WTL

Aviation and climate in the EU

Working Group on the Future of Aviation (WTL)

Aviation and climate in the EU

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This report is intended for policymakers. The Appendix is intended for experts wanting to check the scientific founding of the conclusions.

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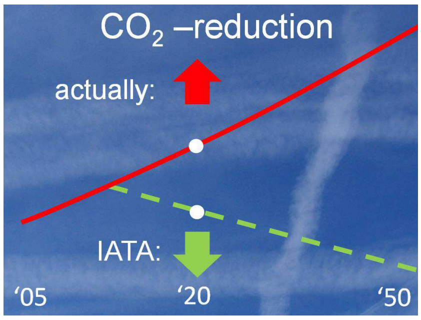
Summary for policymakers

Large CO2 emission increase of aviation requires urgent intervention



In 2010 UN organization ICAO and the aviation industry published measures to halve the CO_2 emissions of a growing aviation in 2050 compared to 2005. The reduction of CO_2 should have begun in 2009 and after 2020 aviation growth should be carbon neutral. The scrutiny in this Report concludes that *these goals will totally fail.* The GHG emissions will not decrease, ***but increase three to four times*** those of 2005. Even without growth after 2020, the emissions and warming effects would eventually in 2050 about equalize those of 2005. This disconcerting observation is based on scientific references. ICAO and the aviation industry are overestimating the effects of bio kerosene and fuel, pleading for a "sustainable" growth of aviation that is bad for the climate. While prominent scientists already are warning for a too high warming of four degrees, aviation will increase its share considerably. In that case the associated threat to global economy will also hit aviation itself.

No new runways, more hi-speed trains and less flying

This report is an urgent appeal on the EU and its Member States to limit the European aviation emissions by waiving the expansion of runways at airports. It is unnecessary, even harmful to let aviation grow as the economy grows. There are other possibilities to respond to economic developments without aviation growth, causing considerable less damage to the climate.

International transport could grow considerably by truly integrating aviation and the large European network of hi-speed trains and supporting conventional trains. Trains will be powered by fully renewable electricity within a few decades, contrarily to aircraft not becoming climate neutral before and maybe also after 2050. Futuristic low GHG-airplanes do not even exist on the drawing board. Airlines could accommodate a majority of their European passengers by hi-speed train and using the airport capacity becoming available. Accelerated deployment of hi-speed trains for international business trips would be quite beneficial to both the economy and the climate.

> Airplanes cause 17 times more warming per passenger km than hi-speed trains. Trains will soon become far more climate friendly, airplanes will hardly. Flying within West-Europe should be urgently questioned

Moreover *a shift may occur of leisure traffic to business and societal air transport***.** The leisure market is very price sensitive. When flying becomes more expensive because of doubling oil prices and higher CO_2 emission charges, decreasing leisure traffic will make room for further business traffic growth without air traffic increase. Also both business and leisure passengers could be stimulated to make more use of video conferencing and waive flights that hardly contribute to the economy and society.

Conclusion: European governments should stop the expansion of runways. Nevertheless business and societal transport could be offered a considerable growth potential.

1. Aviation in a warming climate

Climate warming. The climate is getting warmer due to greenhouse gas (GHG) emissions (especially of CO_2), caused by human activities. The World Bank (2012) and Stern (2013) warned the world being on its way to four degrees warming. Stern said some countries, including China, had started to grasp the seriousness of the risks, but governments should now act forcefully to shift their economies towards less energy-intensive, more environmentally sustainable technologies. Limiting the warming to two degrees requires sacrifices of every country, industry and individual, naturally also the aviation industry.

Contribution of aviation. The International Civil Aviation Organization (ICAO 2010b) published Resolution A37-19 on the sustainability of aviation. It is noting "the collective commitments announced by (…) IATA (…) on behalf of the international transport industry

- to continuously improve CO_2 efficiency by an average of 1.5% per annum from 2009 until 2020,
- to achieve carbon neutral growth from 2020 and
- reducing its carbon emissions by 50% by 2050 compared to 2005 levels".

ICAO specifies measures to reduce these emissions, being:

- a continuous annual fuel efficiency improvement of 2% from 2010 to 2050
- the introduction of sustainable alternative fuels for aviation (bio kerosene).

ICAO is taking into account the sustainable growth of the international aviation industry, and that reduction measures should not negatively impact the growth of transport in developing economies.

Scrutiny. In the Appendix these goals are scrutinized, based on the following questions:

1. How effectively could bio fuels reduce fossil CO_2 emissions of aviation?
2. How realistic is the expectation of a continuous annual fuel efficiency improvement of 2% from 2010 to 2050?
3. Would bio fuel and fuel efficiency improvement enable the aviation industry to reduce its carbon emissions by 50 per cent by 2050 compared to 2005 levels, if aviation would continue to grow? What about warming of both carbon and non-carbon emissions? Would the aviation industry be able to achieve its interim reduction goals before and after 2020?

According to the International Energy Agency (IEA 2011), the amount of bio fuel available for global aviation will be limited in 2050. Due to the increasing fuel use, this will comprise 21% to 30% of the total amount of fuel required in 2050. The fossil CO_2 emission reduction efficiency of this bio fuel is estimated to be some 50%. So the reduction effect will be no more than 10% to 15% in 2050.

The expected 2% annual fuel efficiency improvement is far more optimistic than the findings of Peeters et al. (NLR 2005). Jet technology improvements as from the sixties are at their final stage, being some 1% annually now and further decreasing to some 0.7% p.a. around 2050. Improvements from very innovative technology are not to be expected before 2050. Concepts of fully climate neutral airplanes are not known.

On the basis of these findings, two IPCC (1999) growth scenarios and the survey of Lee et al. (2009) on GHG of aviation, estimates are made fuel use, CO_2 emissions and the warming effects of both CO_2 and non-carbon GHG of aviation. As a third scenario a hypothetical situation of non-growing aviation after 2020 was chosen.

The scrutiny conclusions (Appendix Chapter IV) are: All three aviation industry's reduction goals before and after 2020 will fail. A 1.5% annual CO_2 reduction between 2009 and 2020 will not be achieved because of the low effects of fuel efficiency improvement and the non-availability of appropriate bio fuels. Actually the CO_2 -emission will increase by a factor of 1.75 in 2020 compared to 2005 levels. A carbon-neutral growth of aviation after 2020 will not be possible since this requires airplanes emitting no fossil CO_2 at all, which do not exist.

