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A Flight Risk?

Aviation and climate change in Australia

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Summary

The aviation industry has grown substantially since the 1950s and is expected to continue to expand rapidly. In Australia, between 1996 and 2005, domestic passenger numbers increased by 46 per cent and international passenger numbers by 62 per cent. Domestic and international air passenger numbers are expected to grow at 4.6 and 5.1 per cent per annum respectively between 2005 and 2020, ensuring a doubling of passenger numbers in 15 years.

The success of the Australian airline industry is based on buoyant economic conditions. Low-cost carriers have also stimulated additional demand and are expected to increase their market share in coming years. Government policy at the federal and state level is to encourage further expansion of the industry.

Government enthusiasm for the airline industry is increasingly at odds with the objectives of climate change policy. The evidence suggests global greenhouse gas emissions will have to be cut by between 25 and 70 per cent on 2005 levels by 2050 to avoid dangerous climate change. Australia and other developed countries will need to reduce their emissions by more than 60 per cent over this period.

Aviation's contribution to climate change

The Stern Review estimates that aviation emissions accounted for only 1.6 per cent of total global greenhouse gas emissions in 2005. In Australia, aviation emissions in 2004 were 10.9 Mt CO_2-e, or less than two per cent of total emissions. However, these estimates are misleading as they do not account for the impacts of non-CO_2 aviation emissions.

Aircraft emit a number of direct and indirect greenhouse gases, including carbon dioxide (CO_2), nitrogen oxides (NO_x) and water vapour (H_2O). CO_2 is a direct greenhouse gas that mixes well in the atmosphere, remains in the atmosphere for a relatively long time and its impacts on the climate are well-understood.

Difficulties arise in relation to the non-CO_2 emissions. Most non-CO_2 aviation emissions have short atmospheric lifetimes and their impacts vary depending on when and where they are released. In particular, the release of these gases at altitude can magnify their impact on the climate. There is also uncertainty about the nature of the atmospheric effects of non-CO_2 aviation emissions.

Due to these uncertainties, it is very difficult to measure the impacts associated with non-CO_2 emissions and to compare them to those related to CO_2 and other direct greenhouse gases. As a result, non-CO_2 aviation emissions are generally not converted into carbon dioxide equivalents (CO_2-e) and they are excluded from national totals in reports prepared under the United Nations Framework Convention on Climate Change (UNFCCC). Non-CO_2 aviation emissions are also excluded from the targets under the Kyoto Protocol.

To account for non-CO_2 emissions, ‘uplift factors’ are sometimes used. CO_2 emissions from aviation are multiplied by the relevant uplift factor to provide an estimate of total aviation emissions, measured as CO_2-e.

Using uplift factors of 1.7 and 2.7 suggests aviation accounts for 2.5 to 4.0 per cent of total global emissions. The application of the same uplift factors to Australia’s aviation emissions suggest they were 18 or 29 Mt CO_2-e in 2004, or between 3.0 and 5.0 per cent of total emissions.

An alternative measure of aviation’s contribution to climate change is radiative forcing. The best estimates suggest aviation currently accounts for somewhere in the order of three to six per cent of total net anthropogenic radiative forcing.

Although there is considerable uncertainty surrounding its impacts, the evidence suggests aviation is not currently one of the main causes of global warming. However, it threatens to become one in the near future.

Projecting aviation emissions to 2050

Since 1990, world aviation emissions have risen sharply, in some regions by as much as 70 percent. Australia has witnessed a similar trend. If growth in the aviation industry continues under business-as-usual conditions, it could undermine efforts to address climate change.

To gauge the risks associated with continued growth in the aviation sector, this paper makes projections of emissions from aviation in Australia over the period 2005 to 2050 using three main scenarios: two with uplift factors and one without.

- No Uplift Scenario One (NU1) does not apply an uplift factor and assumes there is a 1.2 per cent per annum improvement in the fuel efficiency of the domestic and international airline fleets over the period 2005 to 2050.
- Uplift Scenario One (US1) uses an uplift factor of 1.7 and assumes there is a 1.2 per cent per annum improvement in the fuel efficiency of the domestic and international airline fleets over the period 2005 to 2050.
- Uplift Scenario Two (US2) is the same as US1, except that it uses an uplift factor of 2.7.

It should be noted that the use of uplift factors is controversial because of the difficulties in converting non-CO_2 aviation emissions into CO_2-e. However, there is a consensus that the impacts of aviation are substantially greater than suggested by measurements based solely on emissions of the direct greenhouse gases included in the national totals under the UNFCCC/Kyoto regime.

Under the three scenarios, emissions increase by 267 per cent between 2005 and 2050 – see Table S1.

Table S1 Growth in emissions between 2005 and 2050 under US1, US2 and NU1

Scenario	Emissions in 2005, Mt CO_2-e	Emissions in 2050, Mt CO_2-e
NU1	11.6	42.5
US1	19.5	71.6
US2	31.0	113.8

The incompatibility between business-as-usual conditions in the aviation sector and greenhouse policy can be seen by comparing the emission scenarios to two possible emission reduction target scenarios for 2050 – see Table S2. The first emission reduction target scenario is based on the objective of reducing Australia's emissions by 60 per cent on 2000 levels by 2050, as proposed by the Australian Labor Party. The second scenario is based on the objective of reducing Australia's emissions by 80 per cent on 2000 levels by 2050, which is consistent with a target for the stabilisation of the atmospheric concentration of greenhouse gases at 550 ppm CO_2-e under a contraction and convergence strategy.

Table S2 Growth scenarios versus emission reduction target scenarios in 2050

	NU1	US1	US2
Emissions in 2050, Mt CO_2-e	42.5	71.6	113.8
60 per cent target in 2050, Mt CO_2-e	223.2	223.2	223.2
Proportion of 60 per cent target consumed by aviation in 2050	**19 per cent**	**32 per cent**	**51 per cent**
80 per cent target in 2050, Mt CO_2-e	104.5	104.5	104.5
Proportion of 80 per cent target consumed by aviation in 2050	**41 per cent**	**69 per cent**	**109 per cent**

As Table S2 shows, if the Australian aviation sector is allowed to continue to operate under business-as-usual conditions and Australia adopts a target of reducing emissions to 60 per cent below 2000 levels by the middle of this century, aviation could account for between 32 and 51 per cent of the total greenhouse gas allowance by 2050. If the reduction target is set at 80 per cent below 2000 levels by 2050, aviation could account for more than Australia's entire emission allowance.

Policy responses

Unlike many other industries, there are few available technological options for reducing aviation's contribution to climate change. Even if unforeseen technological solutions emerge, it will take decades for them to be implemented. The absence of technological options means that to address the issues associated with aviation emissions, the demand for air travel will have to be constrained. Few industries are willing to voluntarily reduce growth in order to address environmental concerns. Therefore, mandatory measures need to be introduced.

In the first instance, governments should cease facilitating and promoting the expansion of the aviation sector. Other measures that could help achieve the necessary reforms include the following.

- Inclusion of the aviation sector in a Kyoto-style open emissions trading scheme integrated with trading schemes in other countries. Due to the uncertainty surrounding non-CO_2 aviation emissions, the aviation sector's participation in an emissions trading scheme should be based on CO_2 emissions only. Australia could assist in promoting this outcome by ratifying the Kyoto Protocol and pressuring the international community to make the necessary changes.

- The International Civil Aviation Organization (ICAO) could encourage the imposition of a mandatory non-CO_2 aviation emission charge to complement the emissions trading scheme in all Annex B countries under the Kyoto Protocol. Over time, the charge could be extended to all other countries in conformity with the processes adopted under the Kyoto Protocol.

Australia should adopt interim measures to curtail growth in aviation emissions while more comprehensive frameworks are being established. These could include a $30 flat-rate greenhouse charge for all domestic flights, which would raise in excess of $1 billion a year in revenue. It is possible that, at its meeting in 2007, the ICAO Assembly will recommend the imposition of an emissions charge. It this does not occur, the $30 flat-rate greenhouse charge could be applied to all international flights departing and arriving in Australia.

Market mechanisms like emissions trading and charges are unlikely to be sufficient on their own to address the issues associated with aviation and transport. Additional measures that could assist in dealing with these sectors include improved operational procedures and air traffic management, performance standards for new aircraft and engines, and long-term strategic planning for, and direct public investment in, transport and telecommunications infrastructure to encourage the substitution of air travel with less emission-intensive alternatives.

Irrespective of which policy instruments are implemented to curtail aviation emissions, Australians cannot expect to fly more than they currently do today. Unless there is a major technological breakthrough presently not foreseeable, the amount of air travel will need to be stabilised and ultimately reduced. To facilitate the necessary changes in the economy and the aviation sector, action needs to be taken now.

1. Introduction

The aviation sector has grown substantially since the 1950s. Global aviation passenger numbers are approximately 50 times larger than they were 50 years ago and the aviation sector now generates more than three billion passenger kilometres a year. Aviation has become an integral part of the world economy. In developed countries like Australia, it is considered to be essential for business and leisure activities.

The growing dependence on aviation sits uncomfortably with the policy ramifications of the available climate science. Data from the Intergovernmental Panel on Climate Change (IPCC) and other scientific organisations have clarified that the global climate is warming and that there is a very high likelihood that the main cause of the changes is the emission of greenhouse gases from human activities. If greenhouse gas emissions continue to grow, the science suggests global average surface temperatures could increase by between 1.1 and 6.4°C by the end of this century, leading to numerous adverse consequences, including rising sea levels, increases in extreme weather events and losses of biodiversity. Due to the threats posed by global warming, there is an emerging consensus that greenhouse gas emissions must be reduced by a considerable amount over the next 50 to 100 years.[1]

Aviation's contribution to climate change is currently relatively small. However, with the sector expected to grow rapidly in the coming decades, there is a risk it will become a major cause of human-induced warming. If appropriate steps are not taken to curb aviation emissions, the sector could become an impediment to reaching emission reduction targets set under the regime established by the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol.

The nexus between the aviation industry and climate change has been the subject of several reports and inquiries in Europe, particularly in the United Kingdom (UK). Research published in 2005 and 2006 by the Tyndall Centre for Climate Change Research and the Environmental Change Institute at Oxford University highlighted how unchecked growth in the aviation sector would make it extremely difficult for the UK and other European countries to meet emission reduction targets (Bows *et al.* 2005; Cairns *et al.* 2006).[2] Since then, a growing number of experts and policy makers have called for measures to be introduced to cut emissions from the aviation sector. For example, in December 2006, a collection of prominent British politicians, bureaucrats, academics and environmentalists called for a 'fundamental rethink of aviation policy to bring it into line with current climate change targets' (Ainsworth *et al.* 2006). The following month, Conservative British MP Tim Yeo, who chairs the House of Commons Select Committee on Environmental Audit, stated domestic flights should be taxed 'so heavily' that 'within ten years there should be virtually no domestic flights' in the UK (Chapman 2007).[3]

In response to the concerns about aviation's contribution to climate change, the European Union (EU) announced in December 2006 that from 2011 all flights within the EU would be subject to its Emissions Trading Scheme. It also announced plans to

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[1] See, for example, Stern (2007) and National Emissions Trading Taskforce (2006).
[2] See also Lee *et al.* (2005).
[3] See also Wintour (2007) and *Australian* (2007a; 2007b).

include all international flights to and from Europe in the scheme by 2012 (EC 2005; Guardian 2006).

While there is growing awareness overseas about aviation's contribution to climate change, there has been little discussion of the issue in Australia.[4] Further, neither governments nor the industry have implemented measures that are likely to substantially reduce the anticipated increase in aviation emissions. On the contrary, the object of government policy at the federal and state level is to encourage growth in the aviation sector. For example, in June 2006, former Federal Transport Minister Warren Truss stated that the 'Howard/Vaile Government is committed to doing everything that it can to ensure' continued growth in the industry (Truss 2006). Similarly, for the past five years, the Victorian tourism agency has aimed to sustain growth in international air services to Victoria of between four and five per cent a year (Tourism Victoria 2002). In Queensland, the Government recently allocated $6.5 million to 'ensure the continued growth of the state's burgeoning aviation sector' (Beattie and Bligh 2006).

In this context, this paper considers whether the unconstrained growth of the aviation industry in Australia is compatible with reducing the nation's greenhouse gas emissions to levels that are required to avoid dangerous climate change. To do this, the paper projects aviation emissions over the period 2005 to 2050, compares the projections to likely emission reduction targets in 2050, and reviews the options that are available to address the greenhouse issues associated with aviation.

Section 2 provides background information on the science of climate change and the level of public concern about global warming. It also provides an overview of Australia's current and projected emissions and analyses what Australia's emission reduction target is likely to be in 2050. Section 3 discusses the state of the aviation industry in Australia, its growth, how it is regulated and the measures the industry has taken to curb its emissions. Section 4 reviews how aviation emissions are treated under the UNFCCC and Kyoto Protocol, provides details of the science concerning aviation emissions and reviews the data on the current levels of aviation emissions. Section 5 projects aviation emissions in Australia over the period 2005 to 2050. Section 6 analyses the technological and policy options that are available for reducing aviation emissions and provides suggestions on how to deal with this issue. Section 7 provides a conclusion.

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[4] There are exceptions. See, for example, Davidson (2005), May (2006), Frew and Jensen (2007) and Vaile (2007).

2. Climate change and emission cuts

2.1 The science of climate change

There is growing awareness and acceptance of the seriousness of climate change and the need to take steps to significantly cut greenhouse gas emissions. This is reflected in the posturing of governments and political parties and in opinion polls. An international survey of over 25,000 internet users conducted by AC Nielson in late 2006 found that 91 per cent of people who use the internet are aware of climate change and almost 60 per cent of them consider that it is a very serious problem (AC Nielson 2007). Polling conducted in Australia has produced similar results. For example, an AC Nielson poll conducted on behalf of the *Sydney Morning Herald* in November 2006 found that 91 per cent of Australians believe climate change is a problem and 62 per cent say they are unhappy with the Federal Government's response (Coorey 2006).[5]

The level of public concern about global warming is partly due to developments in climate science. The first two assessment reports published by the IPCC indicated that global average surface temperatures were increasing and that this was probably due, at least in part, to the increasing concentration of greenhouse gases in the atmosphere due to human activities. The second assessment report concluded that global average surface temperature was projected to increase by between 1 and 3.5°C on 1990 levels by 2100. However, both reports emphasised that there was still considerable uncertainty about the extent of the human influence on global warming and the magnitude of the likely changes in temperatures over the coming century.

By the time the third assessment report was published, these uncertainties had been reduced considerably (IPCC 2001a). The report concluded that average surface temperatures had increased by approximately 0.6°C since reliable direct temperature records began to be kept in the 1860s and that there was a greater than 66 per cent chance that 'most of the observed warming over the last 50 years' was due to the increasing concentration of greenhouse gases in the atmosphere (IPCC 2001a, p. 51). It also found that 'globally averaged surface temperature is projected to increase by 1.4 to 5.8°C over the period 1990 to 2100' under business-as-usual scenarios (IPCC 2001a, p. 61). According to the report, the projected temperature increase was likely to have a number of adverse impacts, including increases in extreme weather events such as droughts and tropical cyclones and an almost one metre rise in sea levels by the end of the 21st century.

In February 2007, the IPCC published a summary of the first instalment from the fourth assessment report, titled *Climate Change 2007: The Physical Science Basis – Summary for Policymakers* (IPCC 2007). The summary report states that the science has advanced further since the third assessment report and concludes that there is no longer any doubt the climate is warming. Global average surface temperatures increased by approximately 0.75°C between 1906 and 2005, significantly above the 0.6°C rise recorded in the third assessment report for the period 1901 – 2000. The rate of warming over the last 50 years (approximately 0.13°C per decade) was nearly twice the rate recorded over the last 100 years. Other important findings include:

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[5] See also Auswind (2006).

- there is a greater than 90 per cent chance that most of the observed increase in global averaged temperatures since the mid-20th century is due to human activities (IPCC 2007, p. 5);

- a doubling of carbon dioxide concentrations in the atmosphere on pre-industrial levels from 280 parts per million (ppm) to 560 ppm is likely (i.e. greater than 66 per cent chance) to increase global average surface temperatures by between 2 and 4.5°C, 'with a best estimate of about 3°C' (IPCC 2007, p. 12);

- based on six scenarios considered by the Working Group, global average surface temperatures are likely to increase by between 1.1 and 6.4°C between 1980 – 1999 and 2090 – 2099; and

- the projected climate change will have negative consequences, including sea level rises of between 0.18 and 0.59 metres, increased acidification of the ocean, and an increase in extreme weather events.

The IPCC assessment reports have been instrumental in reducing the scientific uncertainties surrounding global warming and raising public awareness of the gravity of the issue. This process has been aided by numerous other reports, including work done by scientific bodies like the CSIRO. Internationally, the *Stern Review on the Economics of Climate Change,* released in October 2006 (hereafter referred to as the 'Stern Review'), not only helped raise the profile of climate change, but it also analysed the likely costs of inaction (Stern 2007). It found that that if nothing is done to curb greenhouse emissions, there could be a loss of between five and 20 per cent of global GDP per year. This compares to an estimated cost of one per cent of global GDP in order to appropriately address the issue.

2.2 The Australian situation

Australia's greenhouse gas emissions increased by approximately 2.3 per cent between 1990 and 2004 – see Table 1. This relatively low rate of emissions growth was primarily due to a significant decline in emissions from land use, land use change and forestry (LULUCF).[6] Emissions from all other sectors except waste increased over this period. Stationary energy and transport emissions, which together accounted for 63 per cent of total emissions in 2004, have increased by 43 and 23 per cent respectively since 1990.

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[6] The decline in LULUCF emissions was primarily due to an unusually high rate of land clearing in the late 1980s and early 1990s, the Queensland Government's steps to reduce clearing and changes in agricultural markets. Doubts have been raised about the accuracy of the Federal Government's LULUCF emission estimates (see Macintosh 2007a; 2007b).

Table 1 Australia's greenhouse gas emissions 1990 – 2004, Mt CO_2-e*

	Emissions Mt CO_2-e		**Per cent change in emissions**
	1990	**2004**	
Energy	287.5	387.2	34.7
Stationary energy	195.7	279.9	43.0
Transport	61.7	76.2	23.4
Fugitive	30.0	31.0	3.4
Industrial processes	25.3	29.8	18.0
Agriculture	91.1	93.1	2.2
LULUCF	128.9	35.5	-72.5
Waste	19.2	19.1	-0.7
Net emissions	**551.9**	**564.7**	**2.3**

Source: DEH (2006a).

* These estimates are based on the accounting rules that apply under the Kyoto Protocol. As a result, they do not include an estimate of Australia's contribution to international aviation emissions.

In the coming years, Australia's emissions are expected to increase rapidly, even if current greenhouse policy mechanisms achieve their mitigation targets – see Table 2. Australia's emissions are currently projected to reach 109 per cent of 1990 levels over the period 2008-12, meaning they will exceed the target set under the Kyoto Protocol by one per cent, or approximately 7 million tonnes (Mt) of carbon dioxide equivalent (CO_2-e). By 2020, domestic emissions are expected to reach 702 Mt CO_2-e, which is 127 per cent above Australia's 1990 levels. The majority of the increase is expected to come from the stationary energy and transport sectors, although emissions from all sectors other than waste and LULUCF are projected to continue to increase through to 2020.

Table 2 Australia's projected emissions in 2010 and 2020, with measures*

	Emissions Mt CO_2-e		
	1990	**2010**	**2020**
Energy	287.5	430	516
Stationary energy	195.7	306	361
Transport	61.7	86	99
Fugitive	30.0	38	55
Industrial processes	25.3	38	50
Agriculture	91.1	96	101
LULUCF	128.9	24	25
Waste	19.2	16	11
Net emissions	**551.9**	**603**	**702**

Source: DEH (2006b).

* These estimates take into account the expected abatement from existing policy measures.

