Environmental impact of aviation

From Wikipedia, the free encyclopedia

The **environmental impact of aviation** occurs because aircraft engines emit noise, particulates, and gases which contribute to climate change[1][2] and global dimming.[3] Despite emission reductions from automobiles and more fuel-efficient and less polluting turbofan and turboprop engines, the rapid growth of air travel in recent years contributes to an increase in total pollution attributable to aviation. In the European Union, greenhouse gas emissions from aviation increased by 87% between 1990 and 2006.[4]

There is an ongoing debate about possible taxation of air travel and the inclusion of aviation in an emissions trading scheme, with a view to ensuring that the total external costs of aviation are taken into account.[5]

The environmental impact of aviation

A C-141 Starlifter leaves exhaust contrails over Antarctica.

Contents

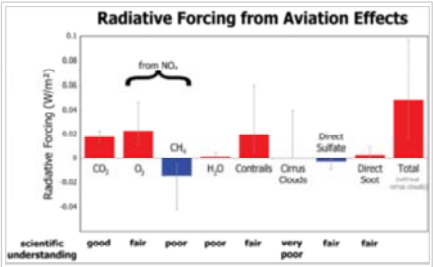
- 1 Climate change
  - 1.1 Mechanisms
  - 1.2 CO_2 Emissions per passenger kilometre
  - 1.3 Total climate effects
  - 1.4 Future emission levels: improved efficiencies vs. the trend in increased travel & freight
  - 1.5 Alternate Fuels
  - 1.6 Reducing air travel
  - 1.7 Kyoto Protocol
  - 1.8 Emissions trading
  - 1.9 Mitigation
- 2 Noise
- 3 Air quality
- 4 See also
- 5 References
- 6 External links

Climate change

Like all human activities involving combustion, most forms of aviation release carbon dioxide (CO_2) and other greenhouse gases into the Earth's atmosphere, contributing to the acceleration of global warming[6] and (in the case of CO_2) ocean acidification.[7]

In addition to the CO_2 released by most aircraft in flight through the burning of fuels such as Jet-A (turbine aircraft) or Avgas (piston aircraft), the aviation industry also contributes greenhouse gas emissions from ground airport vehicles and those used by passengers and staff to access airports, as well as through emissions generated by the production of energy used in airport buildings, the manufacture of aircraft and the construction of airport infrastructure.[8]

While the principal greenhouse gas emission from powered aircraft in flight is CO_2, other emissions may include nitric oxide and nitrogen dioxide, (together termed oxides of nitrogen or NO_x), water vapour and particulates (soot and sulfate particles), sulfur oxides, carbon monoxide (which bonds with oxygen to become CO_2 immediately upon release), incompletely burned hydrocarbons, tetra-ethyl lead (piston aircraft only), and radicals such as hydroxyl, depending on the type of aircraft in use.[9]



Radiative forcings from aviation emissions (gases and aerosols) in 1992 as estimated by the IPCC

The contribution of civil aircraft-in-flight to global CO_2 emissions has been estimated at around 2%.[9] However, in the case of high-altitude airliners which frequently fly near or in the stratosphere, non-CO_2 altitude-sensitive effects may increase the total impact on anthropogenic (man-made) climate change significantly.[9]

Mechanisms

Subsonic aircraft-in-flight contribute to climate change[9] in four ways:

Carbon dioxide (CO_2)

CO_2 emissions from aircraft-in-flight are the most significant and best understood[10] element of aviation's total contribution to climate change. The level and effects of CO_2 emissions are currently believed to be broadly the same regardless of altitude (i.e. they have the same atmospheric effects as ground based emissions). In 1992, emissions of CO_2 from aircraft were estimated at around 2% of all such anthropogenic emissions, and that year the atmospheric concentration of CO_2 attributable to aviation was around 1% of the total anthropogenic increase since the industrial revolution, having accumulated primarily over just the last 50 years.[11]

Oxides of nitrogen (NO_x)

At the high altitudes flown by large jet airliners around the tropopause, emissions of NO_x are particularly effective in forming ozone (O_3) in the upper troposphere. High altitude (8-13km) NO_x emissions result in greater concentrations of O_3 than surface NO_x emissions, and these in turn have a greater global warming effect. The effect of O_3 concentrations are regional and local (as opposed to CO_2 emissions, which are global).

NO_x emissions also reduce ambient levels of methane, another greenhouse gas, resulting in a climate cooling effect. But this effect does not offset the O_3 forming effect of NO_x emissions. It is now believed that aircraft sulfur and water emissions in the stratosphere tend to deplete O_3, partially offsetting the NO_x-induced O_3 increases. These effects have not been quantified.[11] This problem does not apply to aircraft that fly lower in the troposphere, such as light aircraft or many commuter aircraft.

Water vapor (H_2O)

One of the products of burning hydrocarbons in oxygen is water vapour, a greenhouse gas. Water vapour produced by aircraft engines at high altitude, under certain atmospheric conditions, condenses into droplets to form Condensation trails, or contrails. Contrails are visible line clouds that form in cold, humid atmospheres and are thought to have a global warming effect (though one

less significant than either CO_2 emissions or NO_x induced effects) SPM-2 (http://www.ipcc.ch/SPM2feb07.pdf) . Contrails are extremely rare from lower-altitude aircraft, or from propeller-driven aircraft or rotorcraft.

