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Issues Concerning the Reduction
Of Carbon Dioxide
In International Aviation

August, 2007

Japan International Transport Institute
Airport Environment Improvement Foundation

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[1] All titles current as of the Study Group's final meeting, May 30, 2007.

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Chapter 1. Necessity of CO_2 Emissions Reduction in Aviation (Claire L. Felbinger, Shigenori Hiraoka)

1.1 Background - What Do We Currently Know?

In late 1998, the 185 ICAO Assembly nations approved a resolution requesting the governing council to

> study policy options to limit or reduce the greenhouse gas emissions from civil aviation, taking account the findings of the IPCC special report [published in 1999] and the requirements of the Kyoto Protocol [to the U.N framework Convention on Climate Change].[2]

The Kyoto Protocol states that the industrial nations

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[2] Richard Miake-Lye, Ian Waitz, David Fahey, Howard Wesoky, and Chowen Wey. Aviation and Climate Change," in Eno Transportation Foundation, *Global Climate Change and Transportation: Coming to Terms*. Washington, DC: Eno Transportation Foundation, 2002, p.125.

> [s]hall pursue limitation or reduction of greenhouse gasses not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through ICAO and the International Maritime Organization, respectively.[3]

The European Federation for Transport and Environment and the Climate Action Network built off the IPCC report and generated the following conclusions on the impact of aviation on climate change and the economic importance of the aviation sector:

- In 2000, aviation was responsible for 4 to 9 percent of the climate change impact of global human activity – the range reflecting uncertainty surrounding the effects of cirrus clouds;
- aviation has by far the greatest climate impact of any transport mode whether measured by passenger kilometer, per tonne kilometer, per Euro spent, or per hour spent;
- today's passenger aircraft are no more fuel-efficient than those that flew a half a century ago;

[However, this is expected to change between now and 2020 – see Figure 1.1.]

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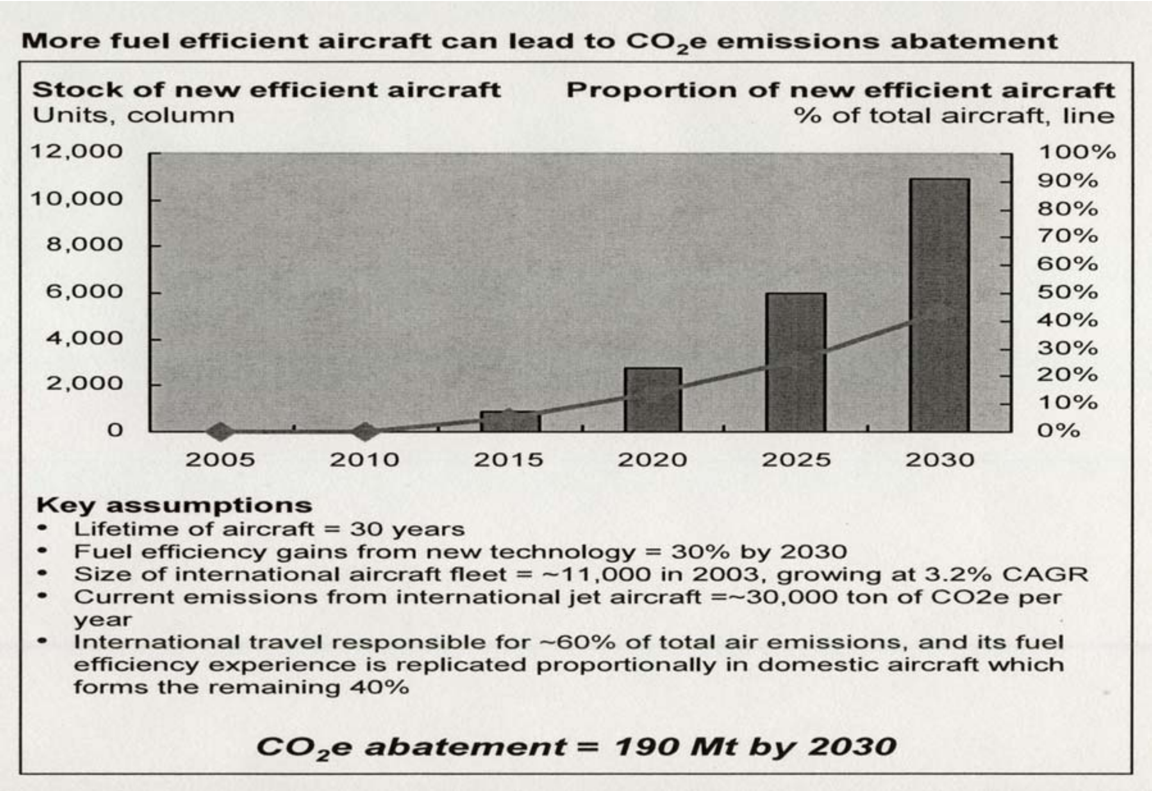
[3] Ibid.