2.3 Avoiding dangerous anthropogenic climate interference

The current trajectory of Australia's emissions is incompatible with the science concerning the emission levels that are necessary to avoid dangerous climate change. To minimise the risk of temperature increases exceeding 2°C on 1990 levels by 2100 and 3°C on 1990 levels in the long-term, data in the third IPCC assessment report indicate that the atmospheric concentrations of carbon dioxide (CO_2) should be stabilised at or below approximately 450 ppm (around 500 ppm CO_2-e).[7] The scenarios considered in the report suggest that achieving a 450 ppm CO_2 target would require emissions to be reduced from 7.8 GtC (29 $GtCO_2$) in 1990 to between 3.0 and 6.9 GtC (11 – 25 $GtCO_2$) in 2050, then reduced again to between 1.0 and 3.7 GtC (3.7 – 13.6 $GtCO_2$) in 2100.

The Stern Review uses data from several sources, including the IPCC and the Hadley Centre, to suggest that the worst impacts of climate change can be avoided if the atmospheric concentration of greenhouse gases is stabilised at between 450 and 550 ppm CO_2-e. A major influence on this conclusion was the projected temperature increases associated with various stabilisation levels – see Table 3.

Table 3 Probability of exceeding temperature increases at equilibrium, 450, 550 and 650 ppm CO_2-e

Stabilisation level (ppm CO_2-e)	**Maximum probability**	**Minimum probability**	**IPCC Third Assessment Report Ensemble**
Probability of exceeding 2°C increase relatively to pre-industrial levels			
450	78%	26%	38%
550	99%	63%	77%
650	100%	82%	92%
Probability of exceeding 3°C increase relatively to pre-industrial levels			
450	50%	4%	6%
550	69%	21%	32%
650	94%	44%	57%

Source: Stern (2007).

Table 3 is a partial reproduction of Box 8.1 from the Stern Review (2007). Columns two and three show the minimum and maximum probability of certain temperature increases being exceeded if greenhouse gases are stabilised at 450, 550 and 650 ppm CO_2-e. These probability ranges were drawn from eleven recent studies presented in Meinshausen (2006). The probability estimates in column four reflect the results from the seven models used in the IPCC's third assessment report.

Using the studies presented in Table 3 as a guide, if greenhouse gases stabilise at 650 ppm CO_2-e, the probability of global average surface temperatures increasing by more

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[7] See IPCC (2001a), pp. 99 – 101.

than 3°C on pre-industrial levels (i.e. approximately 2.5°C above 1990 levels) ranges between 44 and 94 per cent. At 550 ppm CO_2-e, the probability of a greater than 3°C increase is between 21 and 69 per cent. At 450 ppm CO_2-e, the range falls to between 4 and 50 per cent.

Although a lower stabilisation target would reduce the severity of the impacts of climate change, the Stern Review recognises there is a trade-off. As the stabilisation target falls, the costs of abatement (i.e. the economic costs) rise. Consequently, there is a need to find the stabilisation point at which the marginal costs of abatement are likely to be equal to the marginal costs associated with greenhouse emissions. Due to the uncertainties associated with the science and economics of climate change, identifying this point is impossible. To overcome this, the Stern Review defines a preferred range of stabilisation points, arguing that:

> [t]he evidence on the benefits and costs of mitigation at different atmospheric concentrations in our view suggests that the stabilisation goal should lie within the range 450 – 550ppm CO_2-e (Stern 2007, p. 299).

For the atmospheric concentration of greenhouse gases to be stabilised at 550 ppm CO_2-e, the report suggests that global emissions would have to be reduced by at least 25 per cent on 2005 levels by 2050, meaning they would have to fall from 45 $GtCO_2$-e/yr to 34 $GtCO_2$-e/yr over this period. If the target is 450 ppm CO_2-e, there would have to be a 70 per cent reduction on 2005 levels by 2050. In the long-run, in order to stabilise the atmospheric concentration of greenhouse gases at either level, emissions will have to be reduced to a level that is equal to the rate of natural absorption. This will require global emissions to fall from their current level of approximately 45 $GtCO_2$-e/yr to around 5 $GtCO_2$-e/yr by the later half of the 22nd century, a greater than 80 per cent reduction. Importantly, the report makes the point that, '[t]he longer action is delayed, the higher will be the lowest stabilisation level achievable' (p. 299). This is a result of the costs of rapidly reducing global emissions, the long lifetime of many greenhouse gases and the slow rate at which they are naturally absorbed. Consequently, if global emissions are allowed to continue to rise, it will become increasingly difficult to stabilise the atmospheric concentration of greenhouse gases within the 450 – 550ppm CO_2-e range.

On the basis of the available information, it appears that the absolute maximum global stabilisation target should be approximately 550ppm CO_2-e (i.e. approximately 490ppm CO_2).[8] Beyond this point, there is a significant risk of global temperature increases exceeding 3°C on pre-industrial levels, which may have substantial adverse repercussions on global economic, social and environmental systems. Even if the atmospheric concentration of greenhouse gases is stabilised at 550ppm CO_2-e, there are still likely to be significant costs (IPCC 2001a; Schellnhuber 2006; Stern 2007; Dunlop 2007; CSIRO 2007). As the third IPCC assessment report notes:

> [m]odels assessed in the TAR [third assessment report] project sea-level rise of several metres from polar ice sheets and land ice even for stabilization levels of 550ppm CO_2-equivalent (IPCC 2001a, p. 102).

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[8] For further general discussion of the issues associated with stabilisation targets, see Schellnhuber *et al.* (2006).

Due to the risks associated with higher atmospheric concentrations of greenhouse gases (especially the risks related to non-linear climate responses), many argue that governments should aim to limit increases in global average surface temperatures to 2°C on pre-industrial levels (Julien 2006; CSIRO 2007; Dunlop 2007; European Commission 2007). If the object is to keep increases in global average surface temperatures below 2°C, a maximum stabilisation target of 450ppm CO_2-e is likely to be necessary (IPCC 2001a; Meinshausen 2006; Stern 2007; CSIRO 2007; European Commission 2007). As the CSIRO has stated:

> GHG [greenhouse gas] stabilisation at or below 450 ppmv is necessary in order to ensure a reasonable likelihood of warming remaining at or below 2°C (CSIRO 2007, p. 6).

While a stabilisation target of 450ppm CO_2-e may be necessary to avoid dangerous climate change, it is sufficient for current purposes to assume that the higher 550ppm CO_2-e target is adequate.

In order to achieve a stabilisation target of 550ppm CO_2-e, the evidence suggests that global emissions should be reduced by at least 25 per cent to 34 $GtCO_2$-e/yr by 2050.[9] Further reductions will be necessary after 2050 to ensure the atmospheric concentration of greenhouse gases is stabilised at the 550ppm CO_2-e level.

2.4 Towards an Australian emission target

The domestic implications of a global emission reduction target of 25 per cent by 2050 depend on the strategy that is developed to divide emissions between countries. One option is ‘contraction and convergence’. Under this approach, global emission levels are reduced (contraction) and per capita emission levels are gradually equalised amongst developed and developing countries (convergence).

At 2050, the global population is expected to be approximately 9.1 billion, while Australia’s population is expected to be around 28.1 million (ABS 2006). If global greenhouse emissions are reduced to a maximum of 34 $GtCO_2$-e/yr in 2050, per capita emissions should be 3.72 tonnes of CO_2-e/yr, assuming the equalisation of per capita emissions. Consequently, if a contraction and convergence strategy is adopted, Australia’s total emissions should be a maximum of approximately 104.5 Mt CO_2-e/yr by 2050.[10] To meet this target, Australia’s emissions will have to be reduced by

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[9] If global emissions continue to rise beyond 2015, the required reduction in global emissions in 2050 to keep the atmospheric concentration of greenhouse gases below 550 ppm CO_2-e is likely to be greater than 25 per cent.

[10] The precise nature of the emission target will ultimately depend on the trajectory of global and domestic emissions. If emissions are allowed to continue to increase in the short- to medium-term, deeper cuts will be required in later years to keep the atmospheric concentration of greenhouse gases below 550 ppm CO_2-e.

around 80 per cent on 2004 emission levels,[11] or approximately 460 Mt CO_2-e/yr (DEH 2006a).[12]

Different baselines have been used in emission reduction targets. For example, the Kyoto Protocol's targets are based on 1990 emission levels. In contrast, the Australia Labor Party (ALP) currently has a target of reducing Australia's emissions by 60 per cent on 2000 levels by 2050 (Beazley 2006).[13] If 1990 emission levels are used as a baseline (i.e. 551.9 Mt CO_2-e), and a contraction and convergence strategy is assumed, emissions would still have to be cut by approximately 80 per cent. The required percentage target also remains at approximately 80 per cent if 2000 emission levels are used as the baseline (i.e. 558.1 Mt CO_2-e).

If the contraction and convergence strategy is abandoned, or if the timeline for convergence is extended, a lower domestic emission reduction target may be possible while still retaining the global target of a 25 per cent reduction in emissions by 2050. This approach would require greater restrictions be placed on other countries, which would have equity implications. Negotiating an international agreement that allows developed nations to avoid convergence by 2050 may also prove difficult. However, it would reduce the severity of the cuts required in developed countries.

The ALP's 60 per cent emission reduction target on 2000 levels is one example of the type of goal that could be adopted if developed nations decided not to attempt to equalise per capita emission levels by 2050. If this target is adopted, Australia's emissions would have to be reduced to 223.24 Mt CO_2-e in 2050. On the basis of current population projections, this would equate to approximately 7.94 tonnes of CO_2-e/yr per person, well above the 3.72 tonnes of CO_2-e/yr per person required under a contraction and convergence strategy (ABS 2006).

The Government of the UK has also adopted a 60 per cent reduction target based on 1990 emission levels and, at the time of writing, was undertaking a consultation process in relation to a bill to enshrine this target in legislation (DEFRA 2007). Like the ALP's target for Australia, the UK's 60 per cent reduction target will not result in its per capita emissions reaching the global average of 3.72 tonnes of CO_2-e/yr that would be necessary under a contraction and convergence strategy. However, the available data indicate that if this target is reached, per capita emissions in the UK will be approximately 4.69 CO_2-e/yr, significantly lower than they would be Australia (ABS 2006; Office for National Statistics (UK) 2005).

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[11] The actual percentage reduction is 81 per cent. For simplicity, we have adopted 80 per cent as the required target.

[12] The Federal Government's estimate of emissions in 2004 included an interim estimate of emissions from land use change and forestry that is likely to change in later inventories. Consequently, the estimate of the required reduction to meet the emission target may change. Further, this estimate of the required emission cuts is based on the National Greenhouse Gas Inventory, which uses the Kyoto Protocol rules to determine emissions. As a result, the estimate does not account for Australia's contribution to international aviation emissions.

[13] A 60 per cent emission reduction target by 2050 has also been adopted by the New South Wales Labor Government (NSW Government 2005) and, at the time of writing, the South Australian Labor Government was in the process of legislating a 60 per cent target by 2050 on 1990 levels.

Given the above facts, if there is a global commitment to stabilise the atmospheric concentration of greenhouse gases at 550ppm CO_2-e, the minimum target for Australia is likely to be approximately 60 per cent on 2000 levels by 2050. Ultimately, a target of around 80 per cent is likely to be necessary.

To achieve emission reductions of this magnitude, changes are going to be necessary across all sectors of the economy. The aviation sector is one area where reform is urgently needed due to its increasing contribution to climate change.

3. State of the Australian airline industry

The Australian airline industry has undergone significant changes over the last 15 years. Some airlines have collapsed and new ones have emerged. At the same time, the industry has felt the affects of various international events, including the September 11 attacks, the Severe Acute Respiratory Syndrome (SARS) outbreak and increases in fuel prices. Notwithstanding the changes, demand for aviation services has grown over this period, driving continued expansion of the aviation industry.

In this section we consider the state of the Australian airline industry. We canvass the regulatory environment in which the industry operates, the main players, the extent of the growth in the aviation sector and how the aviation industry has responded to the challenges presented by climate change.

3.1 Regulating the airline industry

Domestic airline industry

The Federal Government is primarily responsible for the regulation of the aviation industry and these regulatory functions are carried out by several government bodies, including the Department of Transport and Regional Services (DOTARS), Airservices Australia and the Civil Aviation Safety Authority (CASA). Although the functions of the relevant federal entities differ, the overall objective of the regulatory system is to ensure the safety, efficiency, competitiveness and sustainability of the aviation industry. An overview of the functions of the federal entities that play a significant role in the regulation of the aviation industry is provided in Table 4 below.

The trend in the regulatory environment in Australia over the past 15 years has been toward a more liberal aviation market. In 1990, the Federal Government abolished the two-airline policy, enabling new operators to enter the domestic market. The Government also changed the foreign investment guidelines in 1999 to permit foreign airlines to acquire up to 100 per cent of the equity of an Australian domestic airline or to start a new domestic airline, unless this is contrary to the national interest (Anderson 1999). This change precipitated the entrance of Virgin Blue into the domestic market in 2000.

Despite these changes, there are still several restrictions that apply to the industry. For example, consistent with the arrangements in other countries, cabotage restrictions apply to domestic routes that ensure foreign-based airlines do not carry domestic passengers on domestic sections of their international flights. This guarantees that only Australian-based airlines carry domestic passengers and freight on domestic routes. Further, under the *Qantas Sales Act 1992* (Cwlth), the articles of association of Qantas must ‘prevent foreign persons having relevant interests in shares in Qantas that represent, in total, more than 49% of the total value of the issued share capital of Qantas’.[14]

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[14] *Qantas Sales Act 1992* (Cwlth), section 7.

Table 4 Federal aviation bodies and their functions

Entity	Function
DOTARS – Aviation and Airports Division	To advise the Government on aviation policy, implement international aviation obligations, manage the Government's involvement in the International Civil Aviation Organisation (ICAO), oversee the regulation of aircraft standards, aviation security, international airline licences, ownership and control of leased federal airports, and the development of land surrounding leased federal airports, and coordinate the relationship between the various federal agencies involved in the regulation of the aviation industry.
DOTARS – Australian Transport Safety Bureau	To investigate aviation accidents and other safety occurrences, collect and analyse aviation safety data and raise awareness of safety issues. The operations of the ATSB are not confined to the aviation industry. They include other areas of the transport sector (i.e. marine, rail and road).
Airservices Australia	To provide 'air traffic control management and related airside services to the aviation industry' in Australia and certain neighbouring areas in the Pacific (Airservices Australia 2007). It also provides aviation rescue and fire fighting services at 19 major airports and carries out certain regulatory functions (for example, aircraft noise) under delegation from DOTARS.
CASA	To regulate civil air operations in Australia and the operation of Australian aircraft overseas to ensure the safe provision of aviation services.
International Air Services Commission	To determine applications by Australian airlines for capacity and route entitlements under international air services arrangements. It aims to promote economic efficiency through competition in the provision of international air services so as to increase the responsiveness of airlines to the needs of consumers, expand Australian tourism and trade, and ensure Australian carriers are capable of competing effectively with foreign airlines.
Australian Competition and Consumer Commission (ACCC)	To promote competition and ensure airlines and other aviation operators comply with relevant competition and consumer legislation (i.e. *Trade Practices Act 1974* (Cwlth)).
Foreign Investment Review Board	Examines proposals by foreign interests to undertake direct investment in the Australian aviation industry (and other industries) and makes recommendations to the Government under the foreign investment policy.
Department of the Environment and Water Resources	To conduct environmental assessments and provide advice on major airport developments in accordance with the provisions of the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth).

International airline industry

The international aviation industry in Australia is largely regulated under the regime established by the *Convention on International Civil Aviation* (Chicago Convention) of 1944. The Chicago Convention created ICAO and outlined the basic principles for the operation of the international aviation industry. The cornerstone of the Convention is that each country has complete and exclusive sovereignty over the airspace above their territory. The Convention also envisaged that countries would negotiate separate bilateral agreements concerning the rights to operate international air services between and within other countries.[15]

Using the Chicago Convention and other international agreements as a base, Australia has negotiated over 50 separate bilateral air services arrangements, which regulate international aviation services between Australia and other countries. These arrangements grant various ‘freedoms of the air’ and outline other rules concerning airline entry, routes, capacity and frequency. The freedoms of the air cover such things as the right of transit without landing, the right to land in the territory of another state for non-traffic purposes (i.e. to refuel and for maintenance), the right to put down and pick up traffic from the home state of the carrier, and the right to put down and pick up traffic from or destined to a third state.

There are approximately 3,000 bilateral air services arrangements in operation around the world, creating considerable complexity and restrictions for aviation operators. Driven by the desire to facilitate greater trade and competition, and at the behest of airline operators, the system of bilateral agreements is starting to change. Australia and a number of other countries have endorsed moves away from the bilateral system of international aviation regulation to a more liberalised international regime (Kain and Webb 2003; CAPA 2005; AP 2007).

An illustration of the shift toward a more liberal international aviation market is the so-called Australia-New Zealand ‘open skies’ agreement signed in Auckland in 2002.[16] This allows Australian and New Zealand international airlines to operate between the two countries and then to third countries without restrictions. These types of services to a third country were previously restricted in terms of capacity and third country destinations. In addition, Australia now permits foreign international airlines unrestricted access to all international airports except Sydney, Melbourne, Brisbane and Perth (Kain and Webb 2003).

3.2 The Australian airlines

Since the abolition of the two-airline policy and the easing of foreign ownership rules, the domestic market has experienced significant changes with several airlines entering and leaving the market. In 2000, Impulse Airlines and Virgin Blue emerged. The following year saw the collapse of Ansett and the acquisition of Impulse by Qantas. In 2004, Qantas launched the low-cost carrier Jetstar to counter the success of Virgin Blue in the leisure market (BTRE 2006a). Entrepreneur Paul Stoddart launched the boutique all-business-class airline OzJet in late 2005, only for it to close in March 2006. Despite all the changes, in 2007, the market is once again dominated by two main carriers, Qantas and Virgin Blue.

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[15] Australia is also a party to the *International Air Services Transit Agreement* (Two Freedoms Agreement) of 1944, which grants other parties what are known as the first two ‘freedoms of the air’. The first freedom is the right of an aircraft from one country to fly across the territory of another country without landing. The second freedom is the right of an aircraft from one country to land for non-traffic purposes (i.e. for refuelling or maintenance, but not to pick up or drop-off passengers) in the territory of another country.

[16] *Agreement between the Government of Australia and the Government of New Zealand relating to Air Services*, Australian Treaty Series, No. 18, 2003. See also Anderson and Gosche (2000).

Qantas

Since it was founded in 1920, Qantas has become the face of the Australian airline industry. It is the largest Australian airline and is the only provider of nationwide ‘full-service’ scheduled air services. Qantas, or the Qantas Group, has extensive commercial and ownership links with other airlines, including British Airways and Fiji’s Air Pacific (Kain and Webb 2003).

In 2006, the Qantas Group held almost 70 per cent of the domestic market and about 35 per cent of the international market. It recorded revenue of $13.6 billion for the 2005/06 financial year with an after tax profit of $480 million (Qantas 2006).

The Qantas Group’s dominance in the domestic market is partly due to its expansion into the low fare segment of the market via Jetstar. In two years, Jetstar increased its share of the domestic market to 14 per cent and now also offers a small range of selected international flights (Qantas 2006).

Virgin Blue

Following the collapse of Ansett in 2001, Virgin Blue emerged as the only major competitor to Qantas. Established in 2000, it operates mainly on the busiest domestic trunk routes, offering single-class budget air travel. It also offers a small selection of international flights. The major shareholders in the airline are the Virgin Group and Plzen Pty Ltd (a wholly owned subsidiary of Patrick Corporation) (Virgin Blue 2006).

In 2006, Virgin Blue had a little more than 30 per cent of the domestic market. It recorded revenue of $1.4 billion for the 2005/06 financial year with an after tax profit of $85 million (Virgin Blue 2006).[17] The success of Virgin Blue is similar to what has occurred with other low-cost carriers overseas.

The pattern of growth overseas, the establishment of Jetstar and the rise of Virgin Blue suggest that low-cost carriers are likely to play an increasingly important role in the aviation market in Australia over the next 20 years. This has seemingly been confirmed by the recent emergence of a new player in the domestic airline market, Tiger Airways. A Singapore-based budget airline, it plans to offer domestic flights at less than one dollar excluding taxes (Benns 2007; Zonneveldt 2007).