Cirrus clouds have been observed to develop after the persistent formation of contrails and have been found to have a global warming effect over-and-above that of contrail formation alone. There is a degree of scientific uncertainty about the contribution of contrail and cirrus cloud formation to global warming and attempts to estimate aviation's overall climate change contribution do not tend to include its effects on cirrus cloud enhancement.[10]


Contrails


Cirrus cloud formation

Particulates

Least significant is the release of soot and sulfate particles. Soot absorbs heat and has a warming effect; sulfate particles reflect radiation and have a small cooling effect. In addition, they can influence the formation and properties of clouds.[12] All aircraft powered by combustion will release some amount of soot.

CO_2 Emissions per passenger kilometre

Emissions of passenger aircraft per passenger kilometre vary extensively, according to variables such as the size of the aircraft, the number of passengers on board, and the altitude and distance of the journey as the practical effect of emissions at high altitides may be greater than those of emissions at low altitudes. Some representative figures for CO2 emissions are provided by LIPASTO's survey of average direct emissions (not accounting for high-altitude radiative effects) of airliners expressed as CO_2 and CO_2 equivalent per passenger kilometre:[13]

- Domestic, short distance, less than 463 km (288 mi): 257 g/km CO_2 or 259 g/km (5.6 oz/mile) CO_2e
- Domestic, long distance, greater than 463 km (288 mi): 177 g/km CO_2 or 178 g/km (3.7 oz/mile) CO_2e
- Long distance flights: 113 g/km CO_2 or 114 g/km (2.5 oz/mile) CO_2e

For perspecitve, per passenger a typical economy-class New York to Los Angeles round trip produces about 715 kg (1574 lb) of CO_2, but is equivalent to 1,917 kg (4,230 lb) of CO_2 when the high altitude “climatic forcing” effect is taken into account.[14] Within the categories of flights above, emissions from scheduled jet flights are substantially higher than turboprop or chartered jet flights. The emissions above are similar to a four-seat car with one person on board;[15] however, flying trips often cover longer distances than would be undertaken by car, so the total emissions are much higher. About 60% of aviation emissions arise from international flights, and these flights are not covered by the Kyoto Protocol and its emissions reduction targets.[16]

Per passenger kilometre, figures from British Airways suggest carbon dioxide emissions of 0.1 kg for large jet airliners (a figure which does not account for the production of other pollutants or condensation trails).[17]

Total climate effects

In attempting to aggregate and quantify the total climate impact of aircraft emissions the Intergovernmental Panel on Climate Change (IPCC) has estimated that aviation’s total climate impact is some 2-4 times that of its direct CO_2 emissions alone (excluding the potential impact of cirrus cloud enhancement).[9] This is measured as radiative forcing. While there is uncertainty about the exact level of impact of NO_x and water vapour, governments have accepted the broad scientific view that they do have an effect. Globally in 2005, aviation contributed "possibly as much as 4.9% of radiative forcing."[16] UK government policy statements have stressed the need for aviation to address its total climate change impacts and not simply the impact of CO_2.[18]

The IPCC has estimated that aviation is responsible for around 3.5% of anthropogenic climate change, a figure which includes both CO_2 and non-CO_2 induced effects. The IPCC has produced scenarios estimating what this figure could be in 2050. The central case estimate is that aviation’s contribution could grow to 5% of the total contribution by 2050 if action is not taken to tackle these emissions, though the highest scenario is 15%.[9] Moreover, if other industries achieve significant cuts in their own greenhouse gas emissions, aviation’s share as a proportion of the remaining emissions could also rise.

Future emission levels: improved efficiencies vs. the trend in increased travel & freight

Even though there have been significant improvements in fuel efficiency through aircraft technology and operational management as described here, these improvements are being continually eclipsed by the increase in air traffic volume.

Continual Increases in Travel & Freight

From 1992 to 2005, passenger kilometers increased 5.2% per year, even with the disruptions of 9/11 and two significant wars. Since the onset of the current recession:

"During the first three quarters of 2010, air travel markets expanded at an annualized rate approaching 10%. This is similar to the rate seen in the rapid expansion prior to the recession. November’s results mean the annualized rate of growth so far in Q4 drops back to around 6%. But this is still in line with long run rates of traffic growth seen historically. The level of international air travel is now 4% above the pre-recession peak of early 2008 and the current expansion looks to have further to run."[19]

"Air freight reached a new high point in May (2010) but, following the end of inventory restocking activity, volumes have slipped back to settle at a similar level seen just before the onset of recession. Even so, that means an expansion of air freight during 2010 of 5-6% on an annualized basis – close to historical trend. With the stimulus of inventory restocking activity removed, further growth in air freight demand will be driven by end consumer demand for goods which utilize the air transport supply chain. ... The end of the inventory cycle does not mean the end of volume expansion but markets are entering a slower growth phase."[19]

In a 2008 presentation[6] and paper [20] Professor Kevin Anderson of the Tyndall Centre for Climate Change Research showed how continued aviation growth in the UK threatens the ability of that nation to meet CO2 emission reduction goals necessary to contain the century-end temperature increase to even 4 or 6C°. (See also: the 4 Degrees and Beyond International Climate Conference (2009)[21] and its proceedings.)[22] His charts show the projected domestic aviation carbon emission increase for the UK as growing from 11 MT in 2006 to 17 MT in 2012, at the UK's historic annual emission growth rate of 7%. Beyond 2012 if the growth rate were reduced to 3% yearly, carbon emissions in 2030 would be 28 MT, which is 70% of the UK's entire carbon emissions budget that year for all sectors of society. This work also suggests the foreseeable future which confronts many other nations that have high dependency on aviation. "Hypermobile Travelers,"[23] an academic study by Stefan Gössling et al. (2009) in the book "Climate Change and Aviation,"[24] also points to the dilemma caused by the increasing hypermobility of air travelers both in particular nations and globally.

