-term (to 2012) set out in Section 2, produce a range of possible net CO_2 emissions from aviation.

A fourth scenario (named Emerald) differs from the others in terms of both passenger growth and technological efficiency improvements. This scenario reflects only partial commitment to both curbing passenger growth rates and instigating the technological efficiency improvements described above, and is highly unlikely to be compatible with a 450ppmv pathway.

Each scenario and the embedded assumptions is described below.

INDIGO

This scenario is the most responsive to the climate change issue and the EU ETS and shows a significant, comprehensive and early drive towards a low-carbon aviation industry within the EU. Net aviation emission change between 2012 & 2050 equates to a *45% reduction,* though compared with 1990, it still represents a 24%- 55% increase*.*

Table 8: Indigo passenger-km growth and carbon intensity improvements

INDIGO	Short	Medium	Long
Annual pass-km growth	3%	1.5%	1%
Annual CO_2/pax(op & tech) improvement	1.5%	2%	4%[9]
Annual emissions change	1.5%	-0.5%	-3%

[9] This figure is assumed to be based on ongoing technical improvements in the efficiency of the fleet mean combined with a gradual shift towards low/zero carbon fuels.

AQUA

Aviation responds more slowly to the EU ETS scheme, compensated by slightly larger reductions by other sectors. Net aviation emission change between 2012 & 2050 equates to a *16% reduction,* though compared with 1990, it represents a 95% to 144% increase.

Table 9: Aqua passenger-km growth and carbon intensity improvements

AQUA	Short	Medium	Long
Annual pass-km growth	4%	3%	2%
Annual CO_2/pax(op & tech) improvement	1.5%	2%	4%[9]
Annual emissions change	2%	1%	-2%

VIOLET

The aviation industry continues to grow its emissions at a higher rate than in the Indigo and Aqua scenarios at the expense of the other sectors in the EU ETS. The net aviation emission change between 2012 & 2050 equates to a *26% increase,* and compared with 1990, a 184% to 256% increase.

Table 10: Violet passenger-km growth and carbon intensity improvements

VIOLET	Short	Medium	Long
Annual pass-km growth	5%	4%	3%
Annual CO_2/pax(op & tech) improvement	1.5%	2%	4%[9]
Annual emissions change	3.5%	2%	-1%

EMERALD

This additional set of scenarios is used to illustrate a future where the current rhetoric on climate change is only partially converted into meaningful action. Such a future would be more attuned to cumulative emissions associated with much higher CO_2 concentrations and a complete failure to respond to the 2°C commitment. In this case, the net aviation emission change between 2012 & 2050 equates to a *146%* increase, and compared with 1990, a 278% to 373% increase. Assumptions behind these growth rates include new EU nations at least expanding their aviation industries towards per capita rates of old EU nations. For example, the mean number of passengers travelling in the EU15 nations per head of population is 1.74, whereas in the EU10 nations it is 0.44, with the mean for the EU being 1.53. If the EU10 nations were to increase to the EU mean today, then this would create a further 11 million passengers.

A modified version of the low-cost model is also assumed to extend to medium and long-haul flights. Point-to-point aircraft (Boeing Dreamliner etc) in combination with the expansion of regional airports is assumed to provide much quicker and convenient air travel for all. Security becomes less of an obstacle to flying and big improvements in check-in improve the quality of experience for the traveller. Furthermore, flying expands to increase the number of flyers from the C, D and E social groups. Increasing globalisation stimulates more migration and consequently international travel to maintain family ties. In economic terms, world GDP growth continues and the EU exits its period of economic stagnation and the EU economy begins to grow at 2.5 – 3% p.a. Although it is impossible to paint an accurate picture of a business as usual future for aviation emissions, the Emerald scenario represents the closest to an extrapolation of current trends of all the scenarios.

Table 11: Emerald passenger-km growth and carbon intensity improvements

EMERALD	Short	Medium	Long
Annual pass-km growth	6%	5%	3%
Annual CO_2/pax(op & tech) improvement	1%	1.5%	2%[10]
Annual emissions change	5%	3.5%	1%

3.2.2 Scenario emissions

When combined with the three near term growth scenarios (low, medium and high) described in Section 2, the scenarios described above result in a full set of nine core scenarios, with a further three for the Emerald set. The resulting net CO_2 emissions for all twelve scenarios are provided in Figure 8.

[10] With less of an incentive to combat climate change, it is assumed that progress towards both better efficiency and low-carbon fuels is slower than in the other scenarios.