3.3 Growth of the airline industry

Between 1960 and the mid-1990s, air passenger traffic (measured as revenue passenger-kilometres) grew by almost nine per cent per year, 2.4 times the average growth rate of GDP (IPCC 1999). Since that time, there has been the East Asian financial crisis, September 11 attacks and SARS, all of which affected growth in the aviation sector. However, the industry has rebounded strongly, with revenue passenger-kilometres growing by in excess of five per cent per annum since 2004 (Airbus 2006; IATA 2007).

In the last decade the growth in aviation has been fuelled by the expansion of the world economy, the proliferation of low-cost carriers and the industry’s success in new markets. In Europe, low-cost carriers such as EasyJet and Ryanair have redefined

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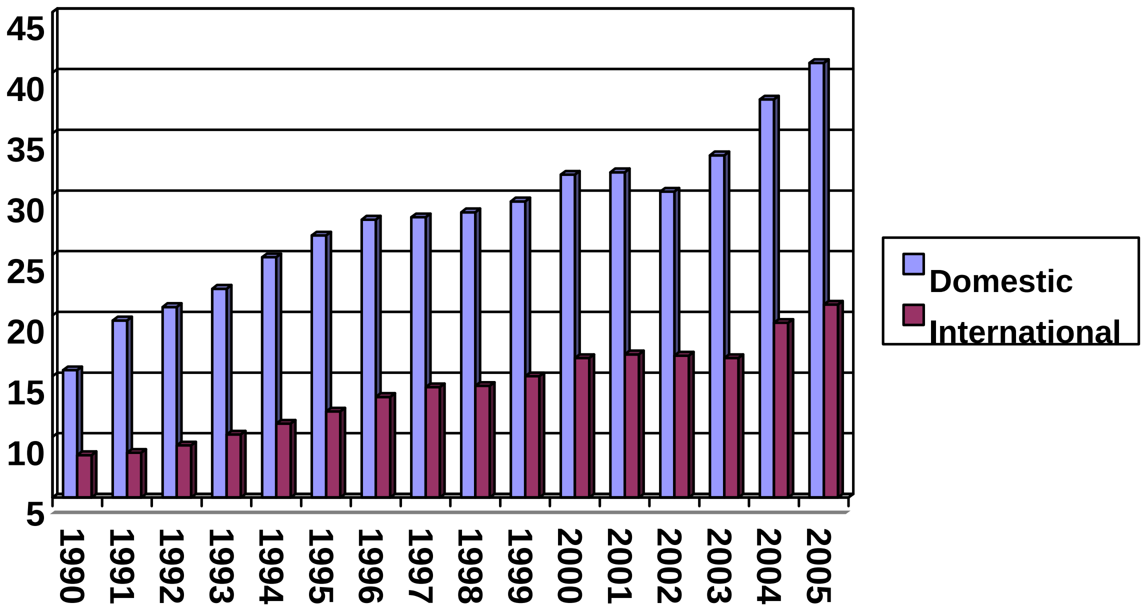
[17] These figures are for the nine month period to 30 June 2006, as reported in the 2006 annual report.

budget air travel by offering one-way flights within Europe for as low as one pound excluding taxes. There are now more than 50 low-cost carriers in Europe with a combined market share of 26 per cent in terms of available seats. In the United States, there are 10 low-cost carriers with a combined market share of almost 30 per cent. Low-cost carriers are also experiencing rapid growth in Asia, where they have nine per cent of market share (Airbus 2006). In Australia too, low-cost carriers such as Virgin Blue and Jetstar are expanding by offering selected flights at very low prices. The high growth strategies of low-cost carriers have stimulated substantial demand in the aviation industry and are expected to continue to do so in the foreseeable future (CAPA 2005; Airbus 2006).

The development of Asian markets, especially in China and India, is seen as a major driver of expected growth in the aviation industry. China has overtaken Japan as the largest aviation market in Asia and now has the largest aircraft fleet in the world outside of the US. China's aircraft fleet is increasing at an estimated 100 new aircraft per year and the number of outbound trips by passengers from China increased by 50 per cent to 28.9 million in 2004 (CAPA 2005).

In Australia the picture is less frenetic than in Asia, but the industry has still experienced strong growth. As Figure 1 shows, aside from a fall in demand for air travel as a result of September 11 and SARS in 2001 and 2002, over the last decade the domestic and international airline industry has experienced sustained growth. Between 1996 and 2005, domestic passenger numbers increased by 46 per cent and international passenger numbers by 62 per cent. Annual domestic passenger numbers are now in excess of 40 million and international passenger numbers are greater than 20 million.

Figure 1 Growth in air passenger numbers in Australia, in millions

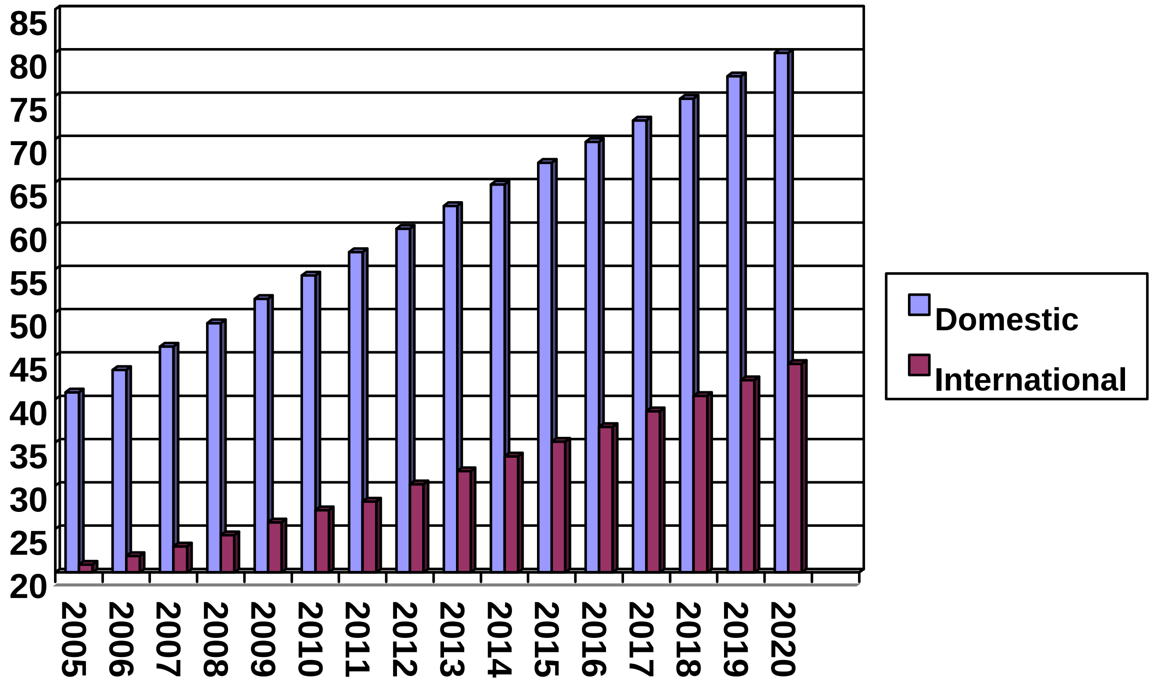


Source: BTRE (2006b).
Note: Domestic includes regional passengers.

The growth in the demand for aviation services is projected to continue. Global flight numbers are forecast to double by 2020 and triple by 2030 (Lucas 2006). Airbus has predicted that global revenue passenger-kilometres will grow by an average of 4.8 per cent a year between 2006 and 2025 (5.3 per cent a year between 2006 and 2015, falling to 4.4 per cent a year between 2016 and 2025 as markets mature) (Airbus 2006). The strongest growth is expected in the Middle East and Asia, where revenue passenger-kilometres are expected to grow at an average annual rate in excess of six per cent between 2006 and 2025. These projections are similar to those published by the International Air Transport Association (IATA), which suggest that international air passenger traffic in the Middle East will grow by almost seven per cent per annum between 2006 and 2010 and by 5.7 per cent per annum in the Asia-Pacific region over the same period (IATA 2007).

Consistent with these trends, domestic and international air travel in Australia is expected to continue to grow rapidly in the short to medium term. Based on data from the Bureau of Transport and Regional Economics (BTRE), it is estimated that domestic and international air passenger numbers will double between now and 2020. As Figure 2 shows, domestic passenger numbers are expected to jump from 40.8 million in 2005 to 80 million in 2020, an average growth rate of 4.6 per cent per annum. Similarly, international passenger numbers are expected to rise from 20.9 to 44.1 million between 2005 and 2020, an average annual growth rate of 5.1 per cent.

Figure 2 Projected growth in air passenger numbers, in millions



Source: BTRE (2005) and BTRE (2006b).
Note: These growth projections are derived from taking the base figures for domestic and international passenger numbers in Australia for 2005 and multiplying them by the projected percentage growth rate for each sector as estimated by the BTRE for each year to 2020.

3.4 The aviation industry’s emission reduction initiatives

With growing public awareness about climate change, airlines around the world have been forced to consider their contribution to global warming. In December 2005, IATA endorsed an industry-wide strategy to address climate change. The strategy focussed on ‘technological advancements’ and ‘encourages the use of voluntary initiatives’ (IATA 2006a). According to IATA:

> [a] voluntary agreement can be particularly attractive as a first step towards demonstrating to governments and the public that the aviation industry is acting responsibly to address, for example, the concerns about global warming (IATA 2004, p. 32).

In Australia, Qantas and Virgin Blue have both introduced voluntary measures. However, a number of these programs do not appear to increase abatement above what would otherwise have occurred. For example, Qantas has promoted its investment in new aircraft as a means of increasing fuel efficiency (Macken 2006). In 2005, it established a fuel conservation project to investigate other fuel saving initiatives ‘that will deliver significant reductions in greenhouse gas emissions’ (Qantas 2006, p. 35). Similarly, Virgin Blue has a fuel management project to increase fuel efficiencies and the company promotes the fact that its new fleet of aircraft produces less emissions than older fleets (Virgin Blue 2006). Virgin Blue chief executive, Brett Godfrey, has stated that ‘naturally there’s a commercial benefit to operating a fuel-efficient fleet, but the larger responsibility is related to climate change’ (Creedy 2006).

Although the voluntary initiatives undertaken by Qantas and Virgin Blue are unlikely to substantially reduce aviation emissions, there are several programs that do seem to go beyond the scope of normal business operations. For example, Qantas has a partnership with Landcare for sequestration and reforestation activities. It also participates in a Greenfleet program to offset emissions from the group’s executive car fleet (Macken 2006).

In 2006, Sir Richard Branson, the CEO of the Virgin Group, announced the establishment of Virgin Fuels, which he hopes will lead to the development of alternatives to kerosene-based aviation fuels (BBC News 2006). Virgin Blue has also announced plans to offer customers ‘carbon neutral’ flights, where passengers pay an additional fee to have their emissions offset by a range of abatement projects such as tree planting and energy efficiency projects (Virgin Blue 2007).

4. Aviation emissions

To provide a basis for projecting aviation emissions and discussing potential technical and policy solutions, this section provides details on how aviation emissions are accounted for under the UNFCCC/Kyoto Protocol regime. It then evaluates the climate science concerning aviation and the current level of aviation emissions.

4.1 Aviation and the UNFCCC/Kyoto Protocol Regime

The principal international agreement relating to climate change is the UNFCCC. Its object is to ensure the concentration of greenhouse gases in the atmosphere are stabilised ‘at a level that would prevent dangerous anthropogenic interference with the climate system’. To help achieve this, Australia and the other Annex I countries (i.e. developed countries and several transitional countries from the old eastern bloc) are required to limit their emissions, with the aim of returning them to 1990 levels either ‘individually or jointly’.[18]

The Kyoto Protocol was designed to facilitate the achievement of the objective of the UNFCCC by committing most of the Annex I countries (known as Annex B countries) to binding emission reduction targets.[19] Under the Protocol, Australia is required to limit its emissions to an average of 108 per cent of 1990 emission levels over the period 2008 to 2012. The Australian Government has not ratified the Protocol, but it has publicly stated it is committed to ensuring Australia meets its target.

There are two aspects of the UNFCCC/Kyoto regime that are of particular relevance when evaluating the climate implications of the aviation sector. Firstly, the IPCC guidelines that govern the preparation of national inventory reports under the UNFCCC stipulate that only a select group of direct greenhouse gases should be counted towards national totals: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). If other gases are reported, it is as a separate item and they are not included in the national totals. The targets under the Kyoto Protocol apply to the same group of direct greenhouse gases. As is discussed in greater detail in Section 4.2, aviation results in the emission of a number of greenhouse gases (often called non-CO_2 aviation emissions) that are not counted toward the national totals or emission targets.

Secondly, a distinction is made between international and domestic aviation emissions under the regime. The IPCC guidelines require domestic aviation emissions to be counted toward a country’s total emissions, but not international aviation emissions. However, if fuel is sold in a country that is used in international aviation operations, the country is required to estimate the international aviation emissions from these operations and include them in its inventory as a separate memo item.

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[18] UNFCCC, Article 4(2).

[19] Belarus and Turkey are the only Annex I countries without binding emissions reduction targets under the Kyoto Protocol.

The effect of the IPCC inventory guidelines is to exclude international aviation operations from the emission reduction commitments under both the UNFCCC and the Kyoto Protocol. To account for the complexities associated with international aviation emissions, Article 2(2) of the Kyoto Protocol simply states that:

> [t]he Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.

Consequently, under the terms of the Kyoto Protocol, Annex I countries are currently supposed to pursue reductions in international aviation emissions through the ICAO.

To date, the ICAO has not introduced any binding measures that are specifically designed to address the greenhouse impacts of international aviation operations. Annex 16, Volume II to the Chicago Convention sets emission standards for aircraft engines that cover several gases, including nitrogen oxides (NO_x) and carbon monoxide (CO) that contribute to the greenhouse effects associated with aviation. However, these standards are primarily designed to deal with local air quality issues at airports rather than greenhouse matters. The ICAO has considered the greenhouse impacts of aviation, but it has not yet introduced mandatory measures to deal with the problem. Resolution A 35-5 of the ICAO merely states that it will 'strive to … limit or reduce the impact of aviation greenhouse gas emissions on the global climate', while endorsing the 'further development of an open emissions trading system for international aviation'.

In summary, the main concern in relation to aviation under the UNFCCC/Kyoto regime is currently CO_2 emissions from domestic flights. However, all greenhouse gas emissions from aviation contribute to climate change. Eventually, international aviation emissions and non-CO_2 aviation emissions will have to be addressed to meet the objectives of the UNFCCC.

4.2 The science of aviation emissions

In 1999, the IPCC released a special report entitled *Aviation and the Global Atmosphere* (IPCC 1999), which is widely considered the scientific reference point for understanding the climatic affects of aviation. According to the report:

> [a]ircraft emit gases and particles directly into the upper troposphere and lower stratosphere where they have an impact on atmospheric composition. These gases and particles alter the concentration of atmospheric greenhouse gases, including carbon dioxide (CO_2), ozone (O_3), and methane (CH_4); trigger formation of condensation trails (contrails); and may increase cirrus cloudiness—all of which contribute to climate change (1999, p. 3).

The IPCC uses the concept of radiative forcing to estimate the impact of different factors on the climate. Radiative forcing measures the importance of a potential climate change mechanism in affecting the heat balance of the Earth's atmospheric system.[20] Using this concept, the IPCC estimated the radiative effects of the principal aircraft emissions: CO_2, nitrogen oxides (NO_x),[21] water vapour (H_2O), sulphur oxides (SO_x) (which form sulphate particles) and soot (IPCC 1999). Each of these emissions has a different impact on climate change and some have a greater impact when emitted at altitude.

In 1992, CO_2 emissions from aviation were estimated to account for approximately two per cent of global annual anthropogenic emissions and just over one per cent of the total increase in the atmospheric concentration of CO_2. Unlike most other aircraft emissions, CO_2 mixes well in the atmosphere and has a relatively long atmospheric lifetime.[22] Due to these characteristics, the effects of CO_2 emissions from aviation are believed to be the same irrespective of altitude and its climate impacts are not localised.

The effects of the other aviation emissions differ from CO_2 in that they generally have a shorter atmospheric lifespan and tend not to mix as well in the atmosphere. As a result, their impacts can be localised near popular flight routes. The effects of non-CO_2 aviation emissions can also differ considerably depending on the altitude at which they are released.

Emissions of NO_x have both a positive and negative effect on radiative forcing. Firstly, NO_x leads to the production of ozone (O_3), which is a greenhouse gas. When NO_x is released in the upper troposphere, as it is in aircraft, it is more effective in producing ozone than if the gas was released at the Earth's surface. Consequently, aviation NO_x emissions increase the amount of human-induced radiative forcing.

Working against the warming effects associated with the increase in tropospheric ozone concentrations due to NO_x emissions are aviation sulphur and H_2O emissions in the stratosphere, which decrease ozone levels. The effect of sulphur and H_2O emissions on stratospheric ozone levels is thought to partially offset the impacts of NO_x emissions. However, as the IPCC stated in 1999, '[t]he degree to which this occurs is, as yet, not quantified' (IPCC 1999, p. 6).

The second major impact associated with aviation NO_x emissions relates to methane (CH_4), another greenhouse gas. NO_x emissions are believed to decrease the atmospheric concentrations of CH_4. The reduction in CH_4 caused by the emission of NO_x by aircraft is far smaller than the increase in CH_4 due to other human activities. According to the IPCC's estimates, the emission of NO_x by aircraft resulted in methane concentrations in 1992 being approximately two per cent less than they otherwise would have been. To put this in perspective, other human activities have led to a 250 per cent increase in the levels of methane in the atmosphere since pre-

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[20] It is measured in watts per square metre (Wm^2), where positive values imply a net warming and negative values imply a net cooling.

[21] Nitrogen oxides comprise nitric oxide (NO) and nitrogen dioxide (NO_2).

[22] The atmospheric lifetime (or 'residence time') of CO_2 ranges between approximately five and 200 years, but it is often assumed to be around 100 years (IPCC 1999; 2001b).

industrial times. Notwithstanding this, the reduction in CH_4 caused by aviation NO_x emissions will reduce the amount of radiative forcing.

The average radiative forcing associated with the aviation-induced changes in CH_4 and tropospheric ozone are thought to be of a similar magnitude, only one has a warming effect, the other a cooling effect. At first glance, this suggests the effects should cancel each other out. However, CH_4 is like CO_2 in that it mixes well in the atmosphere. In contrast, the effects of NO_x emissions on tropospheric ozone are more concentrated and localised. Hence, NO_x emissions are still expected to have a net warming effect in the relevant regional areas affected by the changes in tropospheric ozone levels.

Water emissions from aircraft are primarily associated with three atmospheric effects. Firstly, aircraft emit water vapour into the lower stratosphere. Here, it builds up and, as a greenhouse gas the vapour traps infrared radiation, leading to warming. Secondly, water vapour emitted by aircraft creates contrails that are like line-shaped clouds. Just like thin clouds, the contrails have a warming effect on the Earth's surface. Thirdly, the presence of contrails can lead to the creation of cirrus clouds, which also lead to warming.[23] While a considerable amount of research has been carried out on the effects of emissions of H_2O, the precise nature of the effects on the atmosphere remain uncertain, particularly in relation to cirrus cloud effects.

The final two aviation emissions that were considered by the IPCC were sulphate and soot aerosols. The impacts of these emissions are thought to partly offset each other as soot has a warming effect while sulphate has a cooling effect (IPCC 1999). However, the impacts associated with soot and sulphate aerosols are thought to be relatively small.

In summary, aircraft emit a cocktail of gases that have different impacts on the atmosphere. The greatest contributors to climate change are CO_2, NO_x and H_2O. While the impacts of aviation CO_2 emissions are well understood, there is a considerable amount of uncertainty surrounding the effects of NO_x and H_2O. The complexity associated with non-CO_2 aviation emissions is magnified by the fact that the atmospheric impacts of these gases can differ depending on the altitude at which they are released. Some of the climatic impacts of non-CO_2 aviation emissions are also localised.