Increasing efficiencies of aircraft and their operation

Modern jet aircraft are significantly more fuel efficient (and thus emit less CO_2 in particular) than 30 years ago.[25] Moreover, manufacturers have forecast and are committed to achieving reductions in both CO_2 and NO_x emissions with each new generation of design of aircraft and engine.[26] Thus, the accelerated introduction of more modern aircraft represents an opportunity to reduce emissions per passenger kilometre flown. However, aircraft are major investments that endure for many decades, and replacement of the international fleet is therefore a long-term proposition which will greatly delay realizing the climate benefits of many kinds of improvements. Engines can be changed at some point, but nevertheless airframes have a long life.

Other opportunities arise from the optimisation of airline timetables, route networks and flight frequencies to increase load factors (minimise the number of empty seats flown),[27] together with the optimisation of airspace. However, these are each one-time gains, and as these opportunities are successively fulfilled, diminishing returns can be expected from the remaining opportunities.

Another possible reduction of the climate-change impact is the limitation of cruise altitude of aircraft. This would lead to a significant reduction in high-altitude contrails for a marginal trade-off of increased flight time and an estimated 4% increase in CO_2 emissions. Drawbacks of this solution include very limited airspace capacity to do this, especially in Europe and North America and increased fuel burn because jet aircraft are less efficient at lower cruise altitudes.[28]

While they are not suitable for long-haul or transoceanic flights, turboprop aircraft used for commuter flights bring two significant benefits: they often burn considerably less fuel per passenger mile, and they typically fly at lower altitudes, well inside the tropopause, where there are no concerns about ozone or contrail production.

Alternate Fuels

Some scientists and companies such as GE Aviation and Virgin Fuels are researching biofuel technology for use in jet aircraft.[29] As part of this test Virgin Atlantic Airways flew a Boeing 747 from London Heathrow Airport to Amsterdam Schiphol Airport on 24 February 2008, with one engine burning a combination of coconut oil and babassu oil.[29] Greenpeace's chief scientist Doug Parr said that the flight was "high-altitude greenwash" and that producing organic oils to make biofuel could lead to deforestation and a large increase in greenhouse gas emissions.[29] Also, the majority of the world's aircraft are not large jetliners but smaller piston aircraft, and with major modifications many are capable of using ethanol as a fuel.[30] Another consideration is the vast amount of land that would be necessary to provide the biomass feedstock needed to support the needs of aviation, both civil and military.[31]

In December 2008 an Air New Zealand jet completed the world's first commercial aviation test flight partially using jatropha-based fuel. Jatropha, used for biodiesel, can thrive on marginal agricultural land where many trees and crops won't grow, or would produce only slow growth yields.[32][33] Air New Zealand set several general sustainability criteria for its Jatropha, saying that such biofuels must not compete with food resources, that they must be as good as traditional jet fuels, and that they should be cost competitive with existing fuels.[34]

In January 2009, Continental Airlines used a sustainable biofuel to power a commercial aircraft for the first time in North America. This demonstration flight marks the first sustainable biofuel demonstration flight by a commercial carrier using a twin-engined aircraft, a Boeing 737-800, powered by CFM International CFM56-7B engines. The biofuel blend included components derived from algae and jatropha plants.[35]

One fuel biofuel alternative to avgas that is under development is Swift Fuel. Swift fuel was approved as a test fuel by ASTM International in December 2009, allowing the company to continue their research and to pursue certification testing. Mary Rusek, president and co-owner of Swift Enterprises predicted at that time that "100SF will be comparably priced, environmentally friendlier and more fuel-efficient than other general aviation fuels on the market".[36][37]

As of June 2011, revised international aviation fuel standards officially allow commercial airlines to blend conventional jet fuel with up to 50 percent biofuels. The renewable fuels "can be blended with conventional commercial and military jet fuel through requirements in the newly issued edition of ASTM D7566, Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons".[38]

Reducing air travel

As George Monbiot said in a 2006 column:

> "Aviation has been growing faster than any other source of greenhouse gases. Between 1990 and 2004, the number of people using airports in the UK rose by 120%, and the energy the planes consumed increased by 79%. Their carbon dioxide emissions almost doubled in that period - from 20.1 to 39.5 megatonnes, or 5.5% of all the emissions this country produces. Unless something is done to stop this growth, flying will soon overwhelm all the cuts we manage to make elsewhere. But the measures the government proposes are useless."[39]

Thought on how to grapple with this unsustainable growth, and even to reduce air travel from its present level in order to avoid dangerous climate change, seems to be most prominent in the UK. Although the specifics differ globally, this work in the UK is likely to be widely applicable.

Personal choices and social pressure

The German video short *The Bill*[40] explores how travel and its impacts are commonly viewed in everyday developed-world life, and the social pressures that are at play. Using the concept of "love miles" George Monbiot also delved into this topic in his above 2006 column:

> "When it comes to flying, there seems to be no connection between intention and action. This is partly because the people who are most concerned about the inhabitants of other countries are often those who have travelled widely. ... When you form relationships with people from other nations, you accumulate what I call "love miles": the distance you must travel to visit friends and partners and relatives on the other side of the planet. If your sister-in-law is getting married in Buenos Aires, it is both immoral to travel there, because of climate change, and immoral not to, because of the offence it causes. ... Who could be surprised to discover that "ethical" people are in denial about the impacts of flying?"[39]

British writer George Marshall has investigated common rationalizations that act as barriers to making personal choices to travel less, or to justify recent trips. In an informal research project, "one you are welcome to join," he says, he deliberately steered conversations with people who are attuned to climate change problems to questions about recent long-distance flights and why the travel was justified. Reflecting on actions contrary to their beliefs, he noted, "(i)ntriguing as their dissonance may be, what is especially revealing is that every one of these people has a career that is predicated on the assumption that information is sufficient to generate change -- an assumption that a moment's introspection would show them was deeply flawed."[41]

Business and professional choices

> "With most international conferences having hundreds if not thousands of participants, and the bulk of these usually travelling by plane, conference travel is an area where significant reductions in air-travel-related GHG emissions could be made. ... This does not mean non-attendance." (Reay, 2004)[42] For example, by 2003 Access Grid technology has already been successfully used to host several international conferences,[42] and technology has likely progressed substantially since then.