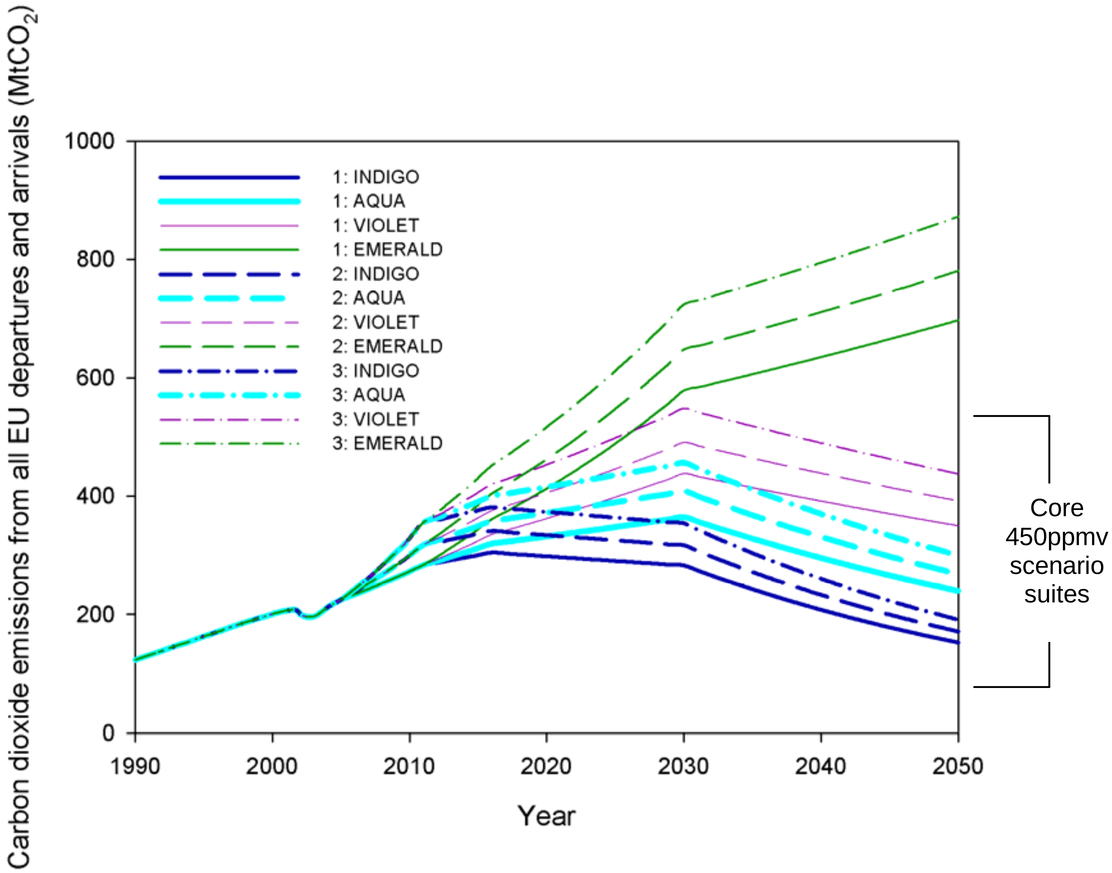

Figure 8: Carbon dioxide emissions from the nine core scenarios (Indigo, Aqua and Violet for pre-2012 near term growth scenarios low-1, medium-2 and high-3) in blues and purples, and the three illustrative higher growth scenarios (Emerald for pre-2012 near term growth scenarios low-1, medium-2 and high-3) shown in green.

Scale of emissions in relation to a 450ppmv budget

In terms of a comparison with total emissions consistent with a 450ppmv budget, it would be unreasonable to compare scenarios that include more than 50% of international flights both to and from the EU with an overall EU 450ppmv carbon budget. However, it is possible to compare the UNFCCC 50% aviation emissions, grown by the same increases as the scenarios presented above with this budget. Figure 8 provides calculated emissions associated with all the scenarios that reflect a concerted effort to reduce aviation emissions (Indigo, Aqua and Violet).