In a realistic IPCC growth scenario *both the CO_2 emissions and the combined warming effects of all GHG emissions (including non-carbon GHG) of aviation will be in 2050 three to four times those in 2005.* This is due to the lower reduction effect of bio fuel, a moderate fuel efficiency improvement and a fuel use in 2050 of four times of the use in 2005. In a somewhat less realistic IPCC scenario of moderated growth, the emissions and warming in 2050 will still be two to three times compared to 2005. At non-growth as from 2020, the CO_2 emissions and warming effects would in 2050 be about the same as those in 2005. *The aviation industry's goal to reduce CO_2 emissions in 2050 to 50% of those in 2005 could only be realized if the use of aviation fuels would shrink after 2020.*

Consequences of growing aviation. It is not probable that a world taking much trouble to sufficiently decreasing its GHG emissions, will accept such an exception of aviation. The transport industry outside aviation will demand a level playing field of reduction obligations. It will not accept the exceptional position the aviation industry is heading to. Transport modes such as trains, buses and cars will become almost fully climate-neutral in a few decades. Jet airplanes do not have that prospect.

Meanwhile aviation keeps on growing, making the GHG problem larger and larger. If this would become one of the causes of warming to values of four degrees and more, the aviation industry would not only contribute to the collapse of global economy, but also to its own. Mark Lynas (Six Degrees, 2007) says: "Civilisational collapse, like the blast wave of a neutron bomb, will sweep around the globe". His (out)spoken summary could be heard on Youtube.

Goals of more ambition. According to CE Delft (Faber et al., 2009) "a sufficient contribution to global climate goals is only possible if aviation is limited."

The combined reduction plans of the aviation industry and ICAO show an absurdity of promising an impressive but impossible GHG emission reduction on the one hand, and assuming that aviation must go on growing on the other.

ICAO however seems to be somewhat more realistic by admitting "that the aspirational goal of 2 per cent annual fuel efficiency improvement is unlikely to deliver the level of reduction necessary to stabilize and then reduce aviation's absolute emissions contribution to climate change, and that *goals of more ambition* will need to be considered to deliver a sustainable path for aviation. (…) To promote sustainable growth of aviation, a comprehensive approach, consisting of work on technology and standards, and on operational and market-based measures (MBM) to reduce emissions is necessary."

Obviously such measures will increase costs of flying to reduce aviation emissions, but they will not directly limit aviation growth as such. The 'goals of more ambition' as mentioned by ICAO in fact should aim at drastically limiting the growth. It is doubtful whether the aviation industry ever will accept that.

Effective growth limiting measures as from 2020 may at least stop the increase of emissions. Actually this would be insufficient to realize the committed 50% CO_2 reduction, because that would require considerable shrinking of aviation.

> In 2011 the British Government decided to no longer expand the airports of London, mainly to spare both environment and climate. Inland flights are to be replaced by hi-speed trains. A breaking point in the political process was the finding that airport expansion appeared not to be very essential for a mature economy owing to the many alternatives to create new employment (Boon, CE Delft 2008).
>
> In 2012 it appeared however that there is a lobby of the aviation industry to build a new airport in the Thames Estuary.

Conclusion: aviation should at least stop growing as from 2020 to prevent the GHG emissions to increase.

2. Economic consequences of an aviation growth stop

Opposition. Growth limitations will be vigorously opposed by both the aviation industry and politicians who consider aviation growth as a self-evident part of a growing economy. Aiming for growth is firmly rooted in the business strategy of the aviation industry. The adage is: “Growth is a must, stagnation means decline”. Carriers, airports and aircraft manufacturers are continuously trying to increase their profits and shareholder value. Strong competition and a price war between airlines are leading to small profit margins, high fuel prices even to losses. Aviation these days means transporting as many passengers as you can to as many destinations as possible at air fares far lower than those in other transport modes. Large hubs compete to other hubs in attracting more transfer passengers and to increase their share of the global market.

The economic argumentation. A generally used economic argument is that aviation is beneficial to the economy and should grow with the economy growth, or even that employment is in danger if aviation would not be enabled to grow. That may be the case in developing countries having low levels of industrialization and employment, but not in developed prosperous countries where the economy is mature, offering many new industrial and employment alternatives that are not depending on the growth of aviation. In the EU, protecting employment is not a valid argument for expansion of airports (Boon et al., 2008).

A growth stop of aviation may disadvantage the economy and society insofar it would be impossible to accommodate a growing market demand of trips for *business and societal ends.* Business travel is a direct contribution to the economy and transport for societal ends is good for the quality of society. The drawback of a growth stop to the leisure market would be less. Incoming tourism adds to a country’s welfare, but outgoing tourism and vacation making have a negative influence on the gross national income. (Boon et al.).Moreover there are many alternatives for leisure trips that do not disadvantage welfare and society.

Conclusion: Aviation growth limiting measures should spare the transport market for business and societal ends.

Political will. The aviation industry presents need for growth as a macro-economic requirement to the public and politicians. Based on this it expects governments to support aviation growth. IATA (2010) states: “governments or airports (should) invest in adequate infrastructure to keep pace with airline demand. (…) There are a multitude of reasons why airports may not be able to meet the demand, but lack of political will is probably the major cause.” Could the aviation industry expect continuation of governmental support in the light of the increasing warming effects? Are governments able, supposing the political will to protect the climate is strong enough, to stop the increase of warming by limiting aviation growth without damaging the economy and the quality of society?

Yes, they are. They could stop the expansion of for instance runways and the number of flights at airports. To protect economy and society, they could simultaneously develop international transport modalities that are more sustainable than aviation. Like the hi-speed train.

3. Sustainable growth by hi-speed trains

Aviation is not the only means of international transport. Travel to nearby destinations of up to some 800 km within Europe can take place by hi-speed trains (and 1,200 km by super hi-speed trains) at equal or less travelling times (Figure 1 and Faber et al., CE Delft 2009). The Hi-speed network in the EU has an enormous capacity to accommodate millions of intercontinental transfer passengers at the connected large airports (Figure 2). Hi-speed trains will be utilised far more intensively, which will improve the exploitation and lower the fares which are presently somewhat high. A great advantage is that hi-speed trains cause 17 times less warming than airplanes per passenger km (Table 1). Unlike airplanes they will be almost fully climate-neutral in a few decades if powered by fully renewable electricity. The difference is getting bigger and bigger. On top of that the pan-European transport system will not be subject to the price effects of oil becoming scarcer. Flying within West-Europe should be urgently discussed.