Ending incentives to fly—frequent flyer programs

Over 130 airlines have "frequent flyer programs" based at least in part on miles, kilometers, points or segments for flights taken. Globally, such programs included about 163 million people as reported in 2006.[43] These programs benefit airlines by habituating people to air travel and, through the mechanics of partnerships with credit card companies and other businesses, in which high profit margin revenue streams can amount to selling free seats for a high price.[43] The only part of United Airlines business that was making money when the company filed for bankruptcy in 2002 was its frequent flyer program.[43]

Concerning business travel, "The ease of international air travel and the fact that, for most of us, the costs are met by our employers, means that ... globe trotting conference travel is often regarded as a perk of the job."[42] However, the perk usually is not only the business trip itself, but also the frequent flyer points which the individual accrues by taking the trip, and which can be redeemed later for personal air travel. Thus a conflict of interest is established, whereby bottom-up pressure may be created within a firm or government agency for travel that is really not necessary. Even when such conflict is not a motivation, the perk of frequent flyer miles can be expected to lead in many cases to personal trips that would not be taken if a ticket had to paid for with personal funds.[44]

By just using an airline-sponsored credit card to pay one's household expenses, personal or business bills, or even bills expensible to an employer, frequent flyer points can be racked up quickly.[43] Thus, free travel—for which the individual has to pay nothing extra—becomes a reality. Across society, this too can be expected to lead to much air travel—and greenhouse gas emissions—that otherwise would not occur.[45]

Several studies have contemplated the elimination of frequent flyer programmes (FFPs), on the grounds of anti-competitiveness,[46] ethics,[47] conflict with society's overall well-being,[48] or climate effects.[49] There is a record of governments disallowing or banning FFPs and of industry players requesting bans. Denmark did not allow the programs until 1992, then changing its policy because its airlines were disadvantaged.[46] In 2002, Norway banned domestic FFPs in order to promote competition among its airlines.[50] In the U.S. in 1989, a vice president of Braniff "said the government should consider ordering an end to frequent-flyer programs, which he said allow unfair competition."[51]

A Canadian study said that because of competition no airline could unilaterally end its FFP, but that a national government could use its regulatory power to end the programs broadly, which in Canada's case would also require North American-wide cooperation.[48] In further analysis, a Scandinavian study which recommended an end to frequent flyer plans said, "the only possible way of prohibiting FFPs successfully now that they have spread from the US to Europe to the Far East would be to do so on a global basis. The basis exists: it could be done by the World Trade Organization."[46] A recent study which surveyed frequent flyers in the U.K. and Norway, looked into behavioral addition to frequent flying and the "flyer's dilemma" of the conflict between "the social and personal benefits of flying and air travel's impact on climate change."[49] It concluded that:

> "Continued growth in both frequent flying practices and concern over air travel's climate impacts are in a dynamic relationship and the question of whether one or the other will reach a tipping point cannot yet be determined. Self-regulation, external regulation, social norms, technology and physical resources will continue to co-constitute the balance. An increasing stigmatisation of 'excessive' air travel may (re)frame flying as more open to collective external mitigation," meaning government action.[49]

Potential for governmental constraints on demand

One means for reducing the environmental impact of aviation is to constrain demand for air travel, through increased fares in place of expanded airport capacity. Several studies have explored this:

- The UK study *Predict and Decide - Aviation, climate change and UK policy*, notes that a 10% increase in fares generates a 5% to 15% reduction in demand, and recommends that the British government should manage demand rather than provide for it.[52] This would be accomplished via a strategy that presumes "… against the expansion of UK airport capacity" and constrains demand by the use of economic instruments to price air travel less attractively.[53]
- A study published by the campaign group Aviation Environment Federation (AEF) concludes that by levying £9 billion of additional taxes, the annual rate of growth in demand in the UK for air travel would be reduced to 2%.[54]
- The ninth report of the House of Commons Environmental Audit Select Committee, published in July 2006, recommends that the British government rethinks its airport expansion policy and considers ways, particularly via increased taxation, in which future demand can be managed in line with industry performance in achieving fuel efficiencies, so that emissions are not allowed to increase in absolute terms.[55]
- In his conclusion, after considering alternative fuels, better efficiency not expanding air fields and terminals, etc., Monbiot wrote:

> "In common with all other sectors, aviation's contribution to global warming must be reduced in the UK by some 87% if we are to avoid a 2C rise in global temperatures. Given that the likely possible efficiencies are small and tend to counteract each other, an 87% cut in emissions requires not only that growth stops, but that most of the aeroplanes flying today be grounded. I realise that this is not a popular message, but it is hard to see how a different conclusion could be extracted from the available evidence." After listing some current privleges this means doing without, he concluded: "But I urge you to remember that these privations affect only a tiny proportion of the world's people. The reason they seem so harsh is that this tiny proportion almost certainly includes you."[39]