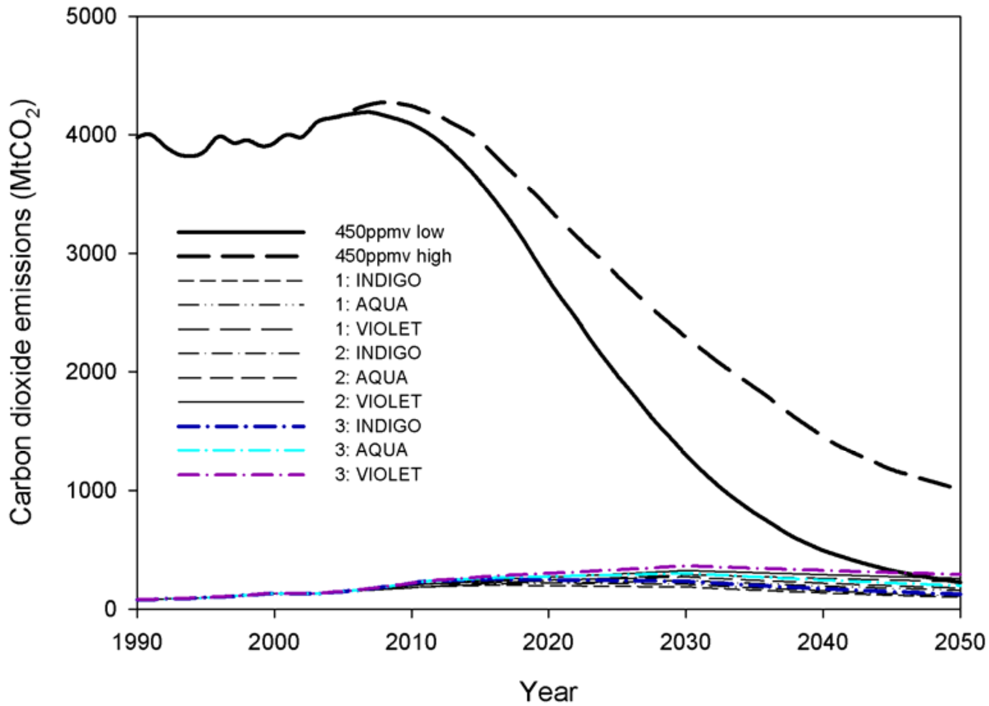

Figure 9: Carbon dioxide emission budgets for 450ppmv compared with aviation emissions scenarios based on the UNFCCC data to account for 50% of international flights and all domestic and intra-EU flights.

This graph illustrates that unless very low growth rates and substantial improvements to carbon efficiency are achieved, aviation emissions will likely exceed the 450ppmv 'low' pathway by the late 2040s (i.e. the Violet scenario exceeds the 450ppmv curve, whilst Indigo is within the 2050 budget). For the 450ppmv 'high' pathway, the emissions from aviation account for at best 10% and at worst 29% of the total budget for all sectors and all emissions.

It is clear from the analysis that all scenarios of the aviation industry within a world striving to achieve a 450ppmv future (Indigo, Aqua and Violet) reflect an increase in CO_2 levels in 2050 compared with 1990. This is in sharp contrast to the other sectors of the economy, where 75 to 90% reductions from 1990 levels have been required.

3.2.3 Financial analysis

In order to investigate the scale of carbon price necessary to bring about the growth and efficiency changes embedded in the scenarios, a basic and illustrate analysis has been carried out in relation to three different emission baseline levels, for three typical flight lengths. The price of carbon is varied to provide a range of possible impacts on flight price.

The first stage in the analysis has been to compare the emissions over different time periods with the baseline levels for 1990, 2000 and 2005 previously presented in Table 3. As the Aqua scenario lies between Indigo and Violet, the results for Indigo and Violet only are presented to give an idea of the min/max range. The resulting carbon permits that must be purchased are presented below in Table 13.

Table 12: Emissions of CO_2 that need to be purchased under different scenario assumptions and different baselines.

INDIGO						
Baseline dates	**Baseline emissions ($MtCO_2$)**	**Emissions in particular year ($MtCO_2$)**				
		2005	**End 2011**	**End 2016**	**End 2030**	**End 2050**
		225	283	305	284	153
		Emissions to purchase ($MtCO_2$)				
1990	123	102	161	182	162	30
2000	200	24	83	104	84	-48
2005	225	0	59	80	60	-72
VIOLET						
Baseline dates	**Baseline emissions ($MtCO_2$)**	**Emissions in particular year ($MtCO_2$)**				
		2005	**End 2011**	**End 2016**	**End 2030**	**End 2050**
		225	355	420	538	437
		Emissions to purchase ($MtCO_2$)				
1990	123	102	232	297	415	315
2000	200	24	154	219	337	237
2005	225	0	130	195	313	213

To estimate what the additional cost of a typical flight might be (assuming that all costs are passed on to the passenger) a range of carbon prices for these permits has been considered.