4.3 Aviation's contribution to climate change

Although there is uncertainty surrounding the impacts of aviation emissions, the available evidence indicates that they are currently responsible for only a relatively small proportion of human-induced climate change. The IPCC estimated that in 1992 the radiative forcing from aviation was approximately 0.05 Wm^2 (excluding cirrus cloud effects), 'or about 3.5% of the total radiative forcing by all anthropogenic activities' (IPCC 1999, p. 8). An update of the IPCC's estimates found that despite a

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[23] Contrails and cirrus clouds reflect solar radiation, which has a cooling effect on the Earth's surface. However, they also absorb thermal radiation, which heats the Earth's surface. The heating effect associated with the absorption of thermal radiation is believed to outweigh the cooling effect associated with the reflection of solar radiation (IPCC 1999; RCEP 2002).

significant increase in aircraft traffic, the total radiative forcing from aviation in 2000 was still around 0.05 Wm^2 (Sausen *et al.* 2005). The apparent stability of the estimated radiative forcing from aviation emissions was due to a downward revision of the estimated effect of contrails. Yet, like the IPCC's 1999 estimate, this approximation of the radiative forcing from aviation did not include the effects on cirrus clouds. Sausen *et al.* (2005) found the effects of cirrus clouds could be far greater than the IPCC suggested. On this basis, they concluded that the 'total aviation RF [radiative forcing] could be twice as large as the total RF given here' (i.e. 0.1 Wm^2) (Sausen *et al.* 2005, p. 559). Using the most recent IPCC data as a guide, these figures suggest aviation currently accounts for somewhere in the order of three to six per cent of total net anthropogenic radiative forcing (IPCC 2007).

Even if the upper estimate by Sausen *et al.* (2005) is correct, the evidence suggests the aviation industry's contribution to climate change is still dwarfed by the radiative forcing caused by other sectors, particularly electricity generation and land-based transport. This is the case in Australia, where domestic and international aviation emissions were approximately 11 Mt CO_2-e in 2004, or less than two per cent of total emissions (DEH 2006a). Similar trends are seen around the world. In the US, aviation accounts for about 10 per cent of emissions from transport, or about 2.7 per cent of total US emissions (CCCEF 2007). Similarly, emissions from aviation are equal to approximately three per cent of total emissions in the EU (EC 2005). The Stern Review estimates that aviation emissions accounted for only 1.6 per cent of total global greenhouse gas emissions in 2005 (Stern 2007).

Taking unadjusted greenhouse gas emissions as the basis for determining aviation's contribution to climate change is misleading because it fails to account for the effects of non-CO_2 aviation emissions. As a result, a number of studies have applied an 'uplift factor' to aviation CO_2 emissions to approximate the total impacts of all aviation emissions.[24] The uplift factor is calculated using a radiative forcing index (RFI), which is defined as:

> … a ratio between the total radiative forcing from aviation at some given time to the radiative forcing from aviation emissions of carbon dioxide at the same time (Forster *et al.* 2006, p. 1118).

The 1999 IPCC report concluded that the radiative forcing associated with aviation was approximately two to four times larger (with a best estimate of 2.7 times larger) than the effects related to aviation CO_2 emissions alone.[25] On this basis, several studies have applied uplift factors of between 2.5 and 2.7 in estimating aviation emissions and their contribution to climate change.[26] More recent data from Sausen *et al.* (2005) indicate that the radiative forcing associated with aviation could range between 1.9 and 5.1 (midpoint of 3.5) times aviation CO_2 emissions, depending on whether cirrus cloud effects are included.

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[24] See, for example, Bows *et al.* (2005), DFT (2004) and SCEA (2004). To calculate aviation emissions using an uplift factor, unadjusted aviation CO_2 emissions are multiplied by the relevant metric (i.e. 2.7).

[25] See IPCC (1999), Table 6-1.

[26] See, for example, Bows *et al.* (2005), DFT (2004) and SCEA (2004). For discussion, see also GAO (2000), RCEP (2002), SCEA (2006) and Forster *et al.* (2006).

The use of uplift factors to adjust aircraft CO_2 emissions to provide an estimate of the total climatic impact of aviation is controversial.[27] The science concerning the impacts of non-CO_2 emissions is uncertain and it is difficult to devise a single metric that accurately accounts for the different atmospheric impacts of the various aviation emissions. To compare the impact of different gases on climate change, global warming potentials (GWPs) are generally used. GWPs are a measure of the cumulative radiative forcing associated with a unit mass of the relevant non-CO_2 gas when compared to the same mass of CO_2 over a specified period (typically 100 years) (IPCC 2001b; DEH 2006c). Hence, for example, GWPs allow a comparison to be made between the impact of one tonne of methane on the climate over 100 years versus one tonne of CO_2 over the same period.

Difficulties arise with aviation because GWPs are not calculated for H_2O and indirect greenhouse gases like CO and NO_x.[28] This is because the atmospheric lifetime of these gases are generally short and their impacts and lifespan vary depending on when and where they are released (IPCC 2001b; Forster *et al.* 2006). The absence of GWPs for these non-CO_2 aviation emissions means it is very difficult to compare the impacts of a unit mass of these gases to those associated with a unit mass of other direct greenhouse gases like CO_2.

Uplift factors provide a basis for estimating the combined impact of CO_2 and non-CO_2 aviation emissions in CO_2-e. However, as discussed, they are calculated on the basis of the radiative forcing associated with aviation, which provides a measure of the cumulative impact of past aviation emissions on the Earth’s heat balance at a particular point in time. This is effectively a measure of the historic impact of aviation. As a result, it may not provide an appropriate basis from which to estimate the impact of current emissions for the purposes of devising policy responses to global warming.

In addition, uplift factors are often applied as if they were GWPs without reference to the time horizon of the analysis or the atmospheric lifetime of the gases involved. The atmospheric lifetime of most non-CO_2 aviation emissions is around 10 days, often less (contrails caused by aviation H_2O emissions can last for only a few hours) (Forster *et al.* 2006).[29] In contrast, CO_2 can remain in the atmosphere for hundreds of years. CO_2 may have a lower initial radiative forcing than some non-CO_2 emissions but because it remains in the atmosphere longer its cumulative impact on the climate is likely to be greater. Consequently, the time horizon of the analysis is a crucial determinant of the size of the uplift factor. If the object is to determine the impact of aviation over a 100 years (consistent with the approach adopted under the UNFCCC and Kyoto Protocol), research by Forster *et al.* (2006) suggests the appropriate uplift factor may be less than 2.5 (approximately 1.7 with uncertainties that could be greater than 50 per cent). If the focus is on short-term effects (20 years or less), an uplift factor substantially higher than 2.5 may be appropriate. Irrespective of the time horizons that are chosen,

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[27] See, for example, Bows *et al.* (2005), Tyndall Centre for Climate Change Research (2006) and Forster *et al.* (2006).

[28] Indirect greenhouse gases contribute to global warming by triggering the build up of direct greenhouse gases (for example, ozone).

[29] See also IPCC (2001b).

Forster *et al.* (2006) and others stress that there are significant difficulties associated with devising accurate uplift factors to account for the impacts of non-CO_2 emissions.[30]

When uplift factors of 1.7 and 2.7 are applied to aviation CO_2 emissions to account for the impact of non-CO_2 emissions, they amount to 2.5 to 4.0 per cent of global emissions. The application of the same uplift factors to Australia's aviation emissions suggest they were 18 or 29 Mt CO_2-e in 2004, or between three and five per cent of total emissions. While aviation emissions only constitute a relatively small proportion of total emissions, they have increased rapidly in recent times due to the expansion of the aviation sector.

Since 1990, world aviation emissions have risen sharply, in some regions by as much as 70 percent. Australia has witnessed a similar trend. Between 1990 and 2004, domestic aviation emissions rose from 2.9 to 4.8 Mt CO_2-e, a 65 per cent increase.[31] Similarly, over the same period, Australia's international aviation emissions increased by 38 per cent, rising from 4.4 to 6 Mt CO_2-e. In comparison, since 1990, emissions from road vehicles rose by 25 per cent while emissions from rail and domestic shipping fell (DEH 2006a).

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[30] See, for example, IPCC (2001b).
[31] Unless otherwise stated, aviation emissions do not include an uplift factor.

5. Projected aviation emissions to 2050

Over the coming decades, the aviation industry is expected to continue to grow, leading to further increases in aviation emissions. According to the Stern Review, under business-as-usual conditions, CO_2 emissions from aviation are expected to grow by more than 300 per cent between 2005 and 2050. Moreover, when the full affects of aviation emissions are taken into account, Stern estimated that aviation will be responsible for approximately five per cent of total anthropogenic radiative forcing in 2050 (Stern 2007).[32]

To date, no projections have been prepared on the possible magnitude of Australia's aviation emissions in 2050 under business-as-usual conditions. This section seeks to address this by estimating the possible growth in domestic and international aviation emissions in Australia between 2005 and 2050 under both unadjusted and uplifted scenarios.

5.1 Method

Aviation emissions are essentially a function of fuel consumption, fuel type, engine design and aircraft management.[33] Due to the complexity associated with evaluating each of these issues separately, fuel consumption is often used as the basis for estimating aviation emissions (Newton and Falk 1997; BTRE 2002; 2005). This approach is justified on the grounds that fuel burn is the primary driver of emissions.

The most recent government aviation emission projections for Australia were prepared by the BTRE in 2005 for the period to 2020 (BTRE 2005). These were an update of previous projections carried out in 2002 and 2003 (BTRE 2002; 2005). The BTRE estimated consumption of the two major types of aviation fuel (i.e. aviation gasoline (avgas) and aviation turbine fuel (avtur)) in litres, converted fuel consumption in litres to megajoules and then converted megajoules of fuel consumed to an estimate of total emissions using relevant emission conversion factors. Fuel consumption was modelled using estimates of seat-kilometres (i.e. passenger-kilometres divided by passenger load factor)[34] and fleet fuel intensity (fuel consumption per seat-kilometre). Growth in seat-kilometres was projected on the basis of estimates of several variables, including real gross non-farm product, real medium distance airfares, price and income elasticities, passenger load factors, and the average kilometres travelled per passenger on trunk routes. The BTRE method

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[32] There are other higher estimates of the likely contribution of aviation to anthropogenic radiative forcing in 2050. For example, the Royal Commission on Environmental Pollution (UK) (RCEP) has suggested aviation's contribution to anthropogenic radiative forcing in 2050 is likely to be between 6 and 10 per cent unless there is a significant reduction in growth in the aviation sector or an unforeseen improvement in aviation technology (RCEP 2002).

[33] Aircraft management is important because emissions differ depending on the stage of an aircraft's operations. At cruising altitude and during takeoff, the main emissions are CO_2 and NO_x. While idle, the major non-CO_2 emissions are of hydrocarbons (HC), but significant amounts of NO_x and carbon monoxide (CO) are also emitted. During the approach stage, there is a mixture of CO_2, NO_x, HC and CO (BTRE 2002).

[34] Passenger load factor refers to the proportion of seats filled by passengers. As the passenger load factor falls, seat-kilometres increase and *vice versa* (all things being equal), meaning more aircraft would have to be used and more fuel consumed. In the 2002 BTRE study, the load factor was assumed to remain constant at the 1999-2000 level of 75 per cent.

assumes that increases in seat-kilometres will be partially offset by improvements in the fuel efficiency of the fleet.

The Tyndall Centre for Climate Change Research has estimated likely emissions from aviation in the European Union to 2050 using an alternative and simpler method (Bows *et al.* 2005). The purpose of the study was to provide an approximate guide to the potential magnitude of aircraft emissions if the industry continued to expand under business-as-usual conditions. Rather than relying on estimates of fuel consumption, the Tyndall Centre applied an adjusted passenger growth rate figure to the latest actual aviation emission figures and extended this out to 2050. The passenger growth rate approach was adopted due to its simplicity and the lack of publicly available data to support other methods.

To determine the passenger growth rate to 2050, the Tyndall Centre extrapolated from recent growth rate trends up until 2015 for older EU countries and to 2025 for newer EU countries. The distinction was made between the countries on the basis that the aviation market in the older EU countries was likely to reach maturity in 2015, while maturity in the aviation market in the newer EU countries would take at least until 2025. Beyond the maturity date, the Tyndall Centre assumed the passenger growth rate across all EU countries would be equal to the rate adopted in the UK Government's Aviation White Paper for the period 2000 – 2030 (i.e. 3.3 per cent).

The passenger growth rate was adjusted by subtracting a figure to account for 'a combination of load factor improvement, aircraft design, aircraft size, air transport management and engine efficiency' (Bows *et al.* 2005, p. 51). The figure used for this purpose was 1.2 per cent, which is the average of the efficiency improvements estimated by the IPCC in its 1999 aviation report (IPCC 1999). Consequently, the Tyndall Centre's estimate of emissions for a given year were calculated by subtracting 1.2 per cent from relevant passenger growth rate, then applying the adjusted growth rate to the emissions for the previous year.

There are several other methods for estimating aviation emissions. However, in this paper, we have chosen to use the Tyndall Centre's unadjusted passenger growth rate method. This is justified on the following grounds.

- Like the Tyndall Centre's report, the purpose of this paper is to estimate the possible level of aviation emissions in 2050 to highlight the inconsistencies between the current rate of growth in the aviation industry and the objectives of emerging greenhouse policies.

- Given the long-term nature of the projections, any model is likely to suffer from considerable uncertainties. The adjusted passenger growth rate approach is simple, easy to understand and is based on one of the major drivers of aviation emissions (i.e. demand for aviation services).

- Although aviation emissions are primarily a function of aircraft movements, passenger numbers are a major determinant of aircraft traffic. Passenger load factors have been very stable over the past 30 years at around 70 – 75 per cent (BTRE 2002). As a result, increases in passenger numbers are likely to result in more flights rather than merely an increase in the numbers of passengers per flight. Further, increases in load factors are likely to result in greater fuel use because of increases in weight.

- The major source of data on aviation fuel use in Australia is the Australian Petroleum Statistics series published by the Department of Industry, Tourism and Resources (DITR 2007). There are problems with this database that prevent the accurate attribution of fuel use between the domestic and international markets. In addition, there is a lack of publicly available information on several important variables that are necessary to extend the BTRE estimates beyond 2020 (for example, income and price elasticities for all relevant segments of the aviation market). As a result, there is a risk that the adoption of a fuel consumption-based model may be no more accurate than an adjusted passenger growth rate approach.

- There are differences in the historic aviation emission estimates published by the BTRE (2005) and the Department of the Environment and Water Resources (DEWR 2007).[35] As the paper compares aviation emission estimates to emission reduction targets based on DEWR (2007) data, there was concern that reliance on the BTRE (2005) data could lead to inconsistencies.

- To minimise the risk of overestimating possible emission levels, relatively conservative assumptions have been adopted in relation to uplift factors, passenger growth rates and the fuel efficiency improvements of the domestic and international aircraft fleets. In addition, we have used passenger-kilometre data to project domestic emissions and growth in passenger numbers to project international emissions. The decision to take this approach was made on the basis that there was no international passenger-kilometre data in the 2005 BTRE report. In adopting this approach for international emissions, we have assumed that there is no growth in the average length of international flights (i.e. no increase in the average kilometres travelled per passenger). This is unlikely, as the average length of flights is expected to increase due to falling airfares, rising incomes and improvements in fuels and aircraft design (BTRE 2002).[36] By excluding increases in the average length of international flights, our adjusted passenger growth rate approach underestimates likely increases in international aviation emissions.

Following the approach adopted by the Tyndall Centre, the formula set out below was used to project domestic emissions in Australia from 2005 to 2050.

$$\text{DE for year}_1 = [\text{DE for year}_0 \times [1 + (\text{PGR} - \text{FEF})]] \times \text{UF}$$

Where:

DE = domestic emissions CO_2-e (or CO_2 for scenarios with uplifts factors)

PGR = passenger growth rate

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[35] The differences are primarily due to a change in the average emission factors of the aviation fleet that occurred after the publication of BTRE (2005).

[36] The BTRE assumed that average kilometres per passenger would increase by 1.5 per cent per annum from 2000 to 2020.

FEF = fuel efficiency factor

UF = uplift factor

International aviation emissions were projected over the same period using the following formula.

IE for year_1 = [IE for year_0 x [1 + (PGR – FEF)]] x UF

Where:

IE = international emissions CO_2-e (or CO_2 for scenarios with uplifts factors)

PGR = passenger growth rate

FEF = fuel efficiency factor

UF = uplift factor

The Australian Greenhouse Emissions Information System (AGEIS) was used to obtain the CO_2 and CO_2-e emissions for domestic and international aviation in the base year (i.e. 2004) (DEWR 2007). The estimates of aviation emissions prepared by DEWR are based on fuel acquired or uplifted in Australia.[37] Like the estimates prepared by the BTRE, they also exclude emissions from military operations. The BTRE has estimated that approximately 10 – 20 per cent of domestic avtur fuel sales are for military purposes. Hence, by excluding emissions from military operations, the base year emission estimates of both CO_2 and CO_2-e are an underestimate of the total emissions from all aircraft.[38]

The estimates of CO_2-e emissions included in the AGEIS are drawn from the National Inventory Report that is submitted by the Federal Government under the UNFCCC. The estimates of Australia’s total CO_2-e emissions in the National Inventory Report are based on the major greenhouse gases (i.e. CO_2, CH_4, N_2O, PFCs, HFCs and SF_6). Details of indirect greenhouse gas emissions, including CO and NO_x, are also included in the national inventory report. However, because there are no GWPs for these indirect greenhouse gases, they are not included in the national totals of CO_2-e emissions. As a result, the base year unadjusted CO_2-e estimates underestimate aviation emissions by excluding relevant gases, particularly NO_x**.**

Data on the passenger growth rate were obtained from the BTRE for the period 2005 to 2020 (BTRE 2005).[39] In contrast to the Tyndall Centre report which relies solely on the growth in passenger numbers, we used the growth in passenger kilometres to determine the domestic passenger growth rate between 2005 and 2020. For international emissions, the passenger growth rate between 2005 and 2020 was

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[37] The international emissions data used in the Tyndall Centre report were calculated using an assumption that emissions from international bunker fuels would be divided equally between the countries of departure and arrival.

[38] The base year estimates are also significantly less than the BTRE estimates for 2004.

[39] BTRE (2005) uses a constrained growth approach that assumes air travel never exceeds a 40 per cent mode share of non-urban passenger-kilometres.

determined using the growth in international passenger numbers. This approach was adopted because the 2005 BTRE report only provides data on growth in passenger kilometres for domestic aviation and the growth in passenger numbers for international aviation.

As the BTRE projections do not extend beyond 2020, an estimate of the passenger growth rate over the period 2021 – 2050 had to be devised. The Australian Bureau of Agricultural and Resource Economics (ABARE) has estimated that over the period 2004-05 to 2029-30, GDP is likely to grow at an average of 2.6 per cent (Cuevas-Cubria and Riwoe 2006). In the medium term to 2010-11, ABARE expects GDP growth of around three per cent per annum, which is then projected to fall to 2.5 per cent between 2010-11 and 2029-30.

The Intergenerational Report that was released as part of the May 2002 Federal Budget presents a more subdued picture of expected GDP growth. During the 2020s, Treasury forecasted real GDP growth of 1.4 to 2.2 per cent, falling to 1.3 to 2.1 per cent in the 2030s (Department of Treasury 2002). The most recent Intergenerational Report, released in April 2007, projects average annual real GDP growth of approximately 2.4 per cent over the next 40 years (Department of Treasury 2007). Like the 2002 report, the 2007 report suggests annual real GDP growth will decline gradually over the coming decades, falling from 2.6 per cent/yr in the 2010s, to 2.3 per cent/yr in the 2020s, 2.2 per cent/yr in the 2030s and finally to 2 per cent/yr in the 2040s.