Kyoto Protocol

Greenhouse gas emissions from fuel consumption in international aviation, in contrast to those from domestic aviation and from energy use by airports, are not assigned under the first round of the Kyoto Protocol, neither are the non-CO_2 climate effects. In place of agreement, Governments agreed to work through the International Civil Aviation Organization (ICAO) to limit or reduce emissions and to find a solution to the allocation of emissions from international aviation in time for the second round of Kyoto in 2009 in Copenhagen; however, that conference failed reach an agreement on these emissions.[56]

Emissions trading

As part of that process the ICAO has endorsed the adoption of an open emissions trading system to meet CO_2 emissions reduction objectives. Guidelines for the adoption and implementation of a global scheme are currently being developed, and will be presented to the ICAO Assembly in 2007,[57] although the prospects of a comprehensive inter-governmental agreement on the adoption of such a scheme are uncertain.

Within the European Union, however, the European Commission has resolved to incorporate aviation in the European Union Emissions Trading Scheme (ETS).[58] A new directive has been adopted by the European Parliament in July 2008 and approved by the Council in October 2008. It will enter into force on 1 January 2012.[59]

Mitigation

Main article: Mitigation of aviation's environmental impact

Increased fuel efficiency, the use of aviation biofuels and route optimisation reduces the impact of aviation on greenhouse gas emissions.[60]

Noise

Main article: Aircraft noise

Aircraft noise is seen by advocacy groups as being very hard to get attention and action on. The fundamental issues are increased traffic at larger airports and airport

expansion at smaller and regional airports.[61]

Air quality

Main article: Avgas#Environmental regulation

See also

- Air transport and the environment (United Kingdom)
- Aviation Environment Federation, a UK focused non-profit direct action group
- Biofuels
- Climate change
- EcoJet
- Electric aircraft
- Flying Matters, a pro-aviation coalition in the United Kingdom
- Global warming
- Hydrogen powered aircraft
- Hypermobility (travel)
- Plane Mad (direct action group)
- Sustainable biofuels