Although carbon prices above €50 have yet to materialise, the premise of this report is that the EU is genuinely committed to 450ppmv. Within this in mind, it is assumed that between 2012-2017 carbon prices are €50-€100, increasing in the longer term to €100 to €300. These prices broadly reflect the higher ranges of values discussed within the literature [p.323 (Stern, 2006)];(Uyterlinkde et al., 2006).

Typical emissions per passenger data is used to provide indicative costs per passenger for flights. Clearly, as carbon intensity improves over time in line with the figures presented in Table 7, so the carbon emissions per passenger will fall for the same flight. For three exemplar flights, Table 13 presents the carbon emissions over time relating to the carbon efficiency improvements.

Table 13: Tonnes of CO_2 per passenger for 3 example flights in 2005 and then in the scenario periods.

	Tonnes of CO_2 per passenger in different years with different carbon efficiencies from Table 8				
One way flight	**2005**	**End 2011**	**End 2016**	**End 2030**	**End 2050**
Short haul (e.g. London – Barcelona)	0.25	0.235	0.218	0.164	0.073
Medium haul (e.g. London – Washington)	1	0.941	0.873	0.658	0.291
Long haul (e.g. London – Sydney)	2	1.883	1.746	1.316	0.582

Finally, to estimate the indicative typical cost per passenger, the percentage of a flight's carbon emissions for which permits are required to be purchased can be applied to the data in Table 13 for the lowest growth scenario, Indigo, and the highest growth scenario, Violet. The percentage of carbon emissions per flight to purchase are presented in Table 14 followed by the typical costs per flight in Table 15 for Indigo and Table 16 Violet.

Table 14: Percentage of permits that would need to be purchased for the lowest Indigo and highest Violet scenarios.

INDIGO				
Baseline dates	**Percentage of the carbon on a flights that needs to be purchased due to different baselines**			
	End 2011	**End 2016**	**End 2030**	**End 2050**
1990	57%	60%	57%	20%
2000	29%	34%	30%	-31%
2005	21%	26%	21%	-47%
VIOLET				
Baseline dates	**Percentage of the carbon on a flights that needs to be purchased due to different baselines**			
	End 2011	**End 2016**	**End 2030**	**End 2050**
1990	65%	71%	77%	72%
2000	44%	52%	63%	54%
2005	37%	46%	58%	49%

Table 14 illustrates that by the end of 2011, between 57% and 65% of emissions must be purchased if 1990 is to be the chosen baseline. Whereas, 21% to 37% would need to purchased if 2005 were the baseline. As these scenarios are designed to be consistent with a 450ppmv future, the later periods for the very low growth Indigo scenario could potentially see the industry recompensed, unless 1990 is the chosen deadline. For the Violet scenario, with its higher growth rate than Indigo, 72% of the carbon from a flight would need to be purchased by the end of 2050 under the 1990 baseline, or 49% if the EU ETS incorporated the 2005 baseline within the scheme. One simplification of this approach is that it assumes the carbon intensity improvements are the same across all types of flight; this is adequate for producing indicative costs.

Table 15: Typical prices for exemplar flights over different periods and baselines for the lowest Indigo scenario. The '--'s in the table below illustrate that, within a 450ppmv budget, a value of € 50 per tonne is unrealistic post-2030. Similarly, much higher carbon prices of € 300 are unlikely in the period prior to 2012.