Given the available data, it appears annual GDP growth is likely to be approximately 2 – 2.2 per cent from 2021 to 2050. Research on the aviation industry also indicates that income elasticities of demand for aviation services are high,[40] but that they will gradually decline over time as the market matures, particularly in relation to domestic services. Analysts have also projected that revenue passenger kilometres will grow by five per cent per annum in the Asian market between 2016 and 2025, down from 7.4 per cent per annum over the period 2006 – 2015 (Airbus 2006). On this basis, and following discussions with the BTRE team responsible for revised aviation growth projections due out later in 2007, we have assumed an annual passenger growth rate for domestic aviation of 3.5 per cent from 2021 to 2035, falling to 3 per cent from 2036 to 2050. For international aviation, we have assumed an annual passenger growth rate of 4.2 per cent from 2021 to 2035 and 4 per cent from 2036 to 2050.[41]

The fuel efficiency factor represents the annual rate of improvement in fuel efficiency that is expected to arise as a result of improvements in aircraft and engine design, advancements in fuel technology and air traffic management. As discussed, based on the 1999 IPCC report, the Tyndall Centre assumed an average fuel efficiency improvement of 1.2 per cent/yr to 2050. The BTRE has suggested that the rate of fuel efficiency improvement of the Australian domestic aircraft fleet to 2020 is likely to be higher, at approximately 1.6 per cent/yr. Its projections for the rate of fuel efficiency improvement of the international aircraft fleet to 2020 are very similar to the rate adopted by the Tyndall Centre (i.e. approximately 1.2 per cent/yr).

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[40] See Section 5 for further discussion of income elasticities of demand for aviation services.

[41] BTRE suggested 3.5 per cent for domestic aviation and 4.2 per cent for international aviation for the entire period 2020 – 2050. We revised these estimates down for the period after 2035 to ensure our outputs were conservative and to account for uncertainties, growth constraints and the expected gradual decline in GDP growth.

On the basis of the data in the 1999 IPCC report, and to ensure consistency with the method employed by the Tyndall Centre, we have used a constant fuel efficiency factor of 1.2 per cent/yr for the period 2005 to 2050 for both domestic and international emissions. This is a relatively high figure as research suggests the IPCC's estimate may have been overly optimistic and that fuel efficiency improvements are decreasing and they will continue to decline over time (Peeters *et al.* 2005).

To account for the BTRE's higher fuel efficiency improvement estimate for the domestic fleet, we have developed alternative scenarios that use a fuel efficiency factor for domestic emissions of 1.6 per cent/yr from 2005 to 2020, 1.4 per cent/yr from 2021 to 2035, and 1.2 per cent/yr from 2035 to 2050. The fuel efficiency factor for international emissions is assumed to remain constant at 1.2 per cent/yr from 2005 to 2050. The decision to reduce the fuel efficiency factor over time in relation to domestic emissions was based on the IPCC's assessment that annual fuel efficiency improvements are likely to fall beyond 2020 as the opportunities for technological advancement diminish (IPCC 1999).[42] While the evidence suggests fuel efficiency improvements could fall below 1.2 per cent/yr over the projected period, this rate was adopted as a minimum level to ensure conservative outputs.

We have developed four emission scenarios to account for the impacts of non-CO_2 emissions released at altitude and the different fuel efficiency improvement assumptions.

- No Uplift Scenarios (NU1 and NU2). These two scenarios assume there is no uplift factor. They are based on estimates of CO_2-e obtained from AGEIS for 2004. As noted, the estimates of CO_2-e in AGEIS do not include all greenhouse gas emissions from aviation (for example, NO_x is excluded). NU1 assumes a constant fuel efficiency factor of 1.2 per cent/yr for the period 2005 to 2050 for both domestic and international emissions. NU2 uses a fuel efficiency factor for domestic emissions of 1.6 per cent/yr from 2005 to 2020, 1.4 per cent/yr from 2021 to 2035, and 1.2 per cent/yr from 2035 to 2050. The fuel efficiency factor for international emissions under NU2 is assumed to remain constant at 1.2 per cent/yr from 2005 to 2050. The use of the official CO_2-e emission data for 2004 and absence of uplift factors in these scenarios means they provide a conservative estimate of aviation emissions and their contribution to climate change.

- Uplift Scenario One (US1). This scenario applies an uplift factor of 1.7 to CO_2 estimates. The base year CO_2 estimates were obtained from the AGEIS. A constant fuel efficiency factor of 1.2 per cent/yr for the period 2005 to 2050 is assumed. The uplift factor of 1.7 was chosen on the basis of the estimates in Forster *et al.* (2006) using a 100 year time horizon. The 100 year time horizon is consistent with the method applied under the UNFCCC and Kyoto Protocol.

- Uplift Scenario Two (US2). This scenario uses an uplift factor of 2.7, as adopted in the Tyndall Centre report. Forster *et al.* (2006) also suggest that their estimate of an uplift factor of 1.7 over a 100 year time horizon could be

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[42] See also Peeters *et al.* (2005).

> subject to uncertainties of greater than 50 per cent. If the actual GWPs of non-CO_2 emissions are 50 per cent higher than Forster *et al.* (2006) estimate, the uplift factor would be almost 2.7. Like US1, the uplift factor of 2.7 is applied to CO_2 estimates and a constant fuel efficiency factor of 1.2 per cent/yr is assumed.

It is important to emphasise the uncertainties associated with the use of uplift factors. As discussed in Section 4, there is no accurate metric to convert non-CO_2 aviation emissions into CO_2-e. US1 and US2 are merely intended to provide a guide as to the potential magnitude of effects of aviation emissions over a 100 year time horizon. They should be viewed as indicative only.

The constant fuel efficiency factor of 1.2 per cent/yr was used in the uplift scenarios to ensure consistency with the method in the Tyndall Centre report. In addition, even if the fuel efficiency factor assumptions that were applied in the NU2 Scenario are used to calculate total unadjusted CO_2 emissions, the difference between the projections at 2050 is relatively small (42.1 Mt CO_2 under the NU1 assumptions versus 40.8 Mt CO_2 under the NU2 – see Appendix C). As a result, it was considered that applying two sets of fuel efficiency factor assumptions to the uplift scenarios on the basis of those adopted in the NU1 and NU2 Scenarios would introduce unnecessary complexity and impede comprehension. For completeness, the outcomes from applying the NU2 fuel efficiency factor assumptions to US1 and US2 are provided in Appendix B.

Due to the similarity in the projections under the NU1 and NU2 Scenarios, the outcomes from the NU2 Scenario are not discussed in the following sections. However, data tables for the NU1, NU2, US1 and US2 Scenarios are provided in Appendix A.

5.2 Projected domestic aviation emissions

Figure 3 plots the projected emission scenarios for domestic aviation from 2005 to 2050. Under US1, domestic aviation emissions rise from 8.7 to 26.3 Mt CO_2-e over this period, a 203 per cent increase. US2 suggests domestic aviation emissions will rise from 13.8 to 41.8 Mt CO_2-e between 2005 and 2050. Under the NU1 Scenario, aviation emissions increase from 5.2 to 15.6 Mt CO_2-e between 2005 and 2050.[43]

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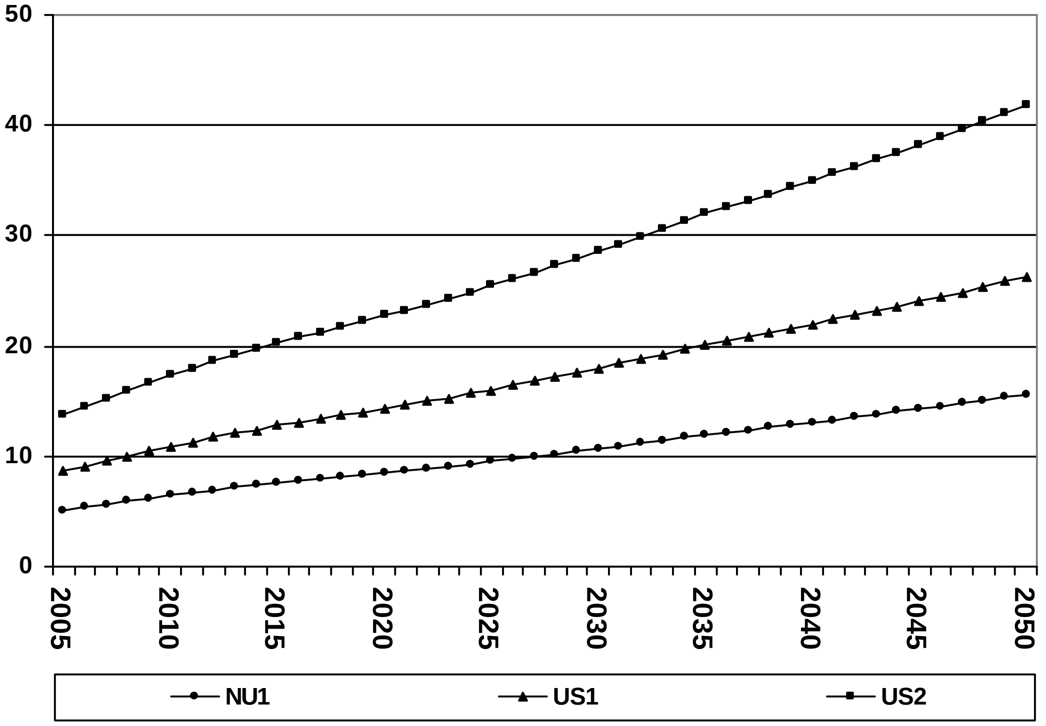
[43] Immediately prior to publication, the Federal Government published the 2005 *National Greenhouse Accounts*, which state that domestic aviation emissions in 2005 were 5.1 Mt CO_2-e, slightly below the NU1 estimate (DEWR 2007)

Figure 3 Projected growth in domestic aviation emissions to 2050, in Mt CO_2-e



5.3 Projected international aviation emissions

Figure 4 plots projected emission scenarios for international aviation to 2050. US1 suggests international aviation emissions will rise from 10.8 to 45.3 Mt CO_2-e between 2005 and 2050, a 318 per cent increase. Under US2, international aviation emissions rise from 17.2 to 72 Mt CO_2-e over this period. Under the NU1 Scenario, emissions from international aviation are projected to increase by 320 per cent between 2005 and 2050, rising from 6.4 to 26.9 Mt CO_2-e.[44]

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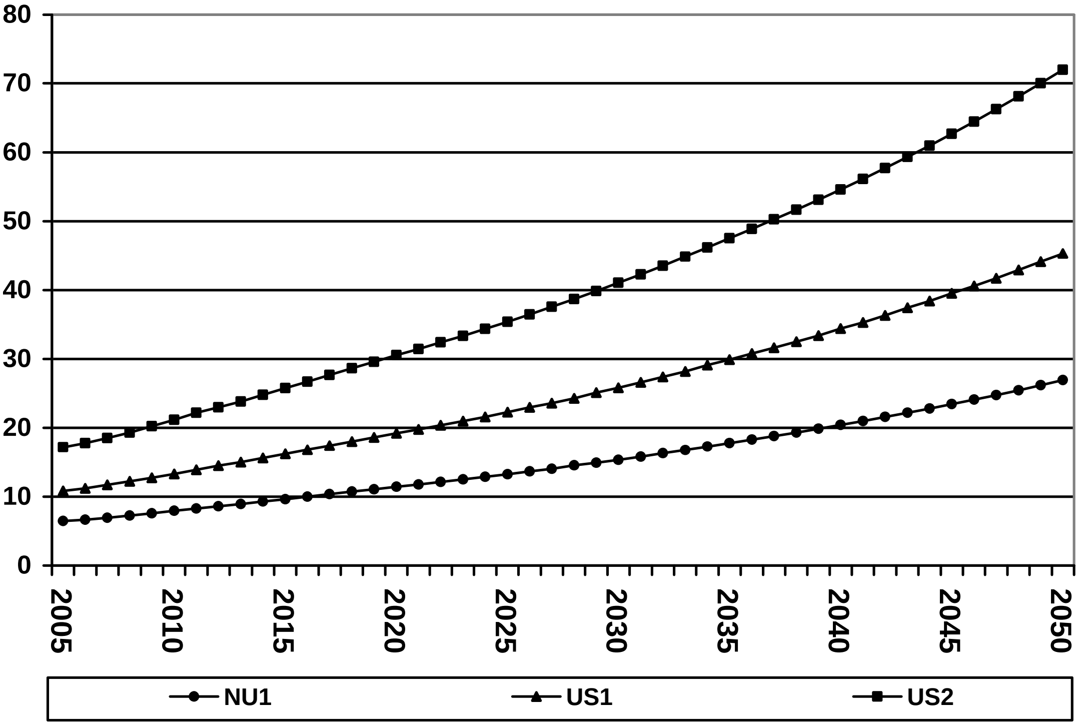
[44] The 2005 *National Greenhouse Accounts* state that international aviation emissions in 2005 were 6.8 Mt CO_2-e (DEWR 2007).

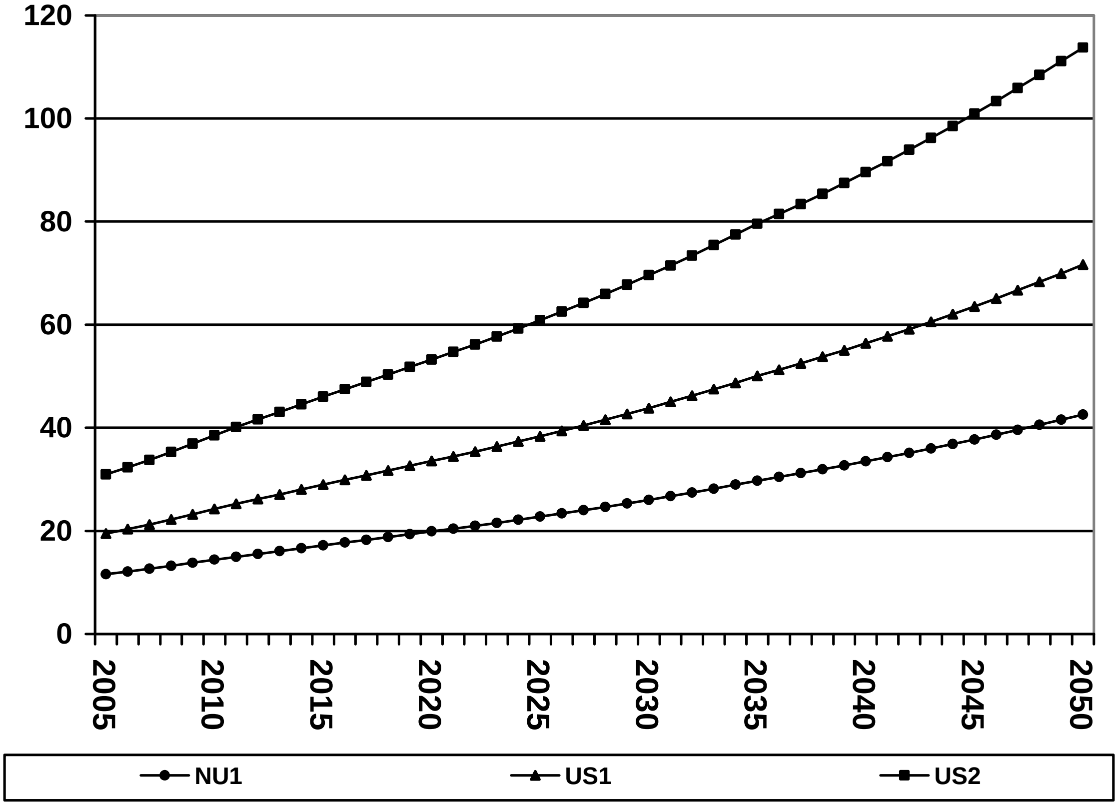
Figure 4 Projected growth in international aviation emissions to 2050, in Mt CO_2-e



5.4 Total projected aviation emissions

Figure 5 shows the growth in Australia's total aviation emissions over the period 2005 to 2050. Under US1, aviation emissions rise from 19.5 to 71.6 Mt CO_2-e, a 267 per cent increase. US2 suggests aviation emissions will rise from 31 to 113.8 Mt CO_2-e. Under the NU1 Scenario, total emissions increase from 11.6 to 42.5 Mt CO_2-e between 2005 and 2050.

Figure 5 Projected growth in total aviation emissions to 2050, in Mt CO_2-e



5.5 Projected aviation emissions versus desired emission reduction targets

There is a significant risk that if the aviation sector is allowed to continue on its current growth trajectory it could undermine efforts to reduce emissions. In Europe, several studies have warned that the limitless growth in aviation emissions could derail attempts by the EU to meet emission reduction targets (RCEP 2002; Bishop and Grayling 2003; Bows *et al.* 2005; Wit *et al.* 2005; Bows and Anderson 2007; Stern 2007). In this section, we consider whether this could happen in Australia.

Based on the analysis in Section 2, we have adopted two emission reduction targets for 2050; 80 per cent below 2000 levels (i.e. 104.5 Mt CO_2-e) and 60 per cent below 2000 levels (i.e. 223.2 Mt CO_2-e). The 80 per cent target assumes that a contraction and convergence strategy is adopted in conjunction with a global emission target of 34 $GtCO_2$-e/yr in 2050, based on the goal of stabilising atmospheric greenhouse gas concentrations at 550 ppm CO_2-e.[45] The 60 per cent target is a political compromise that assumes that a higher stabilisation goal is adopted and/or that the developed nations abandon or postpone convergence.

In this paper, we have chosen the 60 per cent target as the preferred goal because it is consistent with the position adopted by the ALP and governments in other developed nations, particularly in the EU. In the longer term, it is likely that the 80 per cent

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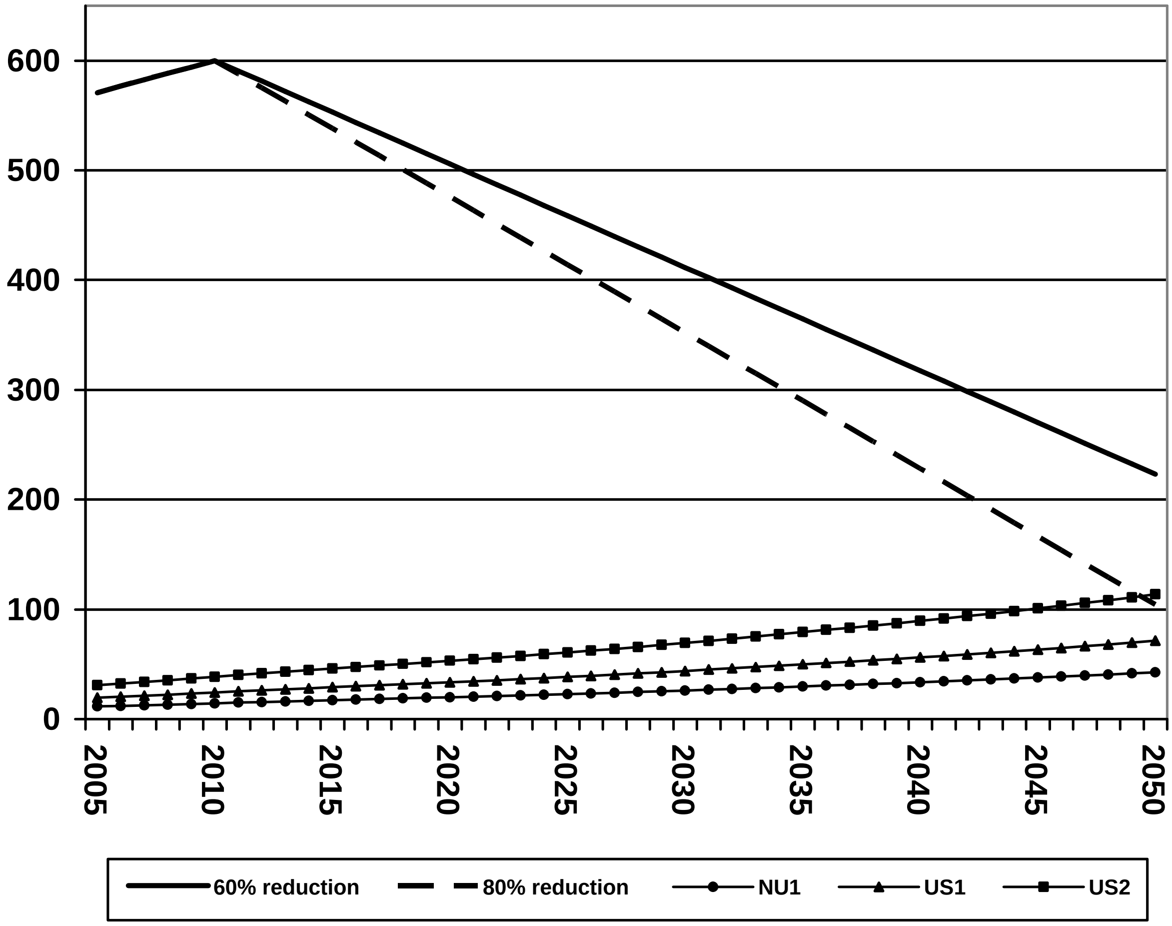
[45] The precise nature of the emission target will ultimately depend on the trajectory of emissions. If emissions are allowed to continue to increase in the short- to medium-term, deeper cuts will be required in later years to keep the atmospheric concentration of greenhouse gases below 550 ppm CO_2-e.

target (or a higher target) will be necessary if the object of government policy is to avoid dangerous climate change.