Figure 1 Travel time of hi-speed train vs air (Faber et al., CE Delft, 2009)

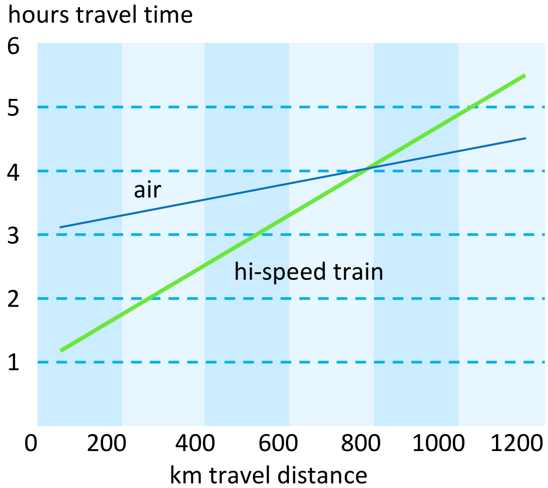


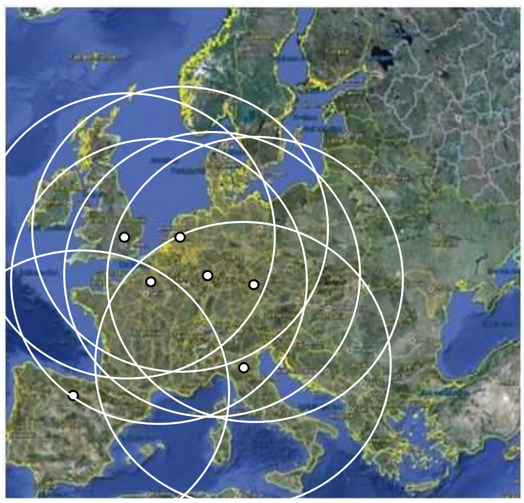
Table 1 Energy use in transport (Mc Kay 2009)

Transport mode	Energy kWh/ 100pk
Cars (one passenger)	80
Cars (two passengers)	40
Average airplane	**51**
Average hi-speed train (Japan)	**6**

Hi-speed trains need 8.5 times less energy per passenger km than airplanes (Table 1). If the CO2 emissions per ton fuel are about the same in both cases, the CO2 emissions of airplanes per passenger km will be 8.5 times those of hi-speed trains.

Since the warming of airplanes is about twice the warming of their CO2 alone, airplanes cause per passenger km 17 times the warming by hi-speed trains.

Figure 2 Hi-speed train ranges of 1,000 km around the major EU airports



Conclusion: The European network of hi-speed trains offers four benefits compared to short-haul European aviation:

- large capacity to accommodate a growing international transport market
- much less energy use per passenger km,
- much less GHG missions that will decrease in a high pace,
- not dependent on more and more expensive oil

4. Segmenting the EU transport market.

What will be the economic and societal effects of a non-growing aviation, combined with growing transport by hi-speed trains? To get an answer to this question, the EU international passenger transport market could be divided into three segments:

1. *The Hi-speed segment*: all airport passengers travelling at destinations within the reach of the EU hi-speed network to which the airports are connected. See Figure 2.
2. *The Business&Societal segment* of airport passengers at destinations *outside* the range of the above mentioned EU hi-speed network.
3. *The Leisure segment* of airport passengers travelling for personal ends, also *outside* the range of the above mentioned EU hi-speed networks.

Segments at Schiphol. To get an impression of the sizes of these segments, an estimate is made for Schiphol. (Traffic Review 2011; see Tables 2A and B below). Each of the three segments at Schiphol appeared to comprise about one third of the total number of 50 million passengers. Ratios may differ at other EU airports, but also there both the Hi-speed and Leisure market segments may comprise many millions of passengers.

Table 2A Potential hi-speed passengers Schiphol (2011)

Origin/ Destination	Mio pass.in 2011	Hi-speed potent'l per O/D	Hi-speed potent'l in mio pass
UK	7,3	80%	5,8
Spain	4,3	50%	2,1
Germany	3,3	90%	3,0
Italy	2,7	75%	2,0
France	2,2	90%	2,0
Switserland	1,5	75%	1,1
Denmark	0,6	50%	0,3
Austria	0,3	50%	0,2
Total	**22,2**		**16,5**

Table 2B Estimated segment sizes Schiphol (2011)

The potential *Hi-speed segment* amounts to **16.5** million passengers (Table 2A). The passengers travelling outside the range of hi-speed numbered 50 million total minus 16.5 million hi-speed, being 33.5 million passengers in 2011.

The *Business&Societal* segment would comprise the categories Business (33%), Congress/study (4%) and half of Visiting family (10%), being (47% of 33 million=) **15.7** million passengers. The *Leisure segment* comprises all remaining passengers (**17.8** million).

Roughly estimated the three segments each are about *one third of the total*.

Growth of hi-speed and business/societal traffic. Suppose the economy shows a growing demand for business and societal transport, how airlines serve this at non-growing airports where flight permissions (slots) are scarce? They could accommodate a majority of their European passengers by hi-speed train and using the airport capacity becoming available for a growing market demand of long haul business and societal trips. This would give the Business&Societal segment a considerable growth potential.

Another growth possibility for this segment would appear if air fares would become higher, for instance because of higher GHG-surcharges and oil prices doubling in the next decade (IMF, 2012). The leisure market is more price sensitive than the business market, so the demand of long haul leisure trips may decrease or move to other alternatives within Europe. This would offer the Business&Societal segment an opportunity to relatively grow at airports, despite their limited numbers of slots. The aviation network will maintain its size, but there will be a shift from leisure travel to more business and societal air traffic.

5. Growth stop at EU airports

Limiting airport capacities. The EC and EU Member States have a key position to control European aviation growth by means of their aviation policy. European aviation is one of the largest of the world. Ceasing to invest in expansion of airports and runways would keep warming effects within the limits.

By causing a shift from non-sustainable aviation within Europe (17 times as much warming, see Chapter 3) to sustainable hi-speed trains, the climate-friendly quality of international transport could increase significantly. Then the EC and Member States should produce the political will to limit the growth of EU aviation because of its belonging warming effects.

Most EU hubs already are reaching the capacity limits of runways and local airspace. The EC and Member States should take a more critical view at planned expansions of aviation facilities, bearing in mind that each expansion will lead to more warming and that the economic benefits in most cases are limited because of the growth alternatives of transport of economic and societal importance.