INDIGO					
1990 BASELINE					
Carbon prices for different types of typical flights					
Carbon price		**End 2011**	**End 2016**	**End 2030**	**End 2050**
€ 50	**Short-haul**	€ 7	€ 7	--	--
	Medium-haul	€ 27	€ 26	--	--
	Long-haul	€ 53	€ 52	--	--
€ 100	**Short-haul**	€ 13	€ 13	€ 9	€ 1
	Medium-haul	€ 53	€ 52	€ 37	€ 6
	Long-haul	€ 107	€ 104	€ 75	€ 11
€ 300	**Short-haul**	--	€ 39	€ 28	€ 4
	Medium-haul	--	€ 156	€ 112	€ 17
	Long-haul	--	€ 313	€ 224	€ 34
2000 BASELINE					
Carbon price		**End 2011**	**End 2016**	**End 2030**	**End 2050**
€ 50	**Short-haul**	€ 3	€ 4	--	--
	Medium-haul	€ 14	€ 15	--	--
	Long-haul	€ 28	€ 30	--	--
€ 100	**Short-haul**	€ 7	€ 7	€ 5	-€ 2
	Medium-haul	€ 28	€ 30	€ 19	-€ 9
	Long-haul	€ 55	€ 60	€ 39	-€ 18
€ 300	**Short-haul**	--	€ 22	€ 15	-€ 7
	Medium-haul	--	€ 90	€ 58	-€ 27
	Long-haul	--	€ 179	€ 117	-€ 55
2005 BASELINE					
Carbon price		**End 2011**	**End 2016**	**End 2030**	**End 2050**
€ 50	**Short-haul**	€ 2	€ 3	--	--
	Medium-haul	€ 10	€ 11	--	--
	Long-haul	€ 20	€ 23	--	--
€ 100	**Short-haul**	€ 5	€ 6	€ 3	-€ 3
	Medium-haul	€ 20	€ 23	€ 14	-€ 14
	Long-haul	€ 39	€ 46	€ 28	-€ 27
€ 300	**Short-haul**	--	€ 17	€ 10	-€ 10
	Medium-haul	--	€ 69	€ 41	-€ 41
	Long-haul	--	€ 138	€ 83	-€ 82

Table 15 and Table 16 illustrate the typical additional costs per passenger for a one-way flight under the Indigo and Violet Scenarios. Clearly, if emissions permits were calculated in relation to the 1990 baseline, this would result in higher costs (and price signal).

However, in terms of the magnitude of the price signal, even in the case of the higher growth scenario (Violet) and even assuming that all costs were passed on to the passenger, it is suggested that an additional €8 to €15 is unlikely to significantly influence passenger growth rates (the €15 figure, equates to a carbon price of €100 per tonne).

For the longer-haul flights, the maximum additional premium would be €371 if 1990 were to be the baseline, and emissions were to grow in line with the Violet scenario. The permit price in this case is €300 – an order of magnitude higher than other studies typically expect in the future. Only at such a level, and with an early baseline, is there likely to be a sufficient price signal to significantly curb the growth in emissions from the aviation sector. When considering the 2005 emission baseline, it is probable that carbon prices would have to rise well above €300 per tonne to have a significant influence growth.

The Violet scenario figures in Table 16 add an additional €30 to a short-haul flight by the end of 2016, €122 to a medium-haul flight and €243 to a long-haul flight (all at €300 per tonne). The respective figures are €5, €20 and €41 at the lower carbon price of €50 per tonne. Here, again, price signals from even high estimates of carbon prices would not seem to be sufficient to produce the required effect.

Table 16: Typical prices for exemplar flights over different periods and baselines for the highest Violet scenario.

VIOLET					
1990 BASELINE					
Carbon prices for different types of typical flights					
Carbon price		**End 2011**	**End 2016**	**End 2030**	**End 2050**
€ 50	**Short-haul**	€ 8	€ 8	**--**	**--**
	Medium-haul	€ 31	€ 31	--	--
	Long-haul	€ 62	€ 62	--	--
€ 100	**Short-haul**	€ 15	€ 15	€ 13	€ 5
	Medium-haul	€ 62	€ 62	€ 51	€ 21
	Long-haul	€ 123	€ 124	€ 102	€ 42
€ 300	**Short-haul**	--	€ 46	€ 38	€ 16
	Medium-haul	--	€ 185	€ 152	€ 63
	Long-haul	--	€ 371	€ 305	€ 125
2000 BASELINE					
Carbon price		**End 2011**	**End 2016**	**End 2030**	**End 2050**
€ 50	**Short-haul**	€ 5	€ 6	--	--
	Medium-haul	€ 20	€ 23	--	--
	Long-haul	€ 41	€ 46	--	--
€ 100	**Short-haul**	€ 10	€ 11	€ 10	€ 4
	Medium-haul	€ 41	€ 46	€ 41	€ 16
	Long-haul	€ 82	€ 91	€ 83	€ 32
€ 300	**Short-haul**	--	€ 34	€ 31	€ 12
	Medium-haul	--	€ 137	€ 124	€ 47
	Long-haul	--	€ 274	€ 248	€ 95
2005 BASELINE					
Carbon price		**End 2011**	**End 2016**	**End 2030**	**End 2050**
€ 50	**Short-haul**	€ 4	€ 5	--	--
	Medium-haul	€ 17	€ 20	--	--
	Long-haul	€ 35	€ 41	--	--
€ 100	**Short-haul**	€ 9	€ 10	€ 10	€ 4
	Medium-haul	€ 35	€ 41	€ 38	€ 14
	Long-haul	€ 69	€ 81	€ 77	€ 28
€ 300	**Short-haul**	--	€ 30	€ 29	€ 11
	Medium-haul	--	€ 122	€ 115	€ 42
	Long-haul	--	€ 243	€ 230	€ 85

4. Discussion and conclusions

In March of this year the EU reaffirmed its commitment to not exceeding the 2°C target. Drawing on this commitment, this study has calculated the implications for the EU's emission-reduction pathway over the next fifty years, with particular focus on what this means for the aviation sector.