Figure 6 plots the projected NU1, US1 and US2 Scenarios alongside the two emission target scenarios. Both emission target scenarios assume emissions increase to a maximum of 600 Mt CO_2-e in 2010, in line with Federal Government forecasts (DEH 2006b). Beyond 2010, we have assumed emissions are reduced by a constant amount each year to 2050. For the 60 per cent target, this assumption results in a reduction of 9.42 Mt CO_2-e per year from 2010. For the 80 per cent target, emissions would have to be reduced by 12.39 Mt CO_2-e per year after 2010.[46]

Figure 6 Projected aviation emissions versus emission reduction targets, to 2050, in Mt CO_2-e



As shown in Figure 6, under US1, aviation emissions account for almost one third (32 per cent) of Australia's total emissions in 2050 if there is a 60 per cent emission reduction target. US1 suggests aviation emissions will consume 69 per cent of Australia's total emissions in 2050 if there is an 80 per cent reduction target.

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[46] In reality, emissions are unlikely to be reduced at a constant rate because of different abatement costs, political factors and the need to limit the total amount of emissions between 2005 – 2050 if the object is to keep the atmospheric concentration of greenhouse gases below 550 ppm CO_2-e. The linearity assumption was adopted due to the difficulty in determining alternatives and the fact that the object of the paper is to highlight the potential contribution of aviation emissions to Australia's total emissions in 2050.

Under US2, aviation emissions account for approximately half (51 per cent) of Australia’s total emissions in 2050 if there is a 60 per cent reduction target. With an 80 per cent target, US2 suggests aviation emissions will consume more than Australia’s entire emissions space (109 per cent) by 2050.

Under the NU1 Scenario, aviation emissions are expected to account for 19 per cent of Australia’s emission space in 2050 with a 60 per cent target. With an 80 per cent target, aviation emissions account for approximately 41 per cent of Australia’s emissions in 2050.

In summary, if the Australian aviation sector is allowed to continue to operate under business-as-usual conditions and the Federal Government adopts a target of reducing emissions to 60 per cent below 2000 levels by the middle of this century, aviation could account for between 32 and 51 per cent of the total greenhouse gas allowance by 2050. If the reduction target is set at 80 per cent below 2000 levels by 2050, aviation could account for more than Australia’s entire emission allowance at 2050.

6. Solutions

6.1 The technology potential

In essence, there are three areas where technological advances have the potential to ameliorate aviation's contribution to climate change: alternative fuels, engine and aircraft design, and operational procedures.

Alternative fuels

All aircraft currently use kerosene-based fuels. This is because kerosene-based fuels provide the best combination of energy density, vapour pressure and combustion characteristics. The burning of this fuel during flight and taxying produces emissions.[47] Accordingly, the development of alternative fuels or means to power aircraft would substantially reduce aircraft emissions, in the same way that gas- or solar-powered motor vehicles reduce emissions.

The principal alternative to kerosene-based fuel is hydrogen. Hydrogen presents a means to eliminate CO_2 and reduce NO_x emissions from aircraft. However, there are a number of potential problems with the use of hydrogen. Firstly, while hydrogen reduces aircraft emissions at the point of use, the total impact of switching from kerosene to hydrogen-based fuels will depend on how the hydrogen is produced. If the hydrogen is produced from non-renewable energy sources, there is unlikely to be a significant reduction in emissions.

Secondly, hydrogen is significantly less dense than kerosene. As a result, it is estimated that a hydrogen-fuelled aircraft would have to carry two and half times the volume of equivalent kerosene. To cope with the additional load, the frame of the aircraft would need to be larger, creating greater drag. Because of the additional drag and reduced weight, the aircraft would need to fly at higher altitudes. Yet flying at higher altitudes is only likely to be viable for long-haul flights. Therefore, if hydrogen-fuelled aircraft are introduced, they are most likely to be concentrated on long-haul routes, leaving short-haul flights dependent on kerosene-fuelled aircraft (RCEP 2002).

The third major problem associated with hydrogen is that it would result in approximately 2.6 times more water vapour emissions than kerosene-based fuels, leading to enhanced contrail and cirrus cloud effects. Because hydrogen-fuelled aircraft are likely to have higher cruise altitudes, the water emitted into the stratosphere from the aircraft could potentially have a larger warming effect than emissions from current kerosene-based aircraft (IPCC 1999; RCEP 2002).

An additional problem with hydrogen is that it would require significant changes in aircraft design and aviation infrastructure (IPCC 1999). Hence, even if the other issues associated with hydrogen-fuelled aircraft were overcome, it would take a considerable amount of time to introduce and is likely to be costly. This is a problem that is likely to be associated with most alternative fuels.

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[47] The major emissions that are directly influenced by fuel type are CO_2, H_2O and SO_x (IPCC 1999).

Another alternative to kerosene-based fuel is ethanol, a type of biofuel normally derived from crops like sugar or corn. A major problem with ethanol is that it has low energy density, meaning aircraft would have to carry a greater mass of fuel. In addition, ethanol has ‘less attractive combustion characteristics’ than existing fuels. These include the fact that ethanol has a very low flash point, making it unsafe. The combustion of ethanol and other similar fuels at ground level can also result in local air quality issues (IPCC 1999). Further, as the Royal Commission on Environmental Pollution (UK) (RCEP) has argued:

> … under conditions prevailing in some phases of a flight, especially approach, it would be difficult to eliminate formation of formaldehyde as a pollutant in the exhaust gases.

Due to these issues, the IPCC described ethanol and other similar biofuels as ‘impractical’ for aviation (IPCC 1999).

In summary, it seems unlikely that alternative fuels will make a significant contribution to reducing aviation’s contribution to climate change in the near future. In the words of the IPCC:

> [t]here would not appear to be any practical alternatives to kerosene-based fuels for commercial jet aircraft for the next several decades (1999, pp.10 – 11).

Engine and aircraft design

Although improvements in jet engine design have led to significant increases in fuel efficiency over the last 40 to 50 years,[48] the dominant form of basic gas turbine engine that emerged in 1947 remains today and there is no evidence to suggest that this will change in the coming decades. Moreover, because engine technology is now relatively mature, the greater share of future improvements in fuel efficiency are likely to come from changes in aircraft design (IPCC 1999; RCEP 2002).

The 1999 IPCC report considered the potential for improvements in aircraft design. Experts from the aeronautical industry developed technology scenarios relating to fuel efficiency and NO_x emissions based on the emerging effects of research and technology programs on airframes and engines. The report states:

> [a]ccording to these scenarios, average fuel efficiency of new production aircraft in the scheduled commercial fleet may improve by 20% between 1997 and 2015. The corresponding scenarios for improvement between 1997 and 2050 involved two different technology scenarios to take account of tradeoffs between fuel efficiency and low NO_x in aircraft designs. In the first case, with fuel efficiency taking priority, a 40-50% improvement in the fuel efficiency of new production aircraft was projected. In the second case, where NO_x reductions took priority, a 30-40% improvement in fuel efficiency was envisaged (IPCC 1999, Chapter 7).

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[48] Research by Peeters *et al.* (2005) found that while the fuel efficiency of jet aircraft has improved considerably since the middle of last century, the current jet aircraft are only about as fuel efficient as the last piston-powered aircraft from the mid-1950s.

Air frame improvements are expected to play a significant role in these scenarios. One example is a new design concept for a blended wing-body aircraft (BWB). The BWB aircraft has the body partly or wholly contained within the wing, so that the inside of the wing is also the passenger cabin. The RCEP claimed that the BWB could ‘be significantly lighter and experience very much lower drag than the conventional swept wing-fuselage airframe design’ (RCEP 2002, p. 25). However, as the RCEP noted, the BWB design is still at the conceptual stage and it will be many decades before BWB aircraft make any significant contribution to aviation. It is also only likely to affect long-haul flights because the passenger cabin needs to be large enough for people to stand meaning large wings and hence large aircraft (RCEP 2002). Accordingly, while some incremental improvements are projected in the coming decades from the use of new materials and composites, it is unlikely that changes in engine or aircraft design will significantly alleviate the effects of aircraft on global warming.

Operational procedures

Immediate improvements can be made in the fuel efficiency of aircraft through changes in operational procedures, particularly air traffic management (ATM). ATM systems are used for the guidance, separation, coordination and control of aircraft movements. According to a report by the Environmental Change Institute at Oxford University, there are two ways in which ATM could limit the emissions from aircraft. Firstly, ATM could reduce the present inefficiency in flight patterns by reducing landing delays and permitting aircraft to fly more optimal routes (Cairns *et al*. 2006). For example, current national and international ATM systems often force aircraft to fly in inefficient holding patterns, resulting in considerable fuel burn. According to the IPCC, improvements in ATM have the potential to reduce aviation fuel burn by between six and 12 per cent to 2020 (IPCC 1999).

Secondly, there is the possibility over the longer term for long-haul flights to be routed to limit their environmental impacts. For example, there is some research to suggest that the contrail effect from aircraft is worse at night. Other research also suggests that differences in conditions can have a significant overall impact on the effect of the flight. It is possible that altitude restrictions for example, could be used to ensure aircraft avoid atmospheric conditions where contrails are more likely to form (Cairns *et al*. 2006). Nevertheless, the possibility for routing flights in this way requires better scientific understanding of the effect of aviation emissions at altitude, and there is a chance that it could increase CO_2 emissions because some of these routes may be longer (RCEP 2002; Cairns *et al*. 2006).

Summary

Since 1999, a number of studies have confirmed the IPCC’s conclusions about alternative fuels, engine and aircraft design and operational procedures. Most have found that technology does not have the potential to stop the projected growth of greenhouse gas emissions from aircraft. Indeed, some reports argue that industry estimates of the potential of technology are overly optimistic and that there are no serious indications that radical new technological advancements are on the horizon to substantially reduce the contribution of aviation to climate change. As the RCEP concluded in 2002:

> [t]he ambitious targets for technological improvement in some industry announcements are clearly aspirations rather than projections; IPCC's projections are already optimistic. Despite the considerable opportunities for incremental improvements to the environmental performance of individual aircraft, these will not offset the effects of growth. Kerosene will continue to be the industry fuel for the foreseeable future. A non-incremental change could result from radically new airframe designs, with improved fuel efficiency and possibly lower noise and emissions, but this change will not affect the industry for decades and even then will only affect large long-haul aircraft (RCEP 2002, p. 37).

Notwithstanding these and other similar findings, the International Air Transport Association (IATA) argues that:

> [a]ccelerated technological advancements and work on potential alternative fuels for aviation must be the primary means to address aviation's greenhouse gas emissions (IATA 2006a).

Despite the optimism of the IATA, it is clear there are no readily available technological solutions to address aviation's contribution to climate change. Consequently, if aviation emissions are to be constrained, policy measures need to be put in place to promote innovation, improve efficiencies and address the expected rapid growth in demand for air travel.

In the remainder of this section, we canvass the principal policy options to reduce the aviation sector's contribution to climate change. They can be divided into four categories: voluntary measures; regulation; taxes and charges; and emissions trading.

6.2 Voluntary measures

Voluntary approaches can be defined as 'any mechanism or program that aims to protect the environment where relevant economic agents are able to decide whether or not to participate' (Macintosh and Hamilton 2006). As this definition suggests, participation in these types of programs is voluntary and no direct penalties are imposed on non-participants or those that withdraw, although incentives may be used to encourage participation.

From an economic perspective, voluntary programs are attractive because they are flexible, which allows polluters to find the most cost-effective way to reduce emissions. Voluntary programs are also non-interventionist; a factor that often makes them attractive to governments because there is no need to force restrictions on unwilling polluters.

The major flaw in voluntary approaches is that they are unlikely to result in an optimal level of environmental protection because of the absence of appropriate price signals and their vulnerability to free-riding. As there are no penalties for non-participation, recalcitrant polluters will be tempted to ignore voluntary programs and rely on the goodwill of others to reduce the environmental impacts of the relevant industry.

Due to their flexibility and the absence of direct sanctions, business groups often support voluntary programs as the solution to environmental problems. This has been the case in relation to aviation emissions. For example, Dave Castelveter from the Air Transport Association of America has stated that:

> [w]e certainly do not oppose curbing emissions, but we think the best approach is through a voluntary set of programs … . We don't think telling U.S. carriers you have to fly through some artificially created emissions program is the right answer (Cusick 2007).

Similarly, in February 2007, Greg Russell, chief executive of Airservices Australia, stated that:

> [a] failure by air navigation service providers to accept the urgency of the need for action on greenhouse emissions will ... lead to punitive action by governments. We must actively pursue, and be seen as pursuing, measures to reduce fuel burn and therefore reduce emissions (cited in Creedy 2007).

Business support for voluntary aviation emission measures has made them appealing to governments and the ICAO. Resolution A 35-5 of the Council of the ICAO states that the Council encourages action by contracting states to limit or reduce international aviation emissions, 'in particular through voluntary measures'.[49] The ICAO has also developed guidelines and a template agreement to facilitate voluntary undertakings.

In Europe, the Report of the Group of Personalities (comprised of leaders from the European aviation industry) that was published in 2001 recommended the establishment of the Advisory Council for Aeronautics Research in Europe (ACARE) and the adoption of a goal of a 50 per cent cut in CO_2 emissions per passenger kilometre in new aircraft by 2020 and a 80 per cent cut in NO_x emissions (Argüelles *et al.* 2001). After ACARE was established, these emission reduction goals were adopted as part of the organisation's strategic research agenda (ACARE 2002; 2004). The National Aeronautics and Space Administration (NASA) in the United States has similar goals (Stern 2007). These emission reduction targets are unilateral voluntary measures in that they are not legally binding and are an expression of the aspirations of the relevant bodies.

Voluntary approaches to aviation emissions have proven popular in Australia. For example, the federal Transport and Transport Infrastructure Working Group Report in 2003 shied away from recommending mandatory measures to address the projected rise in aviation emissions (TTIWG 2003). The Working Group, which was primarily made up of representatives from the transport industry, suggested that the answers lay in voluntary measures, including:

- encouraging aircraft fuel efficiency;
- encouraging and facilitating the introduction of larger capacity aircraft;

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[49] ICAO Assembly Resolutions, A 35-5, Appendix I, 'Market-based measures regarding aircraft engine emissions', Clause 2(a), Document No. 9848, 2004.

- removing aviation fuel excise and potentially removing GST from aviation fuel purchases to encourage investment in new technology;

- encouraging and assisting with the conversion of ground transport and support equipment to alternative power sources; and

- developing better bus, rail and road networks at airports.

The only notable mandatory measure the Working Group recommended was the improvement of air traffic control and airport planning, which is in the commercial interests of aviation operators. The group also emphasised that any measures that are implemented 'must avoid the creation of cost and operational impediments that will affect competitiveness' (TTIWG 2003, p. 27).

Despite the enthusiasm shown toward voluntary approaches, the evidence strongly suggests they are unlikely to address the problems posed by aviation emissions. In order for voluntary approaches to be effective, there must be a strong and credible threat of regulatory intervention by government (Segerson and Miceli 1998; Khanna 2001). At present, that threat does not exist in Australia. Further, the competitive nature of the international aviation industry means there is a substantial risk of free-riding. The nature and magnitude of the emission reduction challenge also does not lend itself to voluntary approaches. Consequently, while voluntary programs may be useful as a complementary or interim policy measure, they should not be relied upon as a main vehicle for addressing the problems associated with international and domestic aviation emissions.

6.3 Regulation

Regulatory instruments impose legally binding restrictions on polluters in order to achieve environmental outcomes. In terms of aviation emissions, regulatory instruments could include such things as mandatory fuel efficiency standards, prescribed flight routes, restrictions on the use of certain fuels or fuel additives, mandatory navigation equipment requirements, bans on certain flights or even restrictions on the number of flights.

As discussed in Section 3, government bodies including DOTARS, Airservices Australia, CASA and the ACCC administer regulatory regimes governing the operation of the aviation industry. However, in the main, the restrictions imposed by these bodies are designed to ensure the safety, efficiency and competitiveness of the aviation industry. There are environmental requirements, but few of these are intended to reduce the emission of gases that are contributing to the greenhouse impacts associated with aviation. One exception is the *Air Navigation (Aircraft Engine Emissions) Regulations 1995* (Cwlth), which implements the aircraft emission requirements in Annex 16, Volume II of the Chicago Convention.

Annex 16, Volume II of the Convention is primarily designed to address local air quality issues associated with aviation operations. The Annex sets required emission levels for hydrocarbons (HC), CO, NO_x and smoke and it is directed at the emissions during the landing and take-off (LTO) cycle (i.e. ground level emissions). It does not cover other relevant gases, such as CO_2, sulphur dioxide (SO_2) and water vapour, and it does not directly regulate cruise altitude emissions. Notwithstanding this, by imposing emission standards on gases like NO_x and CO it does have an incidental impact on aviation-related greenhouse issues.

Another example of the types of steps taken thus far by these bodies to reduce emissions is the designation of ‘fuel friendly’ flight routes and improvements in ATM. The designation of new flight routes and changes to ATM are driven mainly by commercial considerations. However, where the changes cut travel time and fuel use, they will also reduce emissions. For example, in 2002, Airservices Australia said that new fuel friendly routes between Australasia and Europe would ‘drastically reduce aviation fuel consumption, cut greenhouse gas emissions, reduce travel times between Australasia and Europe and enhance aviation safety’ (Airservices Australia 2002). Similarly, in March 2007, the Federal Minister for Transport and Regional Services, Mark Vaile announced ‘a range of measures to reduce aviation greenhouse emissions to help combat climate change’ that included ‘improved fuel efficiency through more flexible flight tracks, improved aircraft air traffic control sequencing to reduce fuel burn/emissions, more efficient runway use and continuous descent approaches which minimise speed changes’ (Vaile 2007).[50] Some of these measures were already in operation when they were announced by the Minister. However, the package described by the Minister should result in improved profitability for airline operators, while simultaneously reducing emissions.

Regulatory instruments are generally inferior to economic instruments like taxes and emissions trading schemes. This is because they are inflexible and do not provide a financial incentive for aviation operators to reduce emissions. They also lack a mechanism to ensure the marginal cost of abating emissions is equalised across all relevant aviation operators, which is essential if emission cuts are to be achieved at least cost. In addition, regulatory mechanisms can be difficult and costly to administer.

Despite these deficiencies, regulatory instruments could play an important interim or complementary role. For example, regulatory measures may be useful in dealing with water vapour emissions that contribute to contrail and enhanced cirrus cloud formation as it may be difficult to capture these issues within a tax or emission trading scheme. Similarly, emission standards implemented through the ICAO may help address NO_x emissions. Regulatory measures can also play a crucial role in improving operational procedures and ATM. However, in most cases, taxes and emissions trading should provide a more cost-effective solution to the challenges posed by rising aviation emissions.