Recommended steps

1. Inform ICAO and the global aviation industry about the doubtful character of their present emission reduction plans. Demand effective measures (including limiting growth) that will actually decrease the emission of aviation GHG in the next decades.
2. Remove a major incentive to aviation growth by *waiving* the expansion of runway capacity at airports reaching their limits. The societal cost/benefit analyses of already planned expansions as yet need to include the extra warming effects arising from to the extra aviation to be attracted.
3. Invest at short notice in hi-speed networks and supporting conventional train networks that could grow further with minor climate consequences. Stimulate better integration of aviation networks with hi-speed networks. An example is the Dutch/Belgian Air/Railticket system. Promote to the public the preferred use of hi-speed trains that are considerably more friendly to the climate than airplanes. Create an equal tariff level playing field between hi-speed and air travel in Europe. In April 2013 SNCF introduces the budget hi-speed train Ouigo to compete with the low-cost airliners.
4. Introduce caps (limited number of flights per year) and management of slots (start and landing permits) at all commercial international airports in Member States, whether or not having reached their capacity limits. Caps will prevent non fully occupied airports to attract air traffic that can no more be accommodated at fully occupied airports, since that would have the same devastating warming effects as creating extra runway capacity. Introducing caps will have positive effects on the sustainability of the international EU transport:
   - Caps on all competing airports will create an equal playing field.
   - Slot scarcity may lead to higher air fares, enabling airlines to improve their margins and focus their marketing and quality management on the less price-sensitive Business&Societal segment.
   - Owing to slot scarcity, airlines will be prepared to replace their EU flights by hi-speed traffic.
5. Stimulate the public to make more use of digital communication and waive flights that hardly contribute to the economy and society.

Appendix. Scrutiny of the aviation emission reduction goals

Introduction

In this Appendix of the Report *Aviation and Climate in the EU* the statements of ICAO Resolution A-37 and the aviation industry on sustainable aviation as mentioned in Chapter 1 of the Report are scrutinized in the light of scientific references.

The need to reduce CO_2 and the relevant goals for reducing aviation emissions are shown in Chapter I. The effects of transition to bio kerosene are surveyed in Chapter II and those of fuel efficiency improvement in Chapter III. The resulting probable reduction of CO_2 and other non-CO_2 emissions are estimated in Chapter IV using some IPCC scenarios of aviation growth and fuel use increase.

I. Global warming and aviation climate goals

The climate is getting warmer due to greenhouse gas (GHG) emissions (especially of CO_2) caused by human activities. There still is a possibility to limit this warming to some two degrees, which is the lowest of various scenarios of IPCC (2007a, pages 791-792). This is supposed to be possible if the concentration of CO_2 in the atmosphere could stabilize to some 450 parts per million as from 2050. Various studies and models indicate that such stabilization would take place if GHG emissions of human activities are reduced quite substantially as from now on. See Figures 3 and 4 below.

Figure 3 Projected CO2 emissions as a percentage of those in 2005, leading to stabilization of CO2 concentration of 450 ppm (IPCC, 2007, SP450, Figure 10.22, page 792).

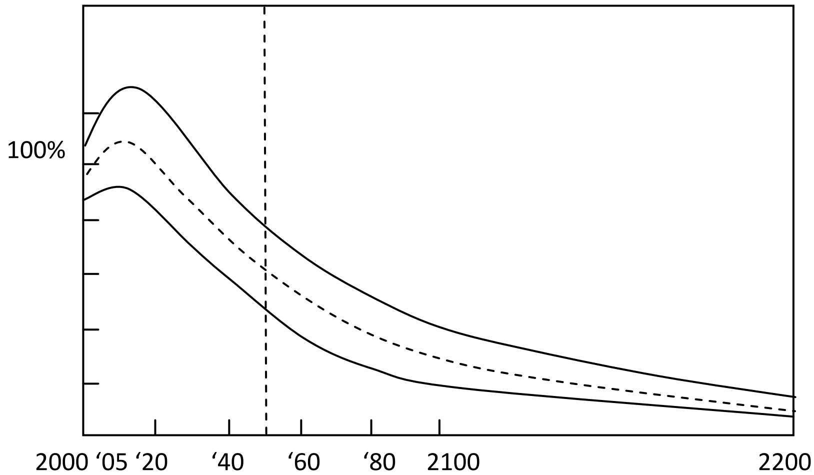
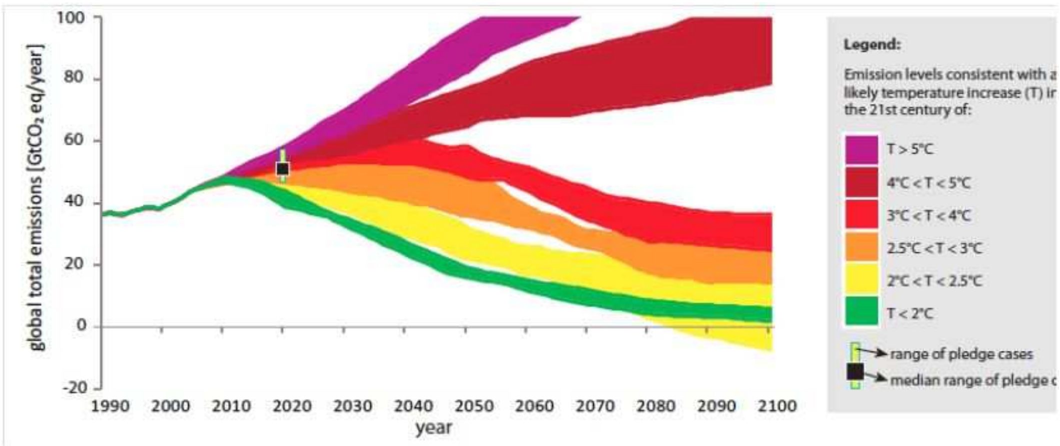


Figure 4 Emission levels consistent with a likely temperature rise. (Lee, 2012)



The "ETP 2010 BLUE Map Scenario of the OECD/IEA sets a target of 50% reduction in all energy-related CO_2 emissions by 2050 from 2005 levels." (IEA 2011, Page 21). This scenario is aiming for "a significant increase in use of low carbon bio fuels (…) required by 2050 (…) to stabilize atmospheric greenhouse gases around 450 parts per million (ppm) to limit global temperature rise to below 2°C,"(IEA page 8).