The three scenario suites presented in this report (Indigo, Aqua and Violet) reflect calculated emission pathways for the aviation sector that, although representing a growing share of the EU's emissions, could nevertheless be reconciled with a 450ppmvCO_2 pathway.

However, in all cases, these scenarios reflect the situation where there is a concerted effort to produce not only very significant increases in the carbon efficiency of aviation but a curbing of passenger-km growth rates. Further, even though the aviation emissions pathways implied by the scenarios can be reconciled with the 450ppmvCO_2 pathway, it should be noted that this requires that a significant (to a very significant) proportion of the total budget for all sectors and all emissions would have to be used to support aviation by the middle of the 21st century.

Taken together, then, whilst these scenarios are, in principle, achievable, they also represent an urgent and radical departure from:

- complacency over the current level of aviation's emissions; and
- the majority of analyses and passenger growth forecasts for the future of the aviation sector.

The key message to policy makers

The findings of the analysis underpinning this report are stark and will likely make uncomfortable reading for aviation stakeholders on both sides of the debate. The core messages from the study are that:

- *Constrained and responsible growth of the aviation sector can be reconciled with a 450ppmv CO_2 future*

- *Immediate policies are necessary to substantially constrain passenger-km growth in the sector prior to the introduction of the EU ETS*

- *Urgent and radical adjustments to the sector are necessary to bring about substantial efficiency improvements*

- *The carbon price currently being discussed is an order of magnitude too low to stimulate the necessary changes*

- *The EU ETS will require additional and substantial flanking instruments*

More generally, the findings of this report echo those contained within our earlier report on UK emissions futures "living within a carbon budget". We continue to delude ourselves if our aspirations for a 2°C future reside substantially in the current framing of the EUETS and the low-carbon technologies and practices that may engender. Whilst technology undoubtedly has an important medium- and long-term role to play in reducing the carbon-intensity of aviation, it is negligent and irresponsible not to engage with a quantitative characterisation of the sectors short-term emissions growth. The urgency with which the industry must make the transition to a low-carbon pathway leaves no option but to instigate a radical and immediate programme of demand management.

How the EU responds to this most thorny of climate change issues will provide a measure of the seriousness with which it is likely to initiate coherent carbon reduction policies across all sectors. Most importantly, the transition from the EU's rhetoric on climate change to a scientifically-literate policy agenda demands a reframing of the debate in terms of cumulative carbon budgets and accompanying carbon-reduction pathways. Within such a framing, addressing urgently aviation's rapidly escalating emissions becomes a prerequisite of any meaningful carbon-reduction strategy.

4.1 Today's aviation emissions are significant

In 2005 aviation emissions were approximately 150MtCO_2, representing 4% of the EU's total CO_2 emissions. It is such percentages that give rise to the repeated and dangerously misleading claim that "aviation is not a major greenhouse gas polluter" (IATA, 2007). Making simplistic comparisons with other emissions sources conveniently chosen to underplay aviations' contribution to total emissions only serves to confuse an already confusing issue see (IATA, 2007) p.12. The same basis of analysis would suggest that the UK's total transport and power station emissions are also not major sources; similarly the emissions from nations such as Belgium, Greece, Portugal and the Netherlands are too small to be the focus of concerted low-carbon action. Unfortunately, this form of loose thinking is all too prevalent in discussions over climate change. The UK's proportion of world emissions is often cited as only 2% of the global total and, so the argument goes, whatever the UK does is in terms of carbon emissions is of little relevance. Similarly, Beijing, New York, Deli, Paris, and all the other major cities of the world are respectively less than 2% of total emissions. Consequently, this apparent logic would suggest there is little benefit in their implementing stringent carbon-reduction strategies. All (i.e. 100%) emissions are inevitably the aggregate of many much smaller percentages; using this as an excuse for relative inaction will collectively lead to individual, sectoral, national and, ultimately, global apathy. The aviation sector's 4% of EU emissions is therefore already a very significant proportion of total EU emissions, and it is essential it be recognised as such.