References

1. ^ International Civil Aviation Organization, Air Transport Bureau (ATB) (undated). "Aircraft Engine Emissions" (http://www.icao.int/icao/en/env/aee.htm) . http://www.icao.int/icao/en/env/aee.htm. Retrieved 2008-03-19.
2. ^ Enviro.aero (undated). "What is the impact of flying?" (http://www.enviro.aero/Impactofflying.aspx) . http://www.enviro.aero/Impactofflying.aspx. Retrieved 2008-03-19.
3. ^ Travis, David J. (2002). "Contrails reduce daily temperature range" (http://facstaff.uww.edu/travisd/pdf/jetcontrailsrecentresearch.pdf) . *Nature* **418** (6898): 601. doi:10.1038/418601a (http://dx.doi.org/10.1038%2F418601a) . PMID 12167846 (http://www.ncbi.nlm.nih.gov/pubmed/12167846) . http://facstaff.uww.edu/travisd/pdf/jetcontrailsrecentresearch.pdf.
4. ^ EU press release (2006-12-20). "Climate change: Commission proposes bringing air transport into EU Emissions Trading Scheme" (http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/1862) . Press release. http://europa.eu/rapid/pressReleasesAction.do?reference=IP/06/1862. Retrieved 2008-01-02.
5. ^ Including Aviation into the EU ETS: Impact on EU allowance prices (http://www.defra.gov.uk/environment/climatechange/trading/eu/pdf/including-aviation-icf.pdf) ICF Consulting for DEFRA February 2006
6. ^ [a] [b] Anderson, K. (2008, June 17). Reframing climate change: from long-term targets to emission pathways (http://transitionculture.org/wp-content/uploads/kevin-anderson-2.ppt) (esp. slide 24 onward).
7. ^ McNeil BI, Matear RJ (2008). Southern Ocean acidification: A tipping point at 450-ppm atmospheric CO2 (http://www.pnas.org/content/105/48/18860.abstract) . Proceedings of the National Academy of Sciences (105:48; p.18860). (In the Southern Ocean, an ecological tipping point due to "wintertime aragonite undersaturation is projected to occur by the year 2030 and no later than 2038.")
8. ^ Horvath A, Chester M (2008). Environmental Life-cycle Assessment of Passenger Transportation An Energy, Greenhouse Gas and Criteria Pollutant Inventory of Rail and Air Transportation (http://escholarship.org/uc/item/6m5865v5.pdf;origin=repeccitec) . Info: University of California Transportation Center, UC Berkeley.
9. ^ [a] [b] [c] [d] [e] [f] IPCC, *Aviation and the Global Atmosphere: A Special Report of the Intergovernmental Panel on Climate Change* (1999), Cambridge University Press (http://www.grida.no/climate/ipcc/aviation/index.htm)
10. ^ [a] [b] Sausen, Robert; Ivar Isaksen, Volker Grewe, Didier Hauglustaine, David S. Lee, Gunnar Myhre, Marcus O. KÖhler, Giovanni Pitari, Ulrich Schumann, Frode Stordal and Christos Zerefos (2005). "Aviation radiative forcing in 2000: an update on IPCC" (http://web.archive.org/web/20071128074423/http://www-lsceinca.cea.fr/pdf/Sausen+et+al.+MetZei+2005.pdf) . *Meteorologische Zeitschrift* (Gebrüder Borntraeger) **14** (4): 555–561. doi:10.1127/0941-2948/2005/0049 (http://dx.doi.org/10.1127%2F0941-2948%2F2005%2F0049) . Archived from the original (http://www-lsceinca.cea.fr/pdf/Sausen%20et%20al.%20MetZei%202005.pdf) on 2007-11-28. http://web.archive.org/web/20071128074423/http://www-lsceinca.cea.fr/pdf/Sausen+et+al.+MetZei+2005.pdf. Retrieved 2008-01-12.
11. ^ [a] [b] *Aviation and the Global Atmosphere: A Special Report of the Intergovernmental Panel on Climate Change* (1999), Cambridge University Press (http://www.grida.no/climate/ipcc/aviation/006.htm#spm41)
12. ^ "Questions & Answers on Aviation & Climate Change" (http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/05/341&format=HTML&aged=0&language=EN&guiLanguage=en) . European Commission. 2005-09-17. http://europa.eu/rapid/pressReleasesAction.do?reference=MEMO/05/341&format=HTML&aged=0&language=EN&guiLanguage=en. Retrieved 2008-01-12.
13. ^ Average passenger aircraft emissions and energy consumption per passenger kilometre in Finland 2008 (http://lipasto.vtt.fi/yksikkopaastot/henkiloliikennee/ilmaliikennee/ilmae.htm) accessed 3rd July 2009
14. ^ Nevins, Joseph (2010, 13-Dec), *Kicking the Habit: Air Travel in the Time of Climate Change (http://www.yesmagazine.org/planet/kicking-the-habit-air-travel-in-a-time-of-climate-change?utm_source=wkly20101217&utm_medium=yesemail&utm_campaign=mrNevins)* .
15. ^ Average emissions and energy consumption per vehicle kilometre of cars in Finland in 2009 (http://lipasto.vtt.fi/yksikkopaastot/henkiloliikennee/tieliikennee/henkiloautote/hayhte.htm) accessed 3rd July 2009
16. ^ [a] [b] Owen B, Lee DS, Lim L, 2010/04/01 P- (2010). Flying into the Future: Aviation Emissions Scenarios to 2050 (http://pubs.acs.org/doi/abs/10.1021/es902530z) . Environmental Science & Technology (44:7, p.2255-2260).
17. ^ Goodall, Chris (2007-02-08). *How to Live a Low-carbon Life: The Individual's Guide to Stopping Climate Change*. Earthscan Publications Ltd. p. 326. ISBN 1844074269.p. 222
18. ^ *The Future of Air Transport White Paper* (2003), HMSO (http://www.dft.gov.uk/stellent/groups/dft_aviation/documents/divisionhomepage/029650.hcsp) "The aviation industry is encouraged to take account of, and where appropriate reduce, its contribution to global warming...The impact of aviation on climate change is increased over that of direct CO_2 emissions alone by some of the other emissions released and their specific effects at altitude".
19. ^ [a] [b] IATA (2010, Nov.) Air Transport Market Analysis (http://www.iata.org/pressroom/facts_figures/traffic_results/pages/2010-06-29-01.aspx) Accessed: 23 January 2011.
20. ^ Anderson K, Bows A (2008). Reframing the climate change challenge in light of post-2000 emission trends. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences (366:1882, p.3863-3882). [1] (http://rsta.royalsocietypublishing.org/content/366/1882/3863.full) ,
21. ^ 4 Degrees and Beyond International Climate Conference, 28-30 Sept 2009, Oxford, UK. http://www.eci.ox.ac.uk/4degrees/
22. ^ Royal Society (2011). Special Issue: "Four degrees and beyond" (Jan 2011). Philosphical Transactions - A (369:1934). http://rsta.royalsocietypublishing.org/content/369/1934.toc
23. ^ Gössling S, Ceron JP, Dubois G, Hall CM, Gössling IS, Upham P, Earthscan L (2009). *Hypermobile travellers.* Chapter 6 in: Climate Change and Aviation: Issues, Challenges and Solutions; http://alicante.academia.edu/documents/0076/1866/chap06_copy.pdf
24. ^ Gössling S, Upham P (2009). Climate change and aviation: Issues, challenges and solutions. http://www.earthscan.co.uk/?tabid=42745
25. ^ IATA/ATAG, *Aviation & the Environment* (1999) "Aircraft fuel efficiency has improved by some 50% over the past 30 years"
26. ^ Advisory Council for Aeronautical Research in Europe (ACARE) *Strategic Research Agenda* (2002) (http://ec.europa.eu/research/growth/pdf/acare_press_release_revised_8-11.pdf) "These objectives include, inter alia, a 50% cut in CO2 and 80% in Nox emissions" [for new aircraft introduced in 2020 relative to new aircraft introduced in 2000].
27. ^ International Civil Aviation *Organization Operational Opportunities to Minimize Fuel Use and Reduce Emissions* (2001)
28. ^ Williams, Victoria; Robert B. Nolanda and Ralf Toumib (November 2002). "Reducing the climate change impacts of aviation by restricting cruise altitudes" (http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VH8-461XGG5-2&_user=2717328&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000056831&_version=1&_urlVersion=0&_userid=2717328&md5=b533e05b2465b167cfb5a88c4fa0cbff) *Transportation Research Part D: Transport and Environment* **7** (6): 451–464. doi:10.1016/S1361-9209(02)00013-5 (http://dx.doi.org/10.1016%2FS1361-9209%2802%2900013-5) . http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VH8-461XGG5-2&_user=2717328&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_acct=C000056831&_version=1&_urlVersion=0&_userid=2717328&md5=b533e05b2465b167cfb5a88c4fa0cbff. Retrieved 2008-04-08.
29. ^ [a] [b] [c] CBC News (February 2008). "Airline flies jumbo jet powered by biofuel" (http://www.cbc.ca/technology/story/2008/02/24/biofuel-flight.html) . http://www.cbc.ca/technology/story/2008/02/24/biofuel-flight.html. Retrieved 2008-02-24.