More fuel efficient aircraft can lead to CO_2e emissions abatement

Key assumptions

- Lifetime of aircraft = 30 years
- Fuel efficiency gains from new technology = 30% by 2030
- Size of international aircraft fleet = ~11,000 in 2003, growing at 3.2% CAGR
- Current emissions from international jet aircraft =~30,000 ton of CO2e per year
- International travel responsible for ~60% of total air emissions, and its fuel efficiency experience is replicated proportionally in domestic aircraft which forms the remaining 40%

CO_2e abatement = 190 Mt by 2030

Figure 1.1

- the importance of aviation for the economy and employment is far less than its importance for climate change;
- every segment of the aviation industry including manufacturers, airlines and airports is subsidized and enjoys major tax exemptions.[4]

In addition, the IPCC offers the following statistics and projections about the aviation industry and climate change:

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[4] European Federation for Transport and Environment and Climate Action Network. *Clearing the Air: The Myth and Reality of Aviation and Climate Change*. Brussels: T&E/CAN, 2006, p.1.

- International air traffic as measured by passenger in revenue passenger km is expected to grow about 5 percent per year between 1990 and 2015.[5] Total aviation fuel use is projected to increase by 3 percent per year over that period.[6]
- The increase in CO_2 from aviation will be from 0.14 Gt C/year – billion tons of carbon (the base in 1992) to between 0.23 and 1.45 Gt C/year (projected for 2050).[7]

[In fact, emissions from air transport are growing more rapidly than that produced by road travel – see Figure 1.2.]

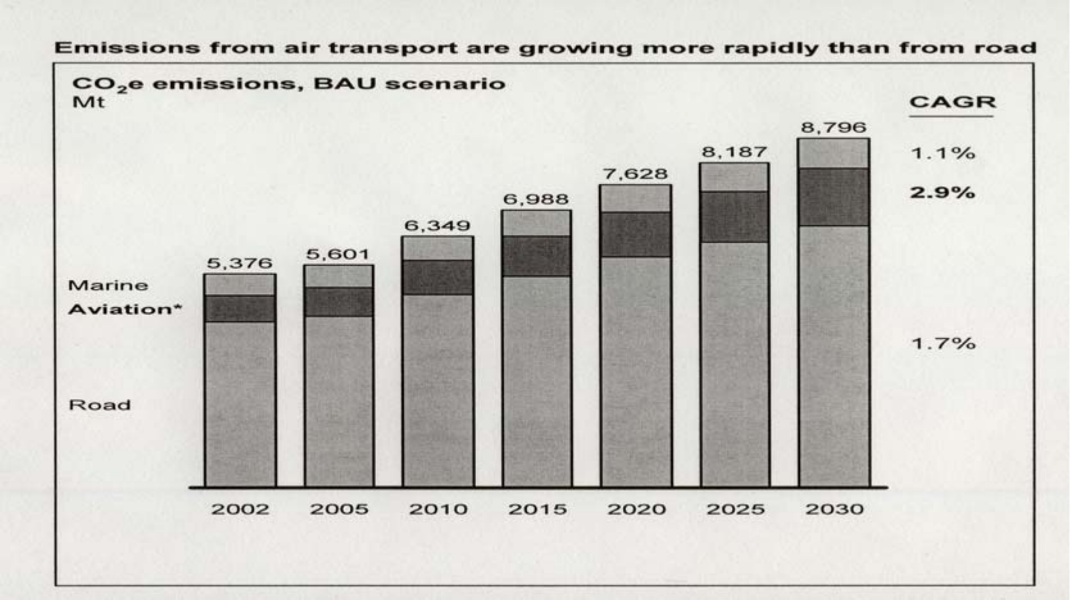

Figure 1.2

- In terms of aircraft and engine efficiencies, they project a 20 percent fuel efficiency by 2015 and a 40-50 percent improvement by 2050 relative to today's fleet.[8]

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[5] United Nations Framework Convention on Climate Change. National Communications: Communications from Parties Included in Annex 1 to the Convention: Guidelines, Schedule and Process for Consideration. Geneva: UN FCCC, 1996, p. 7.