6.4 Taxes and charges

Under the ICAO framework, a distinction is made between taxes and charges. Taxes are viewed as levies that aim to raise revenue for non-aviation purposes, while charges are levies to ‘defray the costs of providing facilities and services for civil

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[50] A day later, the transport ministers from the 21 countries that make up the Asia-Pacific Economic Cooperation (APEC) announced they would ‘work cooperatively on practical measures to reduce aviation greenhouse gas emissions’ (APEC 2007). The measures that were announced included improvements in ATM.

aviation'.[51] Generally, the policies and rules of the ICAO regime aim to eliminate taxes and minimise charges to those viewed as absolutely necessary. For example, under the Chicago Convention, fuel that is retained on board an aircraft that lands in another country that is a party to the Convention is required to be exempt from local fees, duties and charges.[52] Further, the ICAO's *Policies on Taxation in the Field of International Air Transport* recommends that fuel taken on board aircraft involved in international air services be exempt from 'customs or other duties on a reciprocal basis' or that the duties be refunded.[53] It also calls on the contracting parties to 'eliminate as soon as its economic conditions permit all forms of taxation on the sale or use of international transport by air'.[54] These exemptions are implemented via bilateral agreements and are justified on the grounds that multiple taxation and charges on air services could cripple the industry and obstruct international trade and travel.

Notwithstanding these provisions, the ICAO regime does not prohibit environmental charges to help lower aviation emissions. These charges can be applied provided they do not discriminate against other contracting parties and are consistent with the other applicable requirements of the ICAO regime. The current resolutions of the ICAO Council state that it:

> [s]trongly recommends that any environmental levies on air transport which States may introduce should be in the form of charges rather than taxes and that the funds collected should be applied in the first instance to mitigating the environmental impact of aircraft engine emissions.[55]

The resolutions also urge the contracting states to the Convention to be guided by the following principles.[56]

- There should be no fiscal aims behind emission charges.
- Emission charges should be related to costs.
- Emission charges should not discriminate against air transport compared with other modes of transport.

Charges have a number of beneficial attributes, particularly when compared to voluntary and regulatory measures. They are compulsory, which overcomes problems associated with free-riding. By placing a price on emissions (or a surrogate of emissions), charges also provide aviation operators with a financial incentive to innovate in order to find ways to lower their impact on the atmosphere. Further, the higher price of air services will encourage the development of alternative, less carbon

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[51] ICAO, *Council Resolution on Environmental Charges and Taxes*, Adopted by the Council on 9 December 1996 at the 16th Meeting of its 149th Session (available at: http://www.icao.int/icao/en/env/taxes.htm (6 March 2007)).
[52] Article 24(a).
[53] Clause 1(a).
[54] Clause 3.
[55] ICAO, *Council Resolution on Environmental Charges and Taxes*, Adopted by the Council on 9 December 1996 at the 16th Meeting of its 149th Session, Clause 4.
[56] ICAO, *Council Resolution on Environmental Charges and Taxes*, Adopted by the Council on 9 December 1996 at the 16th Meeting of its 149th Session, Clause 5.

intensive forms of transport. In addition, emissions charges ensure the marginal cost of abating emissions is equalised across aviation operators.

A drawback of charges is that it is difficult to predict what level of emissions will result from a given emission charge. Consequently, if an emission charge is used, it would have to be adjusted over time if governments wanted to ensure they meet a particular emission reduction target.

Like all mandatory measures, charges are unlikely to be popular with most operators in the aviation industry. The IATA has expressed opposition to environmental charges. Its 2004 environmental review states:

> IATA strongly opposes environmental taxes or charges that compromise airline financial health without bringing any measurable environmental benefit (IATA 2004, p. 59).

Similarly, in 2006, Giovanni Bisignani, Director General and CEO of IATA, claimed that:

> [t]axes are not the answer**.** They do nothing for the environment. And they kill the economic social benefits that air transport brings (IATA 2006b).

In addition, there are several aspects of the ICAO regime that could hinder the use of charges to address international aviation emission issues. For example, if a charge was levied on fuel use, it is likely to contravene Article 24 of the Convention and the terms of some existing bilateral air service agreements. The unilateral imposition of a fuel charge could also provide an incentive for aviation operators to refuel in other jurisdictions, which could ultimately increase emissions by encouraging operators to carry additional fuel (Cairns *et al.* 2006). Similarly, if the charge was imposed on emissions, it may be challenged on the grounds it breaches prohibitions in Australian bilateral air service agreements concerning the exemption of aircraft from duties and charges.[57] An emission charge could also potentially be challenged on the basis it constitutes a tax on fuel because the size of the tax liability will be related to fuel burn (Cairns *et al.* 2006). To avoid this risk, it may be necessary to renegotiate the existing bilateral air service agreements before introducing the charge (Bishop and Grayling 2003).

Another factor that could impede their immediate introduction is the fact that the ICAO has urged all contracting parties to the Chicago Convention to refrain from unilaterally implementing emission charges until the matter has been considered at the next regular session of the ICAO Assembly in 2007.[58]

Despite the ICAO framework and associated technical issues, emission charges remain an attractive option because of the relative ease with which they can be

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[57] See, for example: *Agreement Between the Government of Australia and the Government of Hong Kong Concerning Air Services*, Australian Treaty Series, No. 28, 1993, Article 8; *Agreement Between the Government of Australia and the Government of the Republic of South Africa relating to Air Services*, Australian Treaty Series, No. 23, 1995, Article 7; and *Agreement between the Government of Australia and the Swiss Federal Council relating to Air Services*, Australian Treaty Series, No. 9, 1993, Article IX.

[58] ICAO Assembly Resolutions, A 35-5, Appendix I, ‘Market-based measures regarding aircraft engine emissions’, Clause 2(b)(4), Document No. 9848, 2004.

introduced and administered compared to an emissions trading scheme. However, there are three economic factors that could undermine their effectiveness.

Firstly, airfares around the world have fallen in recent years as low-cost carriers have entered the market. In Australia, the establishment of Virgin Blue and Jetstar has precipitated a significant drop in the cost of air travel and this is expected to continue, particularly if Tiger Airways enters the market. In Europe, the situation is the same. In the UK, ticket prices are expected to fall by between 30 and 60 per cent over the next 30 years (Bishop and Grayling 2003). Consequently, the impact of an emission charge could easily be overwhelmed by falling prices.

Secondly, the available evidence indicates that the demand for air travel is responsive to changes in income (i.e. the income elasticity of demand is relatively high).[59] Historically, the demand for aviation services has grown at a faster rate than income, suggesting that an increase in income results in a greater than proportionate increase in aviation demand. This is borne out in the economic research that has been conducted on this issue. In the mid 1990s, the Bureau of Transport and Communications Economics (BTCE) estimated that the income elasticity of demand for air travel to Australia by overseas residents from a collection of countries ranged from 0.84 to 5.51 (average 2.6) for leisure travellers and 0.52 to 2.51 (average 1.3) for business travellers.[60] For Australian residents going overseas, the income elasticities of demand were estimated to range from 0.21 to 11.58 (average 2.4) for leisure travellers and 0.91 to 3.04 (average 1.7) for business travellers (BTCE 1995). From this, the Productivity Commission concluded that the income elasticity of demand for relevant Australian international aviation services was approximately 2 (Productivity Commission 1998). More recent research found income elasticities of demand for air travel range between 0.4 and 2 (Scottish Executive 2006). With an income elasticity of demand of 2, a 10 per cent increase in income will result in a 20 per cent increase in demand.

Eventually, as the market reaches maturity, the income elasticity of demand for aviation services should decline. However, the evidence suggests this point is still some way off. As the Productivity Commission has stated, ‘it is apparent that in many cases considerable latent demand still exists’ (Productivity Commission 1998, p. 21). If the demand for air services remains income elastic, there is a risk that the impact of an emission charge will be offset by rising demand driven by rising incomes.

The third issue that could threaten the effectiveness of an emission charge is the fact that the demand for many types of air travel appears to be relatively price inelastic, meaning it is unresponsive to increases in ticket prices.[61] Drawing solid conclusions on the price elasticity of demand in the aviation sector as a whole is difficult because

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[59] Technically, demand for a good is considered to be relatively income elastic if, in response to an X per cent increase in income, demand increases by more than X per cent. In this case, the good is called a ‘luxury good’. If income increases by X per cent, and demand increases by less than X per cent, demand for the good is considered to be relatively income inelastic and the good is called a ‘normal good’. Where income increases and demand falls, the good is called an ‘inferior good’ and will be negatively income inelastic.

[60] Positive values less than one indicate demand is income inelastic (i.e. normal good). Values greater than one indicate demand is income elastic (i.e. luxury good).

[61] Demand for a good or service is considered price inelastic if, in response to an X per cent price rise, demand falls by less than X per cent. If prices increase by X per cent, and demand falls by greater than X per cent, demand for the good or service is considered price elastic.

there are significant differences within the market. Research has found that business air travel is relatively unresponsive to price changes. For example, research by the BTCE published in 1995 found the price elasticities of demand for international business travel to Australia from eight major countries ranged from 0.16 to 0.55 (average 0.33).[62] For Australian residents going overseas on business travel, the price elasticities ranged between 0.01 and 0.4 (average 0.22). A more recent Canadian study found the price elasticities for long-haul international business and short-haul business air travel range between 0.2 and 0.8 (Gillen *et al.* 2002). Demand for domestic air freight services is also likely to be relatively unresponsive to price changes (BTE 1986), although there is no recent information on this segment of the market.

The demand for leisure air travel appears to be more elastic than business and freight demand, probably because of the differences in the budgets of businesses and households. Yet the evidence suggests demand for leisure air travel is still relatively inelastic. The BTCE's estimates from the mid 1990s for Australian leisure travellers going overseas ranged from 0.14 to 1.19 (average 0.65). For foreigners travelling to Australia, the price elasticities were slightly higher, ranging from 0.5 to 1.86 (average 1.09) (BTCE 1995). Several more recent overseas studies found elasticities for leisure air travel of approximately 0.7 – 0.8 (Cairns *et al.* 2006).

Research from overseas suggests that there is a division in the airline market between full service and low-cost carriers. Several studies have found price elasticities of demand for low-cost carriers that generally exceed 1 and often range between 1.2 and 1.5 (Gillen *et al.* 2002; Cairns *et al.* 2006). Further, overseas research has found the demand for domestic and short-haul air travel is often more price elastic than international and long-haul travel, but there can be significant differences between routes (Gillen *et al.* 2002; Cairns *et al.* 2006). Bureau of Transport Economics' (BTE) data from the 1980s indicate that the demand for Australian domestic short- (less than 800 km), medium- (800 to 1,700 km) and long-haul (greater than 1,700 km) routes were all price inelastic, with elasticities ranging from 0.55 to 0.82 (BTE 1986).[63] However, in contrast to the overseas evidence, demand for short-haul routes was less responsive to price than the demand for long-haul routes. Given the changes in the domestic aviation industry since the 1980s, it is unclear whether this pattern in price elasticities is still present in the market.

Despite the variability between the different segments of the airline market, the existing evidence indicates that demand for aviation services in Australia is likely to be relatively price inelastic, with the exception of low fare services. As a result, there is a risk that an emission charge will not elicit the desired fall in aviation emissions.

To overcome the effects of falling ticket prices, relatively high income elasticity of demand and low price elasticity demand, it may be necessary to set the emission charge at a high level. This could create political problems for governments. As British Prime Minister Tony Blair has stated:

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[62] Values less than one indicate demand is relatively inelastic. Values greater than one indicate demand is relatively elastic.

[63] See also May *et al.* (1986).

> … if you really want to impede air travel, to cut it back significantly, for example, through some taxation mechanism, it would have to be a fairly hefty whack … and I will wait to see who first proposes it (cited in Cairns *et al.* 2006).

Nevertheless, due to technical and administrative issues associated with emissions trading schemes, charges remain a viable option as an interim measure and to address non-CO_2 emissions. If the Federal Government establishes an emissions trading scheme, an aviation emission charge could be used as a transitional measure until the sector is included in the scheme. Any increase in the cost of air travel will help avoid the emission increases expected under business-as-usual conditions. Using differentiated charge rates could also help promote innovation and investment. For example, the Swedish Government has introduced differential landing fees. These fees are used to penalise less carbon efficient aircraft relative to more efficient aircraft (SCEA 2006). Even if an emissions trading scheme is established, an emission charge could still be necessary to address the impacts of non-CO_2 emissions due to the difficulty of including them in the scheme.

6.5 Emissions trading

Broadly, emissions trading schemes involve the placement of a cap on the total quantity of emissions that are allowed to be emitted from specific industries or the entire economy. Emission permits equal to the total permitted quantity of emissions are then allocated to polluters, typically through either a grandfathering process (i.e. according to historic emission levels) or a government auction. Polluters are required to hold emission permits that are equal to the quantity of emissions they release over the specified time period. If a polluter has a surplus of pollution permits, they can sell them to polluters with a shortfall. In theory at least, polluters with a high marginal cost of abatement (i.e. those with the highest marginal returns from polluting) will buy permits from those with lower marginal abatement costs until such time as the marginal cost of abatement is equalised across all polluters.

Emissions trading offers many of the advantages of an emissions charge. It would be compulsory, offers flexibility to aviation operators, provides a financial incentive to innovate, and should ensure the marginal cost of abatement is equalised across all relevant polluters. Further, an emissions trading scheme would enable the government to set the desired level of emissions rather than leaving it to market forces, as occurs with an emission charge.

The main challenges with an emissions trading scheme that covers aviation are technical and political. One of the major technical issues concerns non-CO_2 aviation emissions (for example, NO_x and water vapour). As discussed, there are considerable uncertainties associated with the science surrounding these emissions. Hence, there is a question of whether the emissions trading scheme should account for the impact of non-CO_2 aviation emissions, and if so, to what extent.

Another technical issue relates to the treatment of international aviation emissions. Should international emissions be exempt from domestic trading schemes because they are not counted towards national totals under the UNFCCC/Kyoto framework, or should they be incorporated on the basis that they will ultimately have to be brought into the international regime?

Two types of emissions trading schemes have been put forward to account for the complexities of aviation emissions; open and closed.[64] An open scheme essentially involves the inclusion of aviation emissions within the framework envisaged under the Kyoto Protocol. Under this framework, an emissions cap is set for all Annex B countries (i.e. a 5 per cent reduction on 1990 levels) and then individual caps are set for each country. Within each country, carbon permits equal to the country's cap can be allocated to polluters, who can then trade these rights. Trading is also permitted between Annex B countries, including between individual businesses in different countries. In addition, under the Joint Implementation (JI) and Clean Development Mechanism (CDM) processes, Annex B countries can also meet part of their targets by investing in projects that reduce emissions or enhance removals from sinks in other countries. These processes effectively create additional permits for abatement actions that would not otherwise have occurred.

An open emissions trading scheme would include aviation emissions within this Kyoto-style framework. The key feature of this approach for current purposes is that emission permits can be traded between all relevant sectors in the economy, and not just between aviation operators. In contrast, a closed scheme would only apply to the aviation industry. A separate cap would be set for the aviation industry and emissions trading could only occur between aviation operators.

The benefit of an open scheme is that it should generate more efficient outcomes. The total reduction in emissions should be achieved at a lower cost than would be the case if separate schemes are operated for different industries. This is because the trading of emission permits between industries should ensure the marginal cost of abatement is equalised across all sectors in the economy rather than just the aviation sector.

While open schemes offer the benefit of greater efficiency, they suffer from several practical problems, including the following.

- If the emissions trading scheme is based on the Kyoto Protocol, it would not cover most non-CO_2 aviation emissions nor would it cover international aviation emissions. The lack of full coverage would diminish the environmental effectiveness of the scheme.

- To ensure complete coverage, the emissions trading scheme should apply to CO_2 emissions, as well as the non-CO_2 aviation emissions that contribute to climate change. To achieve this, non-CO_2 emissions would have to be converted into an equivalent emission unit (i.e. CO_2-e). As discussed, this is extremely difficult because of the short atmospheric lifetime of most non-CO_2 aviation emissions and the fact that their atmospheric impact is often dependent on when and where they are released (i.e. altitude and geographic location). An alternative is to base the aviation sector's participation in the scheme on CO_2 emissions and to apply an uplift factor to account for the impact of non-CO_2 emissions. Yet given the scientific uncertainties associated

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[64] See, for example, Somerville (2003) and Cairns *et al.* (2006).

with non-CO_2 emissions, it is very difficult to determine the correct uplift factor. Overestimating the magnitude of the impact would impose an unnecessary cost on the aviation industry, while underestimating the impact would undermine the environmental effectiveness of the scheme. There is also no set relationship between CO_2 and non-CO_2 aviation emissions. The quantity and impacts of non-CO_2 emissions, and their relationship to CO_2 emissions, can differ depending on the nature of the aircraft and how it is operated. Hence, while using uplifted CO_2 emissions as the basis for the aviation sector's participation in an emissions trading scheme may provide a more accurate measure of the magnitude of the effects, it may not provide the necessary incentives to promote improvements in non-CO_2 emissions. In addition, the inclusion of non-CO_2 aviation emissions in an emissions trading scheme may be seen as inequitable unless indirect greenhouse gas emissions from other sectors are also included in the scheme. A method of avoiding these problems would be to limit the aviation industry's involvement in the emissions trading scheme to CO_2 emissions and to use other mechanisms (for example, emission charges and compulsory emission standards) to address non-CO_2 emissions.

- To ensure complete coverage, the scheme should also include international aviation emissions. This would require emissions to be divided between countries that are involved in the relevant international aviation services. Various models have been put forward about how this might be achieved, including splitting the emissions between the country of departure and country of arrival of the aircraft, division between countries depending on the country of departure and destination of the passengers or cargo, and division on the basis of where the relevant fuel is sold (IPCC 1999). Adjustments will also be necessary to account for those instances where one of the countries involved is not bound by a Kyoto emission reduction target.

- If aviation is included in an open scheme, there is a risk that aviation operators will take advantage of high initial caps and flexibility mechanisms under the Kyoto Protocol to ensure carbon restrictions do not inhibit short- to medium-term growth in the industry. As explained in the context of emission charges, the growth in the industry is likely to be fuelled by the downward trend in air fares and the fact that demand for aviation is generally income elastic and price inelastic. Continued growth in the aviation industry could entrench dependency on air travel, thereby creating political and economic barriers to future cuts in the emission caps.

A closed aviation scheme could reduce some of the problems associated with an emissions trading scheme. However, by confining the scheme to the aviation industry, it would lead to less efficient outcomes because emission permits could not be traded with other sectors in the economy. Closed schemes are also likely to face greater resistance from industry because they eliminate the opportunity for aviation operators to purchase emission permits from other sectors of the economy. No doubt this is one of the reasons why the ICAO's support for emissions trading is specifically confined to an open scheme.[65]

6.6 Abatement options

Continued expansion of the aviation industry is incompatible with the emission cuts Australia should make over the next 40 years. The Federal Government needs to take steps to curtail the growth in aviation emissions and prompt reform in the transport sector.

Establishment of an effective international framework

The evidence suggests that the most cost-effective way to address the greenhouse implications associated with the aviation sector is to incorporate the sector into a Kyoto-style open emissions trading scheme that is integrated with trading schemes in other countries. This will ensure emission cuts are achieved in the most efficient manner.

In order for this to occur, international aviation emissions would have to be brought into the UNFCCC/Kyoto framework. Australia could assist in promoting this outcome by ratifying the Kyoto Protocol and pressuring the international community to make the necessary changes.

Due to the scientific uncertainty surrounding non-CO_2 aviation emissions, the evidence suggests the preferred option is to base the aviation sector's participation in the emissions trading scheme on CO_2 emissions.[66] Non-CO_2 aviation emissions could be addressed more effectively through complementary measures, including mandatory emission charges.

The ICAO could encourage the imposition of a mandatory non-CO_2 aviation emission charge to complement the emissions trading scheme in all Annex B countries under the UNFCCC. Over time, the charge could be extended to all other countries in conformity with the processes adopted under the Kyoto Protocol.

There is the potential that the caps set under the Kyoto framework, and any charge that may be adopted by the ICAO, could be relatively lax in the short- to medium-term. If the limitations imposed under these regimes are weak, the evidence suggests regulatory measures like improved ICAO emission standards should be considered. Some of these measures could be phased out as the caps are tightened, charges increased and the scope of the market mechanisms broadened.