30. ^ South Dakota State University (2006). "Active Projects" (http://web.archive.org/web/20070928211751/http://www.age85.org/ActiveProjects.htm) . Archived from the original (http://www.age85.org/ActiveProjects.htm) on 2007-09-28. http://web.archive.org/web/20070928211751/http://www.age85.org/ActiveProjects.htm. Retrieved 2008-02-19.
31. ^ Rapier R (2011, 20-Jan). Marginal Land Produces Marginal Biomass (http://www.consumerenergyreport.com/2011/01/20/marginal-land-produces-marginal-biomass/) . Consumer Energy Report
32. ^ Ron Oxburgh. Through biofuels we can reap the fruits of our labours (http://www.guardian.co.uk/commentisfree/2008/feb/28/alternativeenergy.biofuels) *The Guardian*, February 28, 2008. Retrieved December 24, 2008.
33. ^ Patrick Barta. As Biofuels Catch On, Next Task Is to Deal With Environmental, Economic Impact (http://www.climateark.org/shared/reader/welcome.aspx?linkid=95429) *Wall Street Journal*, March 24, 2008. Retrieved December 24, 2008.
34. ^ Air New Zealand Completes Biofuel Test (http://www.greenbiz.com/news/2009/01/05/air-new-zealand-completes-biofuel-test) *GreenBiz.com*, January 5, 2009. Retrieved January 5, 2009.
35. ^ Sustainable flight (http://www.theengineer.co.uk/Articles/Article.aspx?liArticleID=309553) *The Engineer Online*, January 12, 2009. Retrieved January 12, 2009.
36. ^ Grady, Mary (December 2009). "Efforts Move Forward To Produce Alternative Aviation Fuels" (http://www.avweb.com/avwebflash/news/EffortsMoveForwardToProduceAlternativeAviationFuels_201691-1.html) . http://www.avweb.com/avwebflash/news/EffortsMoveForwardToProduceAlternativeAviationFuels_201691-1.html. Retrieved 2009-03-05.
37. ^ Purdue Research Park (December 2009). "Indiana Airline Fuel Developer Moves Ahead With Testing" (http://www.insideindianabusiness.com/newsitem.asp?ID=39195#middle) . http://www.insideindianabusiness.com/newsitem.asp?ID=39195#middle. Retrieved 2009-12-17.
38. ^ "50 Percent Biofuels Now Allowed in Jet Fuel" (http://www.renewableenergyworld.com/rea/news/article/2011/07/50-percent-biofuels-now-allowed-in-jet-fuel?cmpid=WNL-Wednesday-July6-2011) . *Renewable Energy World*. July 1, 2011. http://www.renewableenergyworld.com/rea/news/article/2011/07/50-percent-biofuels-now-allowed-in-jet-fuel?cmpid=WNL-Wednesday-July6-2011.
39. ^ [a] [b] [c] Monbiot, George (2006, 21-Sept), *On the flight path to global meltdown (http://www.guardian.co.uk/environment/2006/sep/21/travelsenvironmentalimpact.ethicalliving)* .
40. ^ *The Bill (http://www.youtube.com/watch?v=rWfb0VMCQHE) ," by Peter Wedel, distributed by GermanWatch.*
41. ^ Marshall, G. (2009, 24-July). *We Still Don't Believe In Climate Change (http://climatedenial.org/2009/07/24/why-we-still-dont-believe-in-climate-change/Why)*
42. ^ [a] [b] [c] Reay DS (2004). *New Directions: Flying in the face of the climate change convention (http://www.ghgonline.org/flyingaea.pdf)* . Atmospheric Environment (38:5, p.793-794).
43. ^ [a] [b] [c] [d] The Economist (2005, 20-Dec), *Frequent-flyer miles - Funny money (http://www.economist.com/node/5323615)* .
44. ^ UNEP DTIE (Sustainable Consumption & Production Branch)(undated). A Guide to Greenhouse Gas Emission Reduction in UN Organizations (DTI/1217/PA). pp.18-19. (http://www.unep.fr/scp/sun/facility/reduce/PDFs/EmissionReductionGuide.pdf)
45. ^ MedCaribbean.com. Making The Most Of Your Airlines Miles Credit Cards. (http://medcaribbean.com/making-the-most-of-your-airlines-miles-credit-cards/)
46. ^ [a] [b] [c] Storm S (1999) *Air transport policies and frequent flyer programmes in the European Community: a Scandinavian perspective. (http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.138.3305&rep=rep1&type=pdf)* Unit of Tourism Research, Recearch Centre of Bornholm (p.1-105).
47. ^ Cognac M, DeLozier M (1997)*Frequent Flyer Programs Promotion: An Analysis Of A Paradoxical Industry. (http://www.sbaer.uca.edu/Research/sma/1997/PDF/toc.pdf.)* Southwestern Marketing Association (p.1-12).
48. ^ [a] [b] Tretheway MW (1989) *Frequent Flyer Programs: Marketing Bonanza or Anti-Competitive Tool? (http://trid.trb.org/view.aspx?type=CO&id=302286.)* (30:1), p.445.
49. ^ [a] [b] [c] Cohen S, Higham J, Cavaliere C (2011). *Binge flying: Behavioural addiction and climate change. (http://eprints.bournemouth.ac.uk/1716)* Annals of Tourism Research
50. ^ Aftenpost (2002). *Sterling polishes plans for new routes (http://www.aftenposten.no/english/business/article296704.ece)* , by Nina Berglund, 19 Mar 2002.
51. ^ Orlando Sentinel (1989). *Braniff Will SlimDown, Keep Flying (http://articles.orlandosentinel.com/1989-10-04/news/8910042722_1_airline-braniff-volz)* , by Kenneth Michael, 4 Oct 1989.
52. ^ Cairns, Dr Sally & Carey Newson et al. (September 2006). "Predict and decide - Aviation, climate change and UK policy" (http://www.eci.ox.ac.uk/research/energy/downloads/predictanddecide.pdf) . pp. 96, section 11.9. http://www.eci.ox.ac.uk/research/energy/downloads/predictanddecide.pdf. Retrieved 2008-05-31.
53. ^ Cairns, Dr Sally & Carey Newson et al. (September 2006). "Predict and decide - Aviation, climate change and UK policy" (http://www.eci.ox.ac.uk/research/energy/downloads/predictanddecide.pdf) . pp. 4. http://www.eci.ox.ac.uk/research/energy/downloads/predictanddecide.pdf. Retrieved 2008-05-31.
54. ^ Sewill, Brendon (February 2003). "The Hidden Cost of Flying" (http://www.aef.org.uk/downloads/HiddenCost.pdf) (PDF). Aviation Environment Federation. pp. 19–20. http://www.aef.org.uk/downloads/HiddenCost.pdf. Retrieved 2007-10-18.
55. ^ "*Select Committee on Environmental Audit Ninth Report*" (http://www.publications.parliament.uk/pa/cm200506/cmselect/cmenvaud/981/98108.htm) . British House of Commons. 19 July 2006. pp. paras. 112, 118–125, 113–114 & 126–133. http://www.publications.parliament.uk/pa/cm200506/cmselect/cmenvaud/981/98108.htm. Retrieved 2007-11-12.
56. ^ GreenAirOnline (2009, 22-Dec). Copenhagen's failure to deliver an aviation emissions deal leaves sector facing an uncertain future (http://www.greenaironline.com/news.php?viewStory=713) .
57. ^ ICAO news release 30 November 2005 (http://www.icao.int/cgi/goto_m.pl?icao/en/nr/2005) "ICAO is also considering market-based options to address engine emissions through the participation of aviation in emissions trading schemes and the use of emissions levies related to local air quality. Guidelines for Contracting States wishing to implement such measures are being formulated and should be completed in time for the next regular Session of the ICAO Assembly in the Fall of 2007, when direction for future action will be set."
58. ^ European Commission, *Reducing the Climate Change Impact of Aviation* (2005)
59. ^ Directive 2008/101/EC of the European Parliament and of the Council (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32008L0101:EN:NOT) of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community (Text with EEA relevance)
60. ^ "Beginner's Guide to Aviation Biofuels" (http://www-org.airbus.com/store/mm_repository/pdf/att00014178/media_object_file_BeginnersGuide_Biofuels.pdf) . Air Transport Action Group. May 2009. http://www-org.airbus.com/store/mm_repository/pdf/att00014178/media_object_file_BeginnersGuide_Biofuels.pdf. Retrieved 2009-09-20.
61. ^ Noise Pollution Clearinghouse (undated). "Aviation Noise" (http://www.nonoise.org/resource/trans/air/airport.htm) . http://www.nonoise.org/resource/trans/air/airport.htm. Retrieved 2007-12-29.