Reduction of warming by aviation. The International Civil Aviation Organization (ICAO) published Resolution A37-19 (ICAO 2010b) on the sustainability of aviation. ICAO is noting the "collective commitments" of the "international aviation industry to continuously improve CO_2 efficiency by an average of 1.5 per cent per annum from 2009 until 2020, to achieve carbon neutral growth from 2020 and *reducing the carbon emissions by 50 per cent by 2050 compared to 2005 levels".* Concerning CO_2 emissions this goal indicates the resolution of the aviation industry to at last reduce its carbon emissions in about the rate necessary to limit warming to two degrees. The aviation industry does not mention GHG emissions of aircraft other than CO_2 in this goal.

ICAO resolves in article 4 "that States and relevant organizations will work through ICAO to achieve a global annual average fuel efficiency improvement of 2 per cent until 2020 and an aspirational global fuel efficiency improvement rate of 2 per cent per annum from 2021 to 2050, calculated on the basis of volume of fuel used per revenue tonne kilometre performed". Summarising, ICAO expects *a continuous annual fuel efficiency improvement of 2% from 2010 to 2050.* Next to improving fuel efficiency, ICAO is mentioning ***"****sustainable alternative fuels for aviation*" (Article 23g through i) as a measure to reduce CO_2 emissions.

In article 6 ICAO resolves: "that, without any attribution of specific obligations to individual States, ICAO and its member States with relevant organizations will work together to strive to achieve a collective medium term global aspirational goal of keeping the global net carbon emissions from international aviation from 2020 at the same level, taking into account: (…) (e) *the sustainable growth of the international aviation industry.* The impact of measures on growth of aviation is to be explored (article 8) but aviation growth is to be protected in developing countries, considering article 3.b: "emphasis should be on those policy options that will reduce aircraft engine emissions *without negatively impacting the growth of air transport especially in developing economies".*

The scrutiny of these goals is based on the following questions:

1. How effectively could bio fuels reduce fossil CO_2 emissions of aviation? (Chapter II)
2. How realistic is the expectation of a continuous annual fuel efficiency improvement of 2% from 2010 to 2050? (Chapter III)
3. Would bio fuel and fuel efficiency improvement enable the aviation industry to reduce the carbon emissions by 50 per cent by 2050 compared to 2005 levels if aviation would continue to grow? What about warming effects of both CO_2 and non-carbon emissions? ? Would the aviation industry be able to achieve its interim reduction goals before and after 2020? (Chapter IV)

II. Bio kerosene

The scrutiny question is:

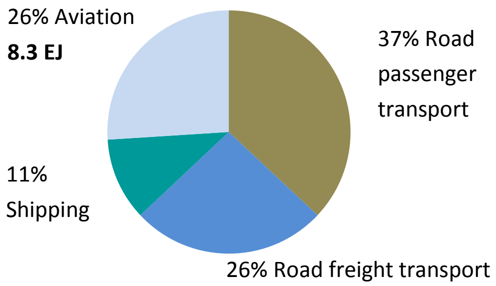
How effectively could bio fuels reduce fossil CO_2 emissions of aviation?

Lee et al (2009, p 3531) mention “fundamental questions of the economic and ecological viability of producing significant quantities of bio fuels, which are likely to find more practical uptake and usage in other transport sectors (Kahn-Ribeiro et al., IPCC 2007). In addition, there are increasing concerns over land-usage conflicts between food and fuel production in developing nations.”

An up-to-date comprehensive survey on available bio fuels and their effectiveness is made by OECD/IEA (2011). “Meeting the bio fuel demand in this roadmap would require (…) around 100 million hectares in 2050. This poses a considerable challenge given competition for land and feed stocks from rapidly growing demand for food and fibre.” (page 5). “To achieve the projected emission savings in the transport sector, ETP 2010 projects that sustainably produced bio fuels will eventually provide 27% of total transport fuel. Based on the BLUE Map Scenario, by 2050 bio fuel demand will reach 32 EJ” (page 21). According to the percentages in Figure 5, aviation is expected to be entitled for a bio kerosene share of 26% of these 32 EJ, being 8.3 EJ, independent of the actual fuel use.

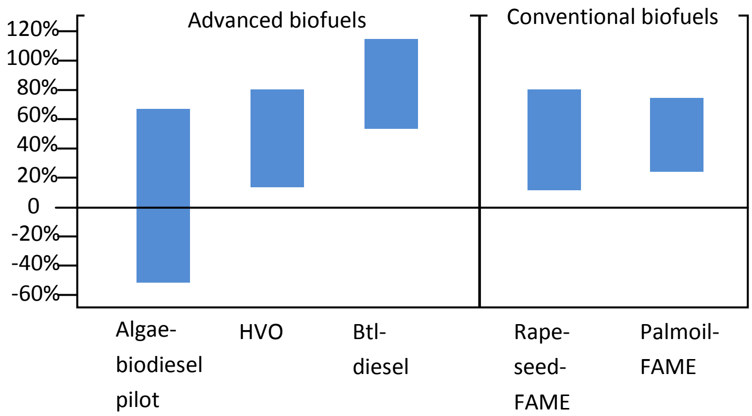
Figure 5 Global use of bio fuel in different transport modes in 2050 (Blue Map Scenario; IEA 2011 Fig 6)

Total 32 EJ



Concerning the actual percentage of life-cycle GHG emission savings by bio kerosene, this IEA survey refers to diesel replacements. According to Figure 6 below, the emissions reductions vary between 20% and 80%, averaging at 50%. They do not include emissions due to land use change bio production. For instance the land-use emissions of rapeseed biodiesel in some studies are some 40 g CO_2-equivalents per MJ. Consequently, these extra emissions would lower the emission reductions without land use change (20-80%) to about 13% - 52%. Therefore, the assumption of 50% emissions reduction by bio kerosene (without land use change effects) is rather realistic.

Figure 6 Life-cycle GHG balance of Diesel replacement bio fuels (IEA, 2011 pp 16-17)



Note: The assessments exclude emissions from indirect land-use change. Emission savings of more than 100% are possible through use of co-products.
BtL = biomass-to-liquids; FAME = fatty acid methyl esthers; HVO = hydrotreated vegetable oil. Source: IEA analysis based on UNEP and IEA review of 60 LCA studies, published in OECD, 2008; IEA, 2009; DBFZ, 2009.

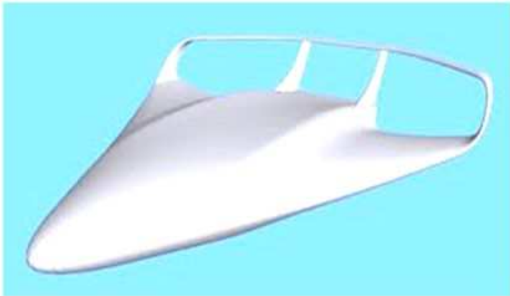
According to Lee et al.(page 3531) hydrogen powered aircraft would not emit CO_2 but “would produce more contrails than kerosene-powered aircraft because of increased water vapour emissions, which could potentially produce contrails that have a smaller optical depth than conventional contrails. Therefore, the benefit in terms of total RF of using LH2 fuel would only become apparent a few decades after introduction of this alternative fuel.” So hydrogen is not considered as a realistic option for bio kerosene.

Conclusion: In 2050 global aviation will have a limited quantity of bio fuel at its disposal of 8.3 EJ of which the fossil CO_2 emission reduction efficiency will be some 50%. Hydrogen fuel is not a realistic option.

III. Annual efficiency improvement

The scrutiny question is:

How realistic is the expectation of a continuous annual fuel efficiency improvement of 2% from 2010 to 2050?

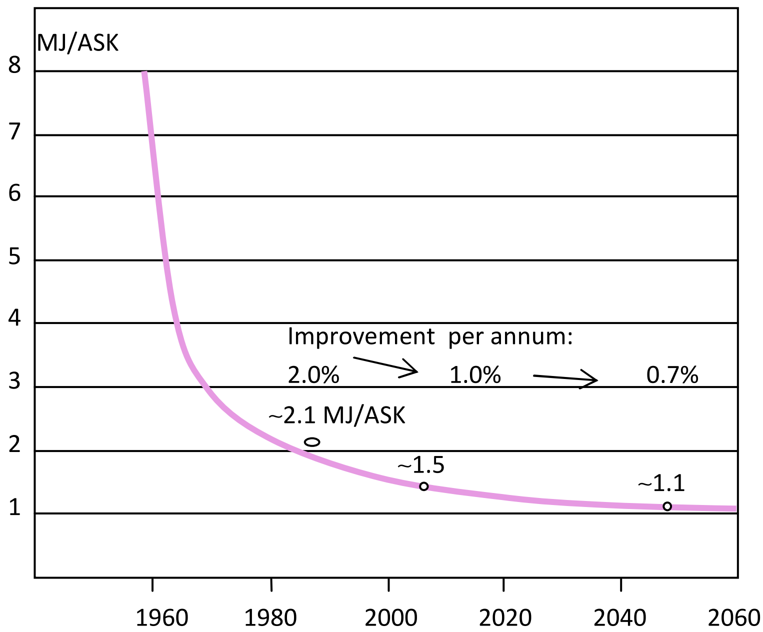


Lee et al. (page 3531) commented: "Whilst fuel efficiency of jet aircraft has been estimated to be improved by more than 60% over the past 40 years (…) in terms of emissions of CO_2 per passenger km (IPCC, 1999), many of these improvements have come from *step changes in technology* (e.g., turbojet-to-first generation turbofan engines such as those on B707/B727 and B747-100 aircraft and first-to-second-generation turbofans, e.g. those on B777 aircraft and its variants). Some efficiency gains have also come about through improved airframe aerodynamics and material changes that have reduced weight. In the near term, it is envisaged that most of the further improvements will be brought about through increased usage of lightweight materials.

According to the survey of Peeters et al. (2005) on improving fuel efficiency in the average jet fleet as from 1960, the annual improvements are decreasing following an asymptotic line approaching a "technical maturity around 2040", followed by a very low annual improvement of fuel efficiency afterwards. From Peeters et al.(2005, page 22, graph in figure 10), it could be derived that the fuel efficiency between 1980 and 1990 improved 2% per year and between 1990 and 2005 1.5% per year. From 2005 it will initially improve by 1% per year, then gradually level off to 0.7% per year around 2050 and less afterwards. The total fuel use per ASK between 2005 and 2050 is estimated to be (1.1/1.5=) 73% of the level in 2005. Peeters' graph is reproduced in Figure 7.

About the longer term between 2005 and 2050, Lee et al. (page 3531) comment: "IPCC (2007b) considered that more radical designs such as blended wing body and unducted-propfan engine aircraft (a large open-rotor blade) would be required to realize further step-change improvements (IPCC, 2007b)." Such technologic improvements are indeed expected in the EU by the research program of Acare (2012) but the actual realization is still in its infancy. Certification, production and introduction in the total air fleet may take various decades. We conclude that such a step change after 2040 will not show in the total air fleet before 2060. Concepts of fully climate neutral airplanes presently do not exist.

Figure 7 Development of energy consumption MJ/ASK for the jet fleet. (Peeters et al., 2005, page 22, Figure 10)



The actual annual improvement of 2% between 1980 and 1990 was already leveling off to 1.5% after 1990. The innovation clearly has reached its point of saturation. The assumption of ICAO of a continuing improvement of 2% per year as from 2005 would therefore be unlikely without those quite drastic technologic innovations not to be expected before 2060. If an advanced airplane like the Boeing Dreamliner (being some 20% more efficient) and concepts alike would be introduced into the global air fleet in some 20 years, still leaving a considerable percentage of less efficient older type planes, the annual improvement would be less than 1%. The improvement expectation of 1% in 2005, leveling to 0.7% in 2050 is more realistic.

Conclusion: The estimate of 2% annual fuel efficiency improvement up to 2050 is not at all realistic. The actual improvement will be 1% gradually decreasing to 0.7% in 2050. Improvements from very innovative technology are not to be expected before 2050. Concepts of fully climate neutral airplanes do not exist.

IV. Reduction of GHG emissions in 2050

The scrutiny question is:

Would bio fuel and fuel efficiency improvement enable the aviation industry to reduce the carbon emissions by 50 per cent by 2050 compared to 2005 levels if aviation would continue to grow? What about warming effects of both CO_2 and non-carbon emissions? Would the aviation industry be able to achieve its interim reduction goals before and after 2020?

GHG emissions according to up-to-date science. Warming by aviation is described by IPCC (1999) and updated by Sausen et al. (2005), IPCC (2007b) and Fahey (2007). Lee et al. (2009) give a comprehensive and up to date insight of scientific knowledge on aviation in the global climate change.