Domestic emissions trading and charges

The Federal Government and the states and territories are currently considering establishing national emissions trading schemes (Howard 2006; Council for the Australian Federation 2007). The evidence suggests that efficient and equitable outcomes are most likely to be achieved if the national scheme is compatible with the Kyoto framework. Further, if a national emissions trading scheme is established, the

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[65] See Cairns *et al.* (2006) and ICAO Assembly Resolutions, A 35-5, Appendix I, 'Market-based measures regarding aircraft engine emissions', Clause 2(c), Document No. 9848, 2004.

[66] See Forster *et al.* (2006).

evidence suggests that cost-effective abatement could be achieved by including aviation CO_2 emissions and other forms of transport in the scheme. An emissions charge and other measures could be used to address non-CO_2 aviation emissions.

Adoption of interim domestic measures

The Federal Government currently refuses to ratify the Kyoto Protocol. The international processes will also take time to negotiate and implement, as will a national emissions trading scheme. Further, there is a risk that the aviation sector will not be immediately included in the national emissions trading schemes that are currently being considered.[67] As a result, there is a strong case that Australia should adopt interim measures to curtail growth in aviation emissions while more comprehensive frameworks are being established.

An interim measure that could be used to promote this objective is a $30 flat-rate greenhouse charge for all domestic flights.[68] The charge could be levied on the sale of tickets that entitle a person to travel as a passenger on a flight between two locations in Australia. This would be similar to the $10 per ticket Ansett levy that applied between 2001 and 2003.[69] However, unlike the Ansett levy, the greenhouse charge would be payable on both legs of a return ticket and to tickets for domestic travel purchased overseas. It would not initially be payable on international flights departing from Australia. This charge could be expected to raise in excess of $1 billion a year in revenue,[70] which could be directed towards aviation research and developing alternative transport services, particularly for those airline routes that are readily capable of substitution (for example, Sydney to Canberra).[71]

International air travel could be exempt from the greenhouse charge pending the outcome of the ICAO Assembly meeting later this year. If the ICAO Assembly fails to recommend adequate measures, a similar charge could be applied to all international flights departing and arriving in Australia.

If there is continued delay in the development of international frameworks, the Government could change the greenhouse charge from a flat-rate to an emission-based charge in order to promote innovation and cost-effective abatement in the aviation industry.

In the event that aviation is included in a domestic emissions trading scheme, the proposed greenhouse charge would not be required (other than in a modified form that would only applicable to non-CO_2 aviation emissions).

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[67] See National Emissions Trading Taskforce (2006).

[68] This is of a similar magnitude to the passenger movement charge imposed on international departures from Australia under the *Passenger Movement Charge Act 1978* (Cwlth) and collected under the *Passenger Movement Charge Collection Act 1978* (Cwlth).

[69] For details on the Ansett levy, see Kain (2001), *Air Passenger Ticket Levy (Collection) Act 2001* (Cwlth), and *Air Passenger Ticket Levy (Imposition) Act 2001* (Cwlth).

[70] Calculated on the basis of current domestic (including regional) passenger movements (BTRE 2006b), assuming a price elasticity of demand of 0.8 and an average ticket price of at least $150.

[71] The greenhouse charge would offset the effects of the concessional rate of excise that is levied on aviation fuels (i.e. avtur and avgas). Excise on most transport fuels is levied on the basis of their relative energy content. This approach has not been applied to aviation fuels. In 2006/07, the decision to exempt aviation fuel from the standard fuel excise provisions is expected to result in lost revenues of approximately $805 million (Department of Treasury 2006). See also Webb (2006).

Complementary measures

Market mechanisms like emissions trading and charges are unlikely to be sufficient on their own to address the greenhouse and other policy issues associated with aviation and transport. The evidence suggests combining these measures with other targeted programs could promote efficiency and equity. Complementary measures that could assist in this endeavour include the following.

- Continued cooperation between the Federal Government and the aviation industry to improve operational procedures and ATM.

- Performance standards for new aircraft and engines, preferably adopted through the ICAO procedures.

- The selective use of voluntary programs. For example, the Government could run a social marketing campaign to raise community awareness about climate change, the aviation industry's contribution to it and the need for mandatory measures to address the issue.

- Long-term strategic planning for, and direct public investment in, transport and telecommunications infrastructure to encourage the substitution of air travel with less emission-intensive alternatives. This could include direct investment in public transport services and the promotion of improvements in telecommunications services. Modern teleconferencing and internet services may ultimately prove to be an effective substitute for many consumers of air services. As the market mechanisms become more mature, the need for direct government intervention to promote substitution may decline. However, the evidence suggests there is likely to be a need for significant government involvement in the short- to medium-term in order to ensure the provision of the necessary infrastructure.

- The withdrawal of direct subsidies to the aviation sector and other government programs that promote the expansion of airports and growth in air travel.

7. Conclusions

To date, very little has been done at either a domestic or international level to address the growing contribution of the aviation sector to climate change. The measures that have been implemented domestically are unlikely to have a significant impact on aviation emissions and have been driven primarily by commercial concerns. The best example of these measures is the designation of ‘fuel friendly’ flight routes and improvements in ATM that have occurred over the last five years. While beneficial, the emission reductions associated with these changes are likely to be overwhelmed by increases driven by growth in the industry. Similarly, voluntary programs like Virgin Blue’s recently established carbon offset scheme are unlikely to reduce the sector’s contribution to global warming.

Part of the reason for the absence of greenhouse measures that target aviation is that the industry is responsible for less than two per cent of global greenhouse gas emissions (IATA 2006b; Stern 2007). In Australia, aviation also currently accounts for only a relatively small proportion of total emissions. However, this is likely to change over the coming decades.

In the next 40 years, aviation emissions are projected to rise dramatically. Between 2005 and 2050, total unadjusted aviation emissions are expected to rise from 11.6 to 42.5 Mt CO_2-e, an increase of 267 per cent. When an uplift factor is applied to account for the impact of non-CO_2 emissions, aviation emissions could rise from between 19.5 and 31 Mt CO_2-e in 2005 to between 71.6 and 113.8 Mt CO_2-e in 2050.

The available evidence indicates that to avoid dangerous anthropogenic interference with the climate system, it will be necessary to cut global emissions by a minimum of 25 per cent between 2005 and 2050. If this target is adopted by the international community, it will require developed nations that currently have high per capita emissions to make larger cuts, typically in the order of at least 60 per cent below current levels. In Australia, the federal ALP has signalled it will adopt a 60 per cent emission reduction target on 2000 levels if it is returned to government. Science suggests an 80 per cent reduction target by 2050 is more likely to be necessary. These types of emission cuts are incompatible with the current trajectory of emission increases from the aviation sector.

Under the US1 Scenario adopted here, and assuming a 60 per cent emission reduction target, aviation emissions will account for 32 per cent of Australia’s entire emissions space by 2050. With an 80 per cent target, US1 suggests aviation emissions will account for 69 per cent of Australia’s total emissions in 2050. These estimates are based on a number of conservative assumptions. The true figure could be somewhat higher, particularly if the impact of non-CO_2 emissions is greater than expected. For example, under the US2 Scenario that uses a higher uplift factor, aviation emissions account for 51 per cent of Australia’s total emissions in 2050 if there is a 60 per cent reduction target and 109 per cent of total emissions in 2050 with an 80 per cent target. Despite the uncertainties associated with these projections, it is clear that if the aviation sector continues to grow under business-as-usual conditions, it will be a major contributor to Australia’s emissions by the middle of this century.

Unlike many other industries, there are few available technological options for reducing aviation emissions. As the IPCC found, and other studies have confirmed, it is unlikely there will be any practical alternatives to kerosene-based fuels for commercial jet aircraft for at least 20 years. Further, any radical change in aircraft design would not affect the industry for decades and even then is only likely to affect large long-haul aircraft. The limited technological options means that to address the issues associated with aviation emissions, the demand for air travel will have to be constrained. Few industries are willing to voluntarily reduce growth in order to address environmental concerns. Therefore, mandatory measures need to be introduced to curtail the growing emissions profile of the aviation sector.

The aviation sector is currently almost completely free of environmental regulations that aim to address greenhouse issues. Of particular concern is the fact that international aviation emissions are not subject to the limitation and reduction commitments under the UNFCC/Kyoto framework. This needs to be resolved at the forthcoming meeting of the Conference of the Parties to the UNFCCC and Meeting of the Parties to the Kyoto Protocol. Australia could assist in promoting this outcome by ratifying the Kyoto Protocol and pressuring the international community to make the necessary changes.

Ratifying the Kyoto Protocol is an important but preliminary step. The long-term policy objective should be to incorporate the aviation sector into a Kyoto-style open emissions trading scheme that is part of a global system. Due to the scientific uncertainty surrounding non-CO_2 aviation emissions, it would be preferable if the aviation industry's participation in the scheme was based on CO_2 emissions and an emissions charge and other measures were used to address non-CO_2 emissions.

Due to the time lags associated with establishing an emissions trading scheme and an international non-CO_2 aviation emission charge, there is a need for interim measures. The first of these could be $30 flat-rate greenhouse charge for all domestic flights that may be extended to international flights following the ICAO meeting later this year.

The evidence suggests that market mechanisms like emissions trading and charges are unlikely to be sufficient on their own to address the greenhouse and other policy issues associated with aviation and transport. There is a particular need for federal and state governments to undertake long-term strategic planning for, and investment in, transport and telecommunications infrastructure to encourage the substitution of air travel with less emission-intensive alternatives.

Irrespective of which policy instruments are implemented to curtail aviation emissions, Australians cannot expect to fly more than they currently do today. Unless there is a major technological breakthrough presently not foreseeable, the amount of air travel will need to be stabilised and ultimately reduced. To facilitate the necessary changes in the economy and the aviation sector, action needs to be taken now.

Appendix A

Total projected domestic emissions under NU1, NU2, US1 and US2 Scenarios

Year	NU1	NU2	US1	US2
2005	5.2	5.1	8.7	13.8
2006	5.4	5.4	9.1	14.5
2007	5.7	5.6	9.6	15.2
2008	6.0	5.9	10.0	15.9
2009	6.2	6.1	10.5	16.7
2010	6.5	6.3	10.9	17.3
2011	6.7	6.6	11.3	18.0
2012	7.0	6.8	11.7	18.6
2013	7.2	6.9	12.1	19.2
2014	7.4	7.1	12.4	19.8
2015	7.6	7.3	12.8	20.3
2016	7.8	7.4	13.1	20.7
2017	7.9	7.6	13.4	21.2
2018	8.1	7.7	13.7	21.7
2019	8.3	7.8	14.0	22.2
2020	8.5	8.0	14.3	22.7
2021	8.7	8.2	14.6	23.3
2022	8.9	8.3	15.0	23.8
2023	9.1	8.5	15.3	24.3
2024	9.3	8.7	15.7	24.9
2025	9.5	8.9	16.0	25.5
2026	9.7	9.1	16.4	26.1
2027	10.0	9.2	16.8	26.7
2028	10.2	9.4	17.2	27.3
2029	10.4	9.6	17.6	27.9
2030	10.7	9.8	18.0	28.5
2031	10.9	10.0	18.4	29.2
2032	11.2	10.3	18.8	29.9
2033	11.4	10.5	19.2	30.6
2034	11.7	10.7	19.7	31.3
2035	12.0	10.9	20.1	32.0
2036	12.2	11.1	20.5	32.6
2037	12.4	11.3	20.9	33.1
2038	12.6	11.5	21.2	33.7
2039	12.8	11.7	21.6	34.4
2040	13.1	11.9	22.0	35.0
2041	13.3	12.2	22.4	35.6
2042	13.6	12.4	22.8	36.2
2043	13.8	12.6	23.2	36.9
2044	14.0	12.8	23.6	37.6
2045	14.3	13.1	24.1	38.2
2046	14.6	13.3	24.5	38.9
2047	14.8	13.5	24.9	39.6
2048	15.1	13.8	25.4	40.3
2049	15.4	14.0	25.9	41.1
2050	15.6	14.3	26.3	41.8

Total projected international emissions under NU1, NU2, US1 and US2 Scenarios

Year	NU1/NU2	US1	US2
2005	6.4	10.8	17.2
2006	6.7	11.2	17.8
2007	6.9	11.7	18.5
2008	7.2	12.2	19.3
2009	7.6	12.7	20.2
2010	7.9	13.3	21.2
2011	8.3	13.9	22.1
2012	8.6	14.5	23.0
2013	8.9	15.0	23.8
2014	9.3	15.6	24.8
2015	9.6	16.2	25.7
2016	10.0	16.8	26.7
2017	10.3	17.4	27.7
2018	10.7	18.0	28.6
2019	11.1	18.6	29.6
2020	11.4	19.2	30.5
2021	11.8	19.8	31.4
2022	12.1	20.4	32.4
2023	12.5	21.0	33.4
2024	12.8	21.6	34.4
2025	13.2	22.3	35.4
2026	13.6	23.0	36.5
2027	14.0	23.6	37.5
2028	14.5	24.3	38.7
2029	14.9	25.1	39.8
2030	15.3	25.8	41.0
2031	15.8	26.6	42.3
2032	16.3	27.4	43.5
2033	16.8	28.2	44.8
2034	17.3	29.1	46.2
2035	17.8	29.9	47.6
2036	18.3	30.8	48.9
2037	18.8	31.6	50.3
2038	19.3	32.5	51.7
2039	19.9	33.4	53.1
2040	20.4	34.4	54.6
2041	21.0	35.3	56.1
2042	21.6	36.3	57.7
2043	22.2	37.4	59.3
2044	22.8	38.4	61.0
2045	23.4	39.5	62.7
2046	24.1	40.6	64.4
2047	24.8	41.7	66.3
2048	25.5	42.9	68.1
2049	26.2	44.1	70.0
2050	26.9	45.3	72.0

Total projected emissions under NU1, NU2, US1 and US2 Scenarios

Year	NU1	NU2	US1	US2
2005	11.6	11.6	19.5	31.0
2006	12.1	12.0	20.3	32.3
2007	12.6	12.6	21.2	33.7
2008	13.2	13.1	22.2	35.3
2009	13.8	13.7	23.2	36.9
2010	14.4	14.3	24.3	38.5
2011	15.0	14.8	25.3	40.1
2012	15.5	15.3	26.2	41.6
2013	16.1	15.8	27.1	43.0
2014	16.7	16.4	28.0	44.5
2015	17.2	16.9	29.0	46.0
2016	17.7	17.4	29.9	47.5
2017	18.3	17.9	30.8	48.9
2018	18.8	18.4	31.7	50.4
2019	19.4	18.9	32.6	51.8
2020	19.9	19.4	33.5	53.3
2021	20.5	19.9	34.4	54.7
2022	21.0	20.4	35.4	56.2
2023	21.6	21.0	36.3	57.7
2024	22.2	21.5	37.3	59.3
2025	22.8	22.1	38.3	60.9
2026	23.4	22.7	39.4	62.5
2027	24.0	23.3	40.4	64.2
2028	24.7	23.9	41.5	66.0
2029	25.3	24.5	42.7	67.7
2030	26.0	25.2	43.8	69.6
2031	26.7	25.8	45.0	71.5
2032	27.4	26.5	46.2	73.4
2033	28.2	27.2	47.5	75.4
2034	29.0	28.0	48.8	77.4
2035	29.7	28.7	50.1	79.5
2036	30.5	29.4	51.3	81.5
2037	31.2	30.1	52.5	83.4
2038	31.9	30.8	53.8	85.4
2039	32.7	31.6	55.1	87.5
2040	33.5	32.4	56.4	89.6
2041	34.3	33.1	57.8	91.7
2042	35.1	33.9	59.2	93.9
2043	36.0	34.8	60.6	96.2
2044	36.8	35.6	62.0	98.5
2045	37.7	36.5	63.5	100.9
2046	38.7	37.4	65.1	103.4
2047	39.6	38.3	66.7	105.9
2048	40.5	39.2	68.3	108.4
2049	41.5	40.2	69.9	111.1
2050	42.5	41.2	71.6	113.8

Appendix B

Total projected domestic emissions under US1 and US2, using the fuel efficiency assumptions from the NU2 Scenario

Year	US1	US2
2005	8.6	13.7
2006	9.1	14.4
2007	9.5	15.1
2008	9.9	15.7
2009	10.3	16.3
2010	10.7	16.9
2011	11.0	17.5
2012	11.4	18.1
2013	11.7	18.5
2014	12.0	19.0
2015	12.2	19.4
2016	12.5	19.8
2017	12.7	20.2
2018	13.0	20.6
2019	13.2	21.0
2020	13.5	21.4
2021	13.7	21.8
2022	14.0	22.3
2023	14.3	22.8
2024	14.6	23.2
2025	14.9	23.7
2026	15.2	24.2
2027	15.6	24.7
2028	15.9	25.2
2029	16.2	25.8
2030	16.6	26.3
2031	16.9	26.9
2032	17.3	27.4
2033	17.6	28.0
2034	18.0	28.6
2035	18.4	29.2
2036	18.7	29.7
2037	19.1	30.3
2038	19.4	30.8
2039	19.7	31.4
2040	20.1	31.9
2041	20.5	32.5
2042	20.8	33.1
2043	21.2	33.7
2044	21.6	34.3
2045	22.0	34.9
2046	22.4	35.5
2047	22.8	36.2
2048	23.2	36.8
2049	23.6	37.5
2050	24.0	38.2

Total projected emissions under US1 and US2, using the fuel efficiency assumptions from the NU2 Scenario

Year	US1	US2
2005	19.5	30.9
2006	20.3	32.2
2007	21.1	33.6
2008	22.1	35.0
2009	23.0	36.6
2010	24.0	38.1
2011	25.0	39.6
2012	25.8	41.0
2013	26.7	42.4
2014	27.6	43.8
2015	28.4	45.2
2016	29.3	46.5
2017	30.1	47.9
2018	31.0	49.2
2019	31.8	50.6
2020	32.7	51.9
2021	33.5	53.3
2022	34.4	54.7
2023	35.3	56.1
2024	36.3	57.6
2025	37.2	59.1
2026	38.2	60.7
2027	39.2	62.3
2028	40.2	63.9
2029	41.3	65.6
2030	42.4	67.3
2031	43.5	69.1
2032	44.7	71.0
2033	45.9	72.8
2034	47.1	74.8
2035	48.3	76.8
2036	49.5	78.6
2037	50.7	80.5
2038	51.9	82.5
2039	53.2	84.5
2040	54.5	86.5
2041	55.8	88.6
2042	57.2	90.8
2043	58.6	93.0
2044	60.0	95.3
2045	61.4	97.6
2046	62.9	100.0
2047	64.5	102.4
2048	66.1	104.9
2049	67.7	107.5
2050	69.3	110.1

Appendix C

Total projected carbon dioxide emissions under NU1 and NU2 fuel efficiency assumptions

Year	Total CO2 under NU1 assumptions (Mt)	Total CO2 under NU2 assumptions (Mt)
2005	11.477	11.457
2006	11.967	11.927
2007	12.498	12.435
2008	13.064	12.975
2009	13.665	13.549
2010	14.265	14.120
2011	14.860	14.684
2012	15.401	15.193
2013	15.931	15.690
2014	16.495	16.219
2015	17.045	16.734
2016	17.581	17.234
2017	18.117	17.733
2018	18.656	18.232
2019	19.194	18.730
2020	19.730	19.224
2021	20.263	19.730
2022	20.810	20.249
2023	21.373	20.782
2024	21.951	21.330
2025	22.545	21.892
2026	23.155	22.470
2027	23.782	23.063
2028	24.426	23.673
2029	25.089	24.299
2030	25.769	24.942
2031	26.468	25.602
2032	27.186	26.281
2033	27.924	26.978
2034	28.683	27.694
2035	29.462	28.429
2036	30.169	29.117
2037	30.893	29.822
2038	31.635	30.545
2039	32.396	31.286
2040	33.176	32.046
2041	33.975	32.825
2042	34.795	33.624
2043	35.635	34.443
2044	36.496	35.283
2045	37.379	36.144
2046	38.284	37.026
2047	39.211	37.932
2048	40.163	38.860
2049	41.138	39.811
2050	42.138	40.787

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