External links

- Air travel, climate change, and green consumerism
- Centre for Air Transport and the Environment (http://www.cate.mmu.ac.uk/index.asp?chg=home)
- Commercial aviation industry environmental initiatives (http://www.enviro.aero/)
- Climate Change Denial blog (http://climatedenial.org/) Exploring the psychology of climate change denial.
- Efficient Aviation: The Sky's the Limit (http://knowledge.allianz.com/en/globalissues/climate_change/climate_solutions/aviation_emissions_reduction.html) Eight ways to cut fuel consumption, Allianz Knowledge, June 2008
- European Federation for Transport and Environment (T&E) 'Clearing the Air: The Myth and Reality of Aviation and Climate Change' (http://www.transportenvironment.org)
- EU Parliament to Tighten Airline Emissions Rules (http://www.planetark.com/dailynewsstory.cfm/newsid/45232/story.htm)
- Flight Emission Calculator (http://www.cheap-parking.net/flight-carbon-emissions.php)
- Partnership for AiR Transportation Noise and Emissions Reduction (http://www.partner.aero/)
- Sustainable Aviation (http://www.sustainableaviation.co.uk)
- The Dreadful Cost of Flying (http://www.oneclimate.net/2009/05/24/the-dreadful-cost-of-flying/)

Organisations

- Stop Flying (http://www.stopflying.org/)
- Manchester Climate Action (http://manchesterclimateaction.wordpress.com/)
- Plane Stupid (http://www.planestupid.com/)
- Flight Pledge (http://www.flightpledge.org.uk/)
- GreenSkies Alliance (http://www.greenskies.org/)
- AirportWatch (http://www.airportwatch.org.uk/)
- Air Transport Action Group (http://www.atag.org/content/default.asp)
- Aviation Environment Federation (http://www.aef.org.uk/)

News

- Third runway plan for Heathrow scrapped by BAA (24 May 2010) (http://www.guardian.co.uk/environment/2010/may/24/third-runway-heathrow-scrapped-baa/)
- What is the real price of cheap air travel? by Tom Robbins, The Observer, Sunday 29 January 2006 (http://observer.guardian.co.uk/travel/story/0,,1697190,00.html)