The burning of kerosene in jet engines causes both fossil CO_2 emissions and at high altitudes non-CO_2 emissions. Lee et al. (page 3520): "Aviation emissions contribute to the radiative forcing (RF) of climate. Of importance are emissions of carbon dioxide (CO_2), nitrogen oxides (NOx), aerosols and their precursors (soot and sulphate), and increased cloudiness in the form of persistent linear contrails and induced-cirrus cloudiness". The CO_2 emissions are long-lived species that will cumulate in the atmosphere during many decades, whereas most non-CO_2 warming effects are short-lived and do not cumulate. (Lee et al. p 3523). Naturally, these effects will increase as aviation is growing. The IPCC estimates of the RF of aviation emissions in 1999 were updated by various studies, slightly increasing their scientific reliability. According to Lee et al. the total RF per year is about twice the RF of CO_2 alone.

Lee et al. (p 3530) calculated the increased emissions and resulting warming (RF) by aviation in 2050, based on aviation growth scenarios of IPCC and assumed technological improvements in the air fleet. No compensation of CO_2 by bio fuel was introduced. See Table 3 below. The amount of fuel burn in 2020 is based on an ICAO fleet forecast and the amounts in 2050 are based on four SRES storyline scenarios. The authors conclude that the total RF for these four scenarios are factors of approximately 4 and 3 times greater than total aviation RF in 2000. The estimate of year 2005 is introduced in Table 3 to compare to ICAO's reference year. The increase of fuel use (2nd column in Table 3) is the result of both aviation growth and improved fuel efficiency of which the percentage is not given in these data.

Table 3 Aviation fuel usage and RFs for 2005, 2020 and 2050 (Lee et al. P 3530)

Year and scenario[1]	Fuel use Tg yr^{-1}	CO_2 emission Tg yr^{-1}	RF CO_2 mW m^{-2}	RF non-CO_2 mW m^{-2}	RF total GHG[2] mW m^{-2}
2005	232.4[3]	733[3]	28.0[4]	27.0	55.0
2020[5]	336.0	1060	40.8	43.6	84.4
2050 A1t1	**816.0**	**2573**	**76.3**	**118.1**	**194.4**
2050 A1t2	844.9	2665	77.7	105.3	183.0
2050 B2t1	**568.8**	**1794**	**73.3**	**80.9**	**154.2**
2050 B2t2	588.9	1857	74.5	72.0	146.5

1. According to IPCC scenarios A1 and B2
2. Excluding cirrus clouds from contrails
3. Lee et al. P 3525 Table 1
4. RF CO_2 and non-CO_2: Lee et al. p 3527 Table 2
5. According to ICAO prognosis

Growth of fuel use according to Peeters at al. In order to estimate the fuel use with an efficiency improvement according to Peeters et al., these findings (Chapter III above)had to be applied to the annual aviation growth that was assumed by Lee et al. in the scenarios in Table 3 above: (Lee et al. page 11) "the overall growth of aviation in scenario B2 is not greatly dissimilar to that of the mid-range IPCC (1999) scenario, Fa1, and the A1 scenario is likewise similar to the upper-range IPCC (1999 Table

9-10) scenario, Fe1." These scenarios show gradually levelling growth percentages as shown in Table 4A. Scenario Fe1 (A1) is starting with 5.3% growth which is in agreement with the more up-to-date growth expectations of Lee et al. (page 3528). It is therefore considered as somewhat more realistic than scenario Fa1 (B2), which is based on a lower growth rate deriving from these expectations.

Extra scenario for no growth. To estimate the possibilities of limiting aviation growth, we added an extra scenario NAG (no aviation growth) based on A1 in 2005, assuming that the growth percentages will decrease up to 2020 and aviation will stop growing after 2020.

Introducing the efficiency improvement percentages of Peeters et al. In Table 4B the growth percentages of fuel use are calculated as the growth of aviation minus the improvement of fuel use as derived from Peeters et al., being 1% gradually decreasing to 0.7% (Figure 7 above). The increase of nominal fuel use in Table 4C is calculated for each year based on 232 Tg yr^{-1} in reference year 2005 as given by Lee et al. in Table 3. The values for fuel use in scenarios A1 and B2 found in Table 4C are somewhat higher as those of Lee et al. in Table 3.

Table 4. Growth of aviation and fuel use

	4A			4B			4C		
	Annual aviation growth			Annual growth of fuel use incl. efficiency improvement 1% levelling to 0.7% (according to Peeters et al.)			Fuel use incl. efficiency improvement Tg yr^{-1}		
Year	Scenario Fe1 (A1)	Scenario Fa1 (B2)	Scenario NAG	Scenario Fe1 (A1)	Scenario Fa1 (B2)	Scenario NAG	Scenario Fe1 (A1)	Scenario Fa1 (B2)	Scenario NAG
2005	5.3%	4.2%	5.3%	4.3%	3.2%	4.3%	232	232	232
2009	5.3%	4.2%	5.3%	4.3%	3.2%	4.3%	275	263	275
2015	4.3%	3.4%	5.3%	3.3%	2.4%	4.3%	345	312	353
2020	3.8%	3.1%	0	2.8%	2.1%	-0.9%	407	353	396
2040	3.2%	2.5%	0	2.4%	1.7%	-0.8%	705	529	333
2050	3.1%	2.4%	0	2.4%	1.7%	-0.7%	**894**	**627**	**301**

Calculating GHG emissions based on fuel use and introduction of bio fuel. In Table 5 estimates are made of CO_2 emissions and RF in 2050, based on the following assumptions and calculations:

1) The values of CO_2 and RF of 2005 in Table 3 (Lee et al.) are the reference values.
2) The values for fuel use in Table 4C are also used as references.
3) The values of CO_2 and RF of 2020 are the same as in Table 3 (Lee et al.)
4) The resulting CO_2 emissions and CO_2 RF in 2050 are lowered by the relevant compensation factors for bio fuel in Chapter II, according to the following calculations:

a. *Scenario A1t1*: 894Tg kerosene is (894*0.043=) 38.44 EJ of which a maximum of 8.3 EJ is bio fuel. The CO_2 compensation of this bio fuel is 50%, being 4.14 EJ. The non-compensated part of fuel will be (1-4.14/38.44)*894=797 Tg yr^{-1}. The CO_2 emissions of this are estimated as 797/816*2573 (Table 3)=2513 Tg yr^{-1}. The RF of CO_2 is estimated as 797/816 *76.3=74.5 mW m^{-2}

b. *Scenario B2t1*: 627Tg kerosene is (627*0.043=) 26.96 EJ of which a maximum of 8.3 EJ is bio fuel. The CO_2 compensation of this bio fuel is 50%, being 4.14 EJ. The non-compensated part of fuel will be (1-4.14/26.96)*627=530 Tg yr^{-1}. The CO_2 emissions of this are estimated as 530/569*1794 (Table 3)=1671 Tg yr^{-1}. The RF of CO_2 is estimated as 530/569*73.3=68.3 mW m^{-2}.

c. *Scenario NAG after 2020*: 307Tg kerosene is (307*0.043=) 13.20 EJ of which a maximum of 8.3 EJ is bio fuel. The CO_2 compensation of this bio fuel is 50%, being 4.14 EJ. The non-compensated part of fuel will be (1-4.14/13.20)307=211 Tg yr^{-1}. The CO_2 emissions of this are estimated as 211/816*2573=665 Tg yr^{-1}. The RF of CO_2 is estimated as 211/816*76.3=20 mW m^{-2}.

5) The resulting RF of non-CO_2 emissions (not being compensated for) are estimated as follows, assuming that in this complex situation a linear approach is fair, using the fuel use figures of Tables 4 and 3 and the RF values of Table 3:

a. *Scenario A1t1*: (894/816)*118 (Table 3)= 129 mW m^{-2}.

b. *Scenario B2t1*: (627/569)*80.9 (Table 3)= 89 mW m^{-2}

c. *Scenario NAG after 2020*: (307/816)*118 (Table 3)= 44 mW m^{-2}.

Table 5 Aviation fuel usage and RFs after implementation of fuel efficiency (Peeters et al.) and bio fuel compensation

Year and scenario	Fuel use Tg yr^{-1} Table 3	Fuel use Tg yr^{-1} Table 4	CO_2 emission Tg yr^{-1}	CO_2 emission % vs '05	RF CO_2 mW m^{-2}	RF non-CO_2	RF total GHG[1] mW m^{-2}	RF total GHG[1] % vs 05
2005	232	232	733	100%	28	27	55	100%
2009	……	275	865	118%	33	32	65	118%
2020	336	407	1286	175%	49	47	96	175%
2050 A1t1	816	894	2513	343%	75	129	204	371%
2050 B2t1	568	627	1671	228%	68	89	157	285%
2050NAG2020	…….	307	665	91%	20	44	64	116%

1. Excluding cirrus clouds from contrails

Increase of GHG emissions in 2020 according to scenario A1t1. According to the first climate goal of IATA, the CO_2 emissions should decrease by 1.5% annually between 2009 and 2020. That would produce a total reduction of about 15% in 2020. The CO_2 emission in 2009 of 865 Tg yr^{-1} (see the 4th column of Table 5) should be reduced to 0 .85*865=735 Tg yr^{-1} in 2020, which happens to be the same value as in 2005. In scenario A1t1 the actual increase of CO_2 emissions in 2020 (5th column of Table 5) is 1.75 times those in 2005. The resulting RF of total GHG emissions in 2050 (last column of Table 5) is also 1.75 times those in 2005. So this first goal would not be realised in 2020.

Increase of GHG emissions in 2050 according to the three scenarios. In the assumed scenario A1t1 the increase of CO_2 emissions in 2050 (5th column of Table 5) is 3.4 times those in 2005. The resulting RF of total GHG emissions in 2050 (last column of Table 5) is 3.7 times those in 2005.

In the assumed scenario B2t1 the increase of CO_2 emissions in 2050 (5th column of Table 5) is 2.3 times those in 2005. The resulting RF of total GHG emissions in 2050 (last column of Table 5) is 2.9 times those in 2005. The originating growth scenario B2 of IPCC started at 4.2 % in 2005, which is about one percent lower than the actual growth. This scenario was supposed to enable aviation to proportionally contribute to the emission reductions required to limit the warming to two degrees. However, it appears that even in this too optimistic scenario aviation will more than double its emissions rather than reduce them.

According to the second climate goal of IATA, aviation growth after 2020 should be carbon neutral. Considering the actual GHG emissions in 2050, also this goal cannot be realised. No wonder, because growth according to this goal would require new aircraft with no emissions at all, and/or consisting aircraft suddenly dropping its emissions to unrealistic low percentages. Neither of these assumptions could be realised with present combustion techniques.

However, if aviation would *stop growing after 2020*, the CO_2 emissions in 2050 will be 0.9 times those in 2005. The RF of total GHG emissions are 1.2 times those in 2005. So the emissions roughly will be as they were in 2005. The goal of the aviation industry of 50% CO_2 emissions in 2050 compared to 2005 would require aviation to considerably decrease its fuel use as from 2020.

Conclusion: All three aviation industry's reduction goals before and after 2020 will fail. A 1.5% annual CO_2 reduction between 2009 and 2020 will also not be achieved because of the above mentioned low effects of fuel efficiency improvement and the non-availability of appropriate bio fuels. Actually the CO_2 emission will increase by a factor of 1.7 to 1.8 in 2020 compared to 2005 levels. A carbon-neutral growth of aviation after 2020 will not be possible since this requires airplanes emitting no CO_2 at all, which do not exist.

In a realistic IPCC growth scenario both the CO_2 emissions and the combined warming effects of all GHG emissions (including non-carbon GHG) of aviation will be in 2050 four times those in 2005. This is due to the lower reduction effect of bio fuel, a moderate fuel efficiency improvement and a fuel use in 2050 of four times of the use in 2005. In a somewhat less realistic IPCC scenario of moderated growth, the emissions and warming in 2050 would still be two to three times compared to 2005. In case of no growth as from 2020, the CO_2 emissions and warming effects will in 2050 be about the same as those in 2005. The aviation industry's goal to reduce CO_2 emissions in 2050 to 50% of those in 2005 could only be realized if the use of aviation fuels would shrink after 2020.

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List of abbreviations

ASK	Available Seat Kilometer
Acare	Advisory Council for Aeronautics Research in Europe
BtL	Biomass-to-liquids
CO_2 eq.	CO_2 equivalents
EC	European Committee
EJ	Exajoule
FAME	Fatty Acid Methyl Esthers
GHG	Green House Gasses
Gt	Gigaton
HVO	Hydrotreated Vegetable Oil
IATA`	International Air Transport Association
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
LCA	Life-cycle assessment (analysis; ecobalance, cradle-to-grave analysis)
MBM	Market-based Measures
MJ	MegaJoule (one million Joule)
mW	milliWatt
NAG	No Aviation Growth scenario
OECD	Organisation for Economic Co-operation and Development
SRES	Special Report on Emission Scenarios (IPCC 2000)
Tg	Tera grams
UNEP	United Nations Environment Programme
PKM	Passenger Kilometers
Ppm	parts per million
RF	Radiative Forcing