4.2 Current aviation growth is unsustainable

Seriously exacerbating the aviation sector's already significant level of emissions is the rate of growth of the sector. Whilst emissions from most sectors are broadly stable,[11] the latest data for EU aviation show increases in emission of between 6% and 7% per annum. This rate of growth is consistent with long-run trends, once corrected for the effects of September 11th 2001. Such rates of emission growth are repeatedly ignored or underestimated by those with a vested interest in the sector's continued prosperity. Currently, the limited constraints on the expansion of the EU's aviation sector are being dwarfed by the drivers for expansion. In the absence of explicit and coordinated action to both constrain growth and increase efficiency it is difficult to envisage the current situation changing appreciably.

4.3 Action required prior to the EU ETS

This reluctance of the EU and aviation stakeholders to engage with the current quantitative characterisation of the sector is evident by the focus and almost complete reliance on the EU ETS post 2011-12 as the mechanism for addressing aviations emissions. However, unless policies are introduced to constrain emissions growth today, the emissions from aviation will likely rise between 25% and 60% above 2005 levels by the time aviation is fully included within the EU ETS in 2012.

4.4 EU Aviation growth within a 450ppmv carbon budget

The scenarios developed within this report not only depart from non-Tyndall analyses of the aviation sector, but also from those previously developed by Tyndall (Bows et al., 2005). The reason for this latter departure is that whilst the earlier scenarios were intended to demonstrate the impact on emissions of applying only moderate constraints to aviation growth, this suite of scenarios is expressly designed to be compatible with a 450ppmv CO_2 pathway. Understanding the importance of this change in emphasis is essential if the scenarios are to provide a useful heuristic for policy makers and other stakeholders. Previous Tyndall scenarios demonstrated the dangers of relative inaction; by contrast these scenarios illustrate what viable aviation emission-pathways may look like, provided radical policies are implemented to constrain emissions growth as a matter of urgency. Currently, both the political and business communities stubbornly refuse to engage with either the quantitative scale of current and future emissions or the necessary timescale for action.

These latest scenarios contain reductions in carbon intensity per passenger-km well above those assumed within all but the industry's more optimistic predictions. This shift from Tyndall's earlier scenarios, with their more conservative efficiency improvements, is a consequence of the latest scenarios being developed for an explicit 450ppmv CO_2 future. Organisations such as Greener by Design (Green, 2005b) identify a raft of opportunities for reducing the carbon intensity at levels not dissimilar to those used

[11] Seldom increasing or decreasing at more than 1-2% per annum.

within this report. However, such organisations both place little emphasis on the scope and scale of policies necessary to bring about the changes they advocate, and have a tendency to rely on technology and ignore the more immediate and short-term benefits of behavioural and operational adjustments. The analysis within this report begins to sketch out the necessary scope and scale of policies; with an early, and inevitably conditional conclusion, being that if price is to be the principal driver, the € per tonne carbon prices currently being discussed are an order of magnitude too low.

4.5 Aviation remains a privileged sector

On first reading of this report the scenarios may appear to place undue constraints on the aviation sector, however, it is important to note that even under the most demanding scenario (indigo), aviation remains highly privileged in relation to emissions. The 450ppmv CO_2 pathway demands aggregate emission reductions from all sectors, compared with 1990, of approximately between 75% and 90% by 2050. By contrast, even the indigo scenario has an emissions increase from the aviation sector in 2050 of between 23% and 53%, compared with 1990. This growth is despite the exceptionally high levels of efficiency and unprecedented reduction in passenger-km growth assumed within the scenario. Such findings illustrate the scale of the challenge facing the EU and its member states and reveal the complete failure of existing policy instruments to address the rapid growth in aviation emissions. Moreover, it exposes the politically-expedient rather than scientifically-literate basis of discussions informing and framing the scale of forthcoming policy instruments. It is imperative this reluctance to actively engage in evidence-based analysis of current and future emissions be reversed if the EU is to meet even the higher 450ppmv emission pathway, let alone the EU's own 2°C commitment.