[6] This lower percentage is due to projected increases in efficiency. See Joyce E. Penner, David H. Lister, David J. Griggs, David J. Dokken, and Mack McFarland (eds). *Aviation and the Global Atmosphere*. NY: Intergovernmental Panel on Climate Change, 1999, p. 4.

[7] Ibid., p. 6.

[8] Ibid, p. 10.

- IPCC predicts that improvements in air traffic management (ATM) and other operational procedures could reduce aviation fuel burn by between 8-18 percent. The large majority (6-12%) of the reductions comes from ATM improvements which are expected to be fully implemented in 20 years.[9]

CO_2 Reduction Issues and Methods

Two of the basic concerns about reduction methods are how to allocate the emissions and who would hold the allocation permits. Both of these need to be answered before engaging in any emission trading scheme. The United Nations Framework Convention on Climate Change (UN FCCC), identified eight options for allocating emissions, i.e., how will the emissions be assessed then to whom.[10] Their guidelines enumerate the possibilities; however, they suggest decisions should be based on quality and accessibility of good data and the ease with which these data can be gathered.

The first option is not to allocate emissions at all.[11] This would constitute the current status quo situation which is Business as Usual or BAU. This situation would only be of value if countries utilize voluntary measures and/or taxation to reduce emissions. Obviously, there is no existing incentive for countries or air carriers to reduce emissions in this way.

The second option is to base global emissions from bunker fuels to parties in proportion to their national emissions.[12] Under this scheme, there would be an assumption based on the amount of total emissions presumably from aviation (2% in 1990) and allocating 2 percent more than calculated domestic emissions to arrive at an international allocation. Of course, this arbitrary extrapolation assumes that all parties engage in the same percentage of international trips.

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[9] Ibid., p.11.
[10] UN FCC, 1996.
[11] Ibid., point 43.
[12] Ibid., point 44.

The third option is to allocate to parties based on the nationality of the transporting company, the country where the aircraft is registered, or the country of the operator.[13] Although this seems like a viable option, the interaction of the three distinctions here makes disaggregating the responsibility highly complex and unworkable.

A fourth option is to allocate the emissions between the origin and destination countries.[14] In actuality, determining the split of responsibility would be very complex and prone to measurement error or political manipulation. Assessing completely to the country of origin or destination seems, on the face of it, to be unfair.

The next three options are considered by UN FCCC to be less practical because of data requirements or inadequate global coverage[15] so they are just listed:

- Allocation to Parties according to the country of departure or destination of passenger or cargo. Alternatively, the emissions related to the journey of a passenger or cargo could be shared by the country of departure and the country of arrival.[16]
- Allocation to Parties according to the country of origin of the passenger or owner of the cargo.[17]
- Allocation to the Party of emissions generated in its national space .[18]

The option which makes the best sense in terms of ease and efficiency of data gathering and the reliability of the data gathering and the incentive to reduce emissions is an allocation based on the country where the bunker fuel is sold.[19] This has a precedent in that point of sale is a measure used when allocating auto emissions under the current

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[13] Ibid., point 48.
[14] Ibid., point 50.
[15] Ibid., point 51
[16] Ibid., point 52.
[17] Ibid., point 53.
[18] Ibid., point 54.
[19] Ibid., point 46.

emission regulations. There are some drawbacks to this method which would have to be considered in an international context; however, it satisfies data gathering assumptions.

The International Civil Aviation Organization considered who, specifically, would hold the emission permits assuming that the allocation would be based on the sale of the bunker fuels.[20] Among the parties they considered were:

- Fuel suppliers
- Air navigation service providers
- Aircraft manufacturers
- Aircraft operators

After weighing the advantages and disadvantages of each of the parties, they suggest that those who operate the flight would be holders of the permits.[21] This conclusion is based on the assumptions similar to those imposed on data gathering for the allocation of emissions. Moreover, they suggest that only CO_2 emissions should be monitored and then only for chapter 3 and 4 aircraft (i.e., not small) from both domestic and international flights.[22]

Establishing Baseline Emissions

The literature has discussed the rationale for establishing a baseline for emissions and reductions in emissions including a baseline year, especially among existing carriers, to determine baseline allocations and permits. A general consensus builds from the Kyoto suggestions that the baseline year be 1990 and that reduction targets be -8 percent

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[20] International Civil Aviation Organization, Committee on Aviation Environmental Protection. *Draft Guidance on Emissions Trading for Aviation*. Australia: ICAO, 2006.

[21] Ibid., pp 11-20.

[22] Ibid., p. 26. (However, the European Federation for Transport and Environment and the Climate Action Network (2006) make an argument for all emissions to be included. Although this makes intuitive sense, it would be difficult in terms of data gathering and allocation decisions.)

by 2010 and -30 percent by 2020.[23] The current EU discussions embrace these reduction targets.

Determining the baseline itself is a bit more difficult. The International Civil Aviation Organization suggests that a baseline can be based on historical data on emissions, a baseline set as a percentage below the historical level, by establishing an industry-wide performance standard, or by making projections based on historical levels (this method might work well in countries implementing CDM mechanisms).[24]

Determining a baseline for emission allocations can generally be based on either "grandfathering" the baseline – i.e., relying solely on historical data – or by benchmarking. Benchmarking is a bit more complex but incorporates historical data with a built-in reward system for parties which have already invested in new technologies which would reduce emissions. It seems that benchmarking not only is more fair to parties which have voluntarily tried to reduce emissions but also serves to provide a target for new entrants into the allocation/emission system.[25]

The ICAO suggests that benchmarks should be constructed so as to reward previous investment in new technologies to reduce emissions and provide incentives to continue to operate more efficiently in the future. For new entrants, they suggest relying on the new entrant's estimate of their new and projected long-term emissions. They suggest that if projected emission levels do not meet those projected (are higher than projected in reality), then the new entrant's allowances would be reduced by that amount during the next year.[26]

Strategies for Emission Reduction

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[23] T&E, CAN Europe, 2006.
[24] ICAO, 2006, p. 42.
[25] Ibid., p. 45. An example of an equation which incorporates historical and projected information into a benchmark can be found in Ibid.: 46.
[26] Ibid., p. 50.

There are three basic strategies for emission reduction suggested in the literature – voluntary measures, taxation, and emission trading. These three will be outlined briefly. Then one “comprehensive” proposal for the EU will be described.

Historically, voluntary measures of emission reduction reinforce the status quo in aviation. However, as aircraft operators see greater efficiencies due to technology changes, design alternatives, and managerial changes, the emphasis to save money (make profits) may ultimately result in the reduction of emissions.

Taxation is a negative incentive which counters what some think are unnatural advantages of air craft operators. Many airport operations are subsidized by governments. Some are calling for an end to those subsidies forcing aircraft operator to pay the full cost of doing business. Should the subsidies be eliminated, then operators would have to adopt more efficient procedures to maintain profits. Hopefully these cost cutting measures would result in more efficient operations and reduced emissions.

There are proposals in the EU to make passenger flights subject to the value added tax (VAT) through a ticket tax. The UK and France have already instituted ticket taxes based on destination and class (business, coach) of ticket. The income generated in this manner could be used to develop methods for making aircraft operations more efficient.

Kerosene taxes have been implemented in the Netherlands, Norway, Japan, and the United States. The T&E CAN Europe suggests that as kerosene tax of 12.5 cents per litre (one-fifth of the level of most road fuel taxes) would reduce emissions by ten percent.[27]

The more complex and comprehensive approach to emission reduction is through Emission Trading. Emission trading is the buying and selling of permits/allowances to emit greenhouse gasses into the atmosphere. Its effectiveness as a policy tool is due to

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[27] T&E/CAN Europe, 2006: 6).

incentives it creates for minimizing costs of environmental protection. In other words, operators who implement relatively low cost emission strategies can reduce emissions more than their stated goal and sell excess permits to other operators. Typically, one allowance is defined as a permit to emit one tonne of CO_2 equivalent.

There are two families of tradable permit systems – allowance systems and credit systems. Generally speaking, permutations of these can be based on whether the aviation sector is included in the Kyoto system (Kyoto allowances may be used to cover aviation emissions and vice versa) or whether aviation is a system unto itself. In allowance systems (also referred to as tradable quotas or "cap and trade"), "entities must obtain and hold emission allowances sufficient to cover actual emissions during a stated compliance period".[28] In credit systems (also referred to as baseline and credit) "the baseline represents an implicit authorization of emissions for the compliance period. Emission reduction credits result when actual performance – e.g., the actual emission level – is lower than allowed performance".[29]

The European Federation for Transportation and Environment together with the Climate Action Network argue that any trading system should use a comprehensive mix of strategies to address the impacts of aviation on climate control in the EU. Here are their suggestions:

- EU-wide measures promise the greatest environmental benefit;
- Kerosene taxation is long overdue and has significant climate benefits;
- Ticket taxes [can be used] to make up for VAT exemptions;
- En-route emission charges [can be easily integrated in air navigation charges – mitigates some of the effects of the kerosene tax];
- [Implement] Airport NO_x charges;
- [Avoid] contrails and cirrus clouds with Air Traffic Management overhaul;

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[28] ICAO, 2006, p. 36.
[29] Ibid.

- [Create] a dedicated (separate) emissions trading system for aviation.[30]

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[30] T&E/CAN, 2006, p. 6.

1.2 Aircraft are Responsible for Most of the Emissions in the Aviation Sector

Any forecast for aviation demand in coming years points to a rapid increase in traffic. This rapid growth in traffic drives airlines to order more aircraft to meet the increase in demand. This upwards trend indicates rapid growth in CO_2 emissions from aircraft in years to come. How can we keep the growth in CO_2 emissions in check, and bring the aviation sector to a more environmentally friendly, sustainable growth?

The air transportation business does not stand alone, apart from other supporting activities. When an aircraft flies, it flies from an airport, following instructions from air traffic controllers. When it is flying, it follows designated routes to ascend, cruise and descend. It has constant communications with air traffic controllers. It lands at an airport at the end of the journey, following instructions from air traffic controllers. At an airport, many more activities are involved: ticket sales, check-ins, baggage handling, security checks, transportation of passengers from one terminal to another, fueling, maintenance of aircraft, administrative activities at airport authority's offices, to name a few. But when you measure CO_2 emissions from the aviation business, aircraft is responsible for most of emissions.

The Airport Environment Improvement Foundation, Japan analyzed CO_2 emissions from two major airports in Japan, Osaka (Itami) Airport, the second busiest domestic airport in Japan, and Narita International Airport. The foundation measured and aggregated CO_2 emissions from aircraft taking off and landing at the airports,[31] ground power units, ground support equipment and airport facilities.

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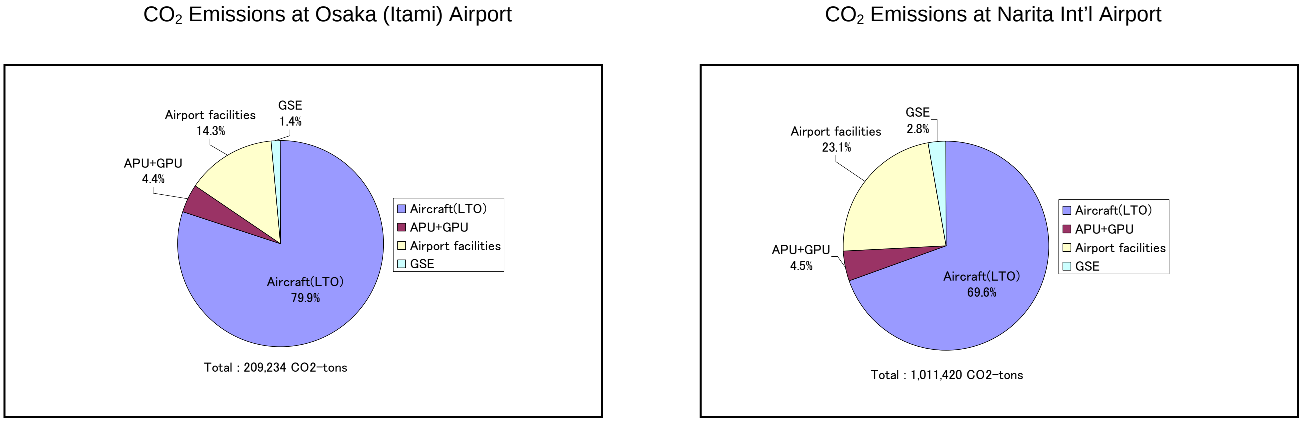
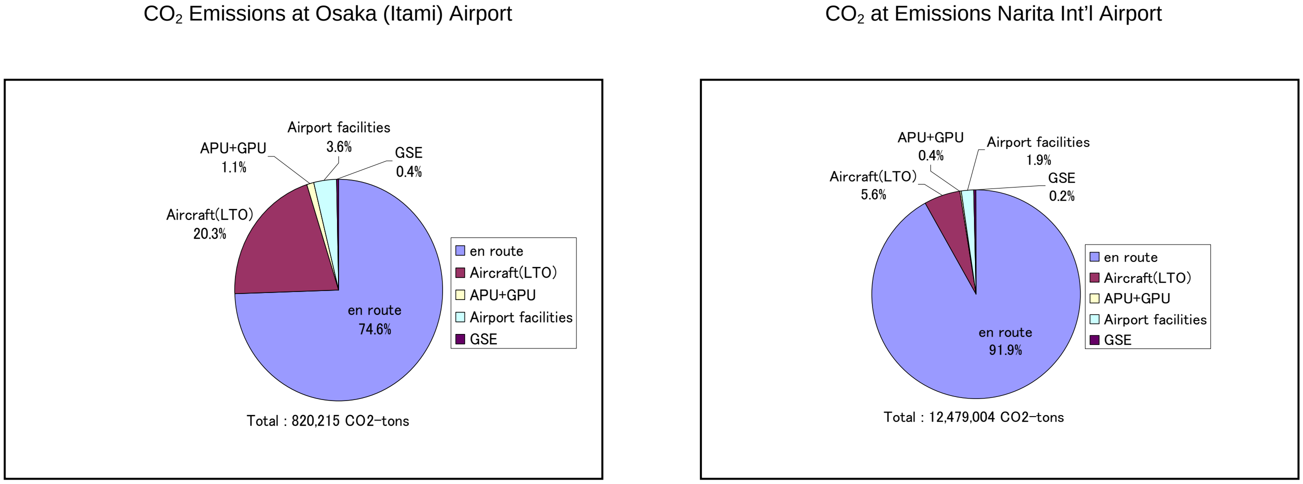
[31] ICAO sets a standard for assessing air quality at airports and defines the landing and taking off cycle to be made of taxing/ idling for 1,560 seconds, approaching (descending from 3,000 feet high) for 240 seconds, taking-off for 42 seconds and climbing (ascending to 3,000 feet high) for 132 seconds. For this assessment, set were taxing/ idling time for 934 seconds at Osaka Airport and 1,387 seconds at Narita International Airports, approaching time for 270 seconds, taking-off time for 45 seconds, and climbing time for 45 seconds.


CO_2 Emissions at Osaka (Itami) Airport

CO_2 Emissions at Narita Int'l Airport

Figure 1.3

Although many activities are played out at airport facilities, CO_2 emissions from airport facilities account for only 14 percent at Osaka Airport and 23 percent at Narita International Airport, leaving most of the CO_2 emissions related to aviation business coming from aircraft. If en-route emissions are added to the calculation, the share of aircraft-originated emissions will leap to 95 percent at Osaka Airport and 98 percent at Narita International Airport.


CO_2 Emissions at Osaka (Itami) Airport

CO_2 at Emissions Narita Int'l Airport

Figure 1.4

This study indicates that unless CO_2 emissions from aircraft are effectively addressed, no matter what efforts are made to reduce CO_2 emissions from other parts of the aviation business, total CO_2 emissions from the aviation sector will go unchecked and continue to grow rapidly without any signs of relenting. This is particularly true for international aviation since international flights cover a longer distance, resulting in more emissions from aircraft per flight.

Given the rapid growth in traffic demand and quickly expanding markets in fast developing countries, it may prove very difficult, economically and politically, to reduce CO_2 emissions from aircraft. But at least some concerted efforts have to be put into practice to put a brake on the rapid growth of CO_2 emissions from aircraft. But is it an easy endeavor or a costly, arduous challenge to rein in CO_2 emissions from aircraft which fly on international routes?

Road vs. Air

Easy or difficult is a relative term. Something difficult to do for one person may be easily done by another. For comparison, we take up here motor vehicles which are the largest source of CO_2 emissions in the transportation sector, and compare them to aircraft in what measures are available to address the issue of CO_2 emissions.

Transportation accounts for about 14 percent of global Green House Gas (GHG) Emissions and 18 percent of CO_2 emissions in 2002.[32] Within the transportation sector, the share of road transportation outweighs the combined shares of any other modes of transportation. It accounts for 72 percent of the total GHG emissions in the transportation sector while the share of international air transportation is 6 percent of the sector.[33] The IEA estimates that the energy consumption in the transportation sector will grow by 2 percent annually and the transportation sector will account for 54 percent of global oil consumption in 2030, up from 47 percent in 2002.[34] The IEA states in its

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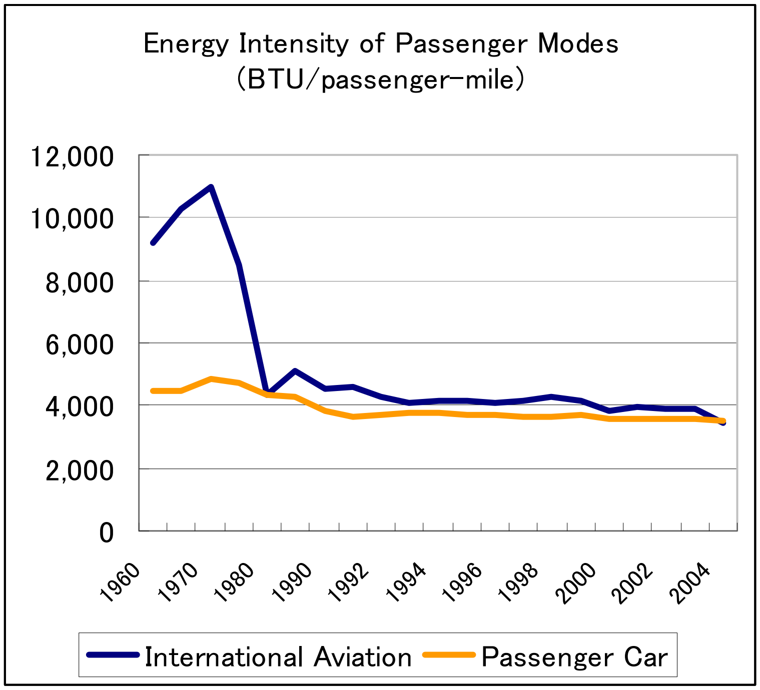
[32] World Resource Institute, “Navigating The Number: Greenhouse Gas Data and International Climate Policy” (2005).
[33] World Resource Institute, “Navigating the Number: Greenhouse Gas Data and International Climate Policy”(2005).
[34] IEA, “The World Energy Outlook 2004” (2004).

World Energy Outlook 2004, “Demand for road transport fuels is growing dramatically in many developing countries in line with rising income and infrastructure development,” and “Freight will also contribute to the increase in oil use for transport in all regions. Most of the increased freight will travel by road.” CO_2 emissions from motor vehicles is expected to continue to grow at a fast pace, significantly driven by motorization taking place in fast developing countries. The IEA/SMP model estimates about 2 percent annual growth in energy use by light vehicles. Therefore, road transportation is and continues to be the biggest contributor to CO_2 emissions in the transportation sector at least in near future, and it has to be given a priority in mitigating its CO2 emissions because of their size and a pace of growth. But one has to be reminded that the growth in CO2 emissions from aircraft is expected to outpace that in road transportation. The IPCC estimates that as aviation demand continues to grow, aircraft fuel use is projected to increase by 3 percent annually through 2015.[35] Another reminder is that although international aviation took a stride in improving energy efficiency in the 1970s, but it is still no more energy efficient than passenger automobiles, which are considered one of the most inefficient modes of transportation. The energy intensity of international aviation has not been changing much for the past decade. Therefore, one needs to pay due attention to aircraft CO_2 emissions and implement effective programs to curb the growth of CO_2 emissions from aircraft before it runs out of control.



(Figure 1.5 above.)

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[35] IPCC, “Aviation and Global Atmosphere: Summary for Policymakers” (1999).

However, aviation requires different approaches to this problem from road transportation. CO_2 is produced by burning fuel in combustion engines in both motor vehicles and aircraft. The amount of CO_2 emitted is determined by four different factors, namely demand, modal share, fuel efficiency, and type of fuel.

Different characteristics of each mode make for different approaches to CO_2 emissions mitigation. When one considers what measures to apply to cut down on CO_2 emissions in each of the four elements, he or she realizes that options to curb CO_2 emissions are limited with aviation relative to motor vehicles.