4.6 An order of magnitude increase in carbon price required

Whilst the EU ETS is an important mechanism for responding to the climate change challenge, this report demonstrates that the carbon prices currently being discussed are wholly inadequate for achieving other than insignificant marginal adjustments to the industry's rate of growth. Current discussions often refer to carbon prices well below €50/tonne, with the latest IATA report [(IATA, 2007) p.3] focussing on values per tonne of CO_2 of between €15 and €33. Within this Tyndall report, such low prices are considered inconsistent with a genuine drive towards an EU 450ppmv CO_2 pathway, and consequently the prices are revised upwards significantly. However, even with the radically higher price of €300 per tonne considered here, the price signal may prove too weak to bring about the growth and efficiency changes embedded within the scenarios. Consequently, a clear conclusion of this report is that the EU ETS, even with carbon prices an order of magnitude higher than those currently being considered by the industry (i.e. €100 to €300 per tonne as opposed to IATA's €15 to €33 figure), and with an early baseline year, may have insufficient impact on reducing current levels of emission growth.

For the carbon-sustainable scenarios developed in this report, carbon prices of €50 to €100 tonne in 2012 equate to a typical short-haul flight (e.g. London to Barcelona) price increase of €2-€15 per passenger, medium haul flights €10-€60, and flights from, for example, the UK to Australia, €40-€120. It is difficult to envisage such small price signals having other than marginal impacts on the rate of growth of aviation emissions. In relation to the more demanding of the report's scenarios (Indigo), the €300 carbon price in 2017 equates to a per passenger supplement for typical short, medium and long haul flights of €15-€40, €70-€155 and €140-€310 respectively. Given the radical departure from aviation's current high emission growth represented by the Indigo scenario, these additional costs are still likely to be insufficient.

4.7 An early baseline year is essential

The effectiveness or otherwise of a reformed EU ETS or other carbon trading regime will likely be highly dependent on the chosen baseline year. If aviation emissions are held within the bounds typified by the Indigo scenario, a 1990 baseline equates to a carbon supplement per passenger of approximately 3 times greater than would be incurred under a 2005 baseline; this holds true until around 2030. For higher emission futures similar to that illustrated by the Aqua scenario, the significance of the baseline year, though reduced, remains important; equivalent to about 1.8 times in 2012 reducing to 1.3 times by 2030. Unfortunately, data for 1990 is less robust than for 2002 and beyond. However, the scale of the impact of the baseline suggests that 1990 data should be revisited in order to develop an early and fair baseline, recognising that data for 1990 will inevitably be less robust than that of more recent times.

4.8 Indirect issues must be considered

Whatever approach is used to reduce the emissions of the aviation sector, it is essential the impact on the second hand market for aircraft is considered. The carbon reductions claimed for an accelerated shift towards new European fleets of more efficient aircraft could be more than negated by the impact a faster throughput of aircraft would have on the global second hand market. This is a non-trivial issue that has received scant regard in all current analyses, yet has the potential to substantially impact on the viability of what may otherwise appear to be sensible low-carbon options.

4.9 Outline recommendations

From this relatively simple 'what-if' economic analysis, a series of options, either alternative or complementary, for reconciling aviation with a 450ppmv CO_2 pathway are evident:

A meaningful EU ETS

- The EU ETS cap to be designed in keeping with a 450ppmv pathway (based on cumulative emissions)
- To maximise the efficiency of the scheme, a high proportion, if not all, carbon allowances to be allocated through a process of auction
- In the absence of meaningful emissions caps on other countries or regions, the EU ETS should be self-contained with no, or extremely limited opportunity, for purchasing carbon credits from elsewhere

Aviation within a meaningful EU ETS

- An early baseline year be a prerequisite for aviations' inclusion in the EU ETS (not later than 1990)
- Aviation must be included in the EU ETS as soon as is possible and stringent constraints on the sector's emission growth be implemented in the interim
- The overall EU ETS cap be sufficiently tight that carbon prices well in excess of €300/tonne are achieved
- To maximise the efficiency by which the aviation industry mitigates carbon, the sector be required to purchase all its carbon permits by auction
- Additional and substantial flanking instruments be implemented to take account of aviation's non-CO_2 climate change impacts

Alternatives to addressing aviation within the EU ETS

- The aviation sector operate within a sector-specific cap; this could be aviation only, or be for all transport modes. The cap be based on the sector making its fair contribution to a 450ppmvCO2 pathway (based on cumulative emissions)
- A very high carbon-related price be imposed on the industry. This could, for example, be in the form of a fuel tax, air passenger duty, or some other innovative charging instrument
- A stringent carbon rationing regime be introduced, for example one of the various forms of personal carbon allowances currently being considered. The quantity of allowances should be accordance with a 450ppmvCO2 pathway (based on cumulative emissions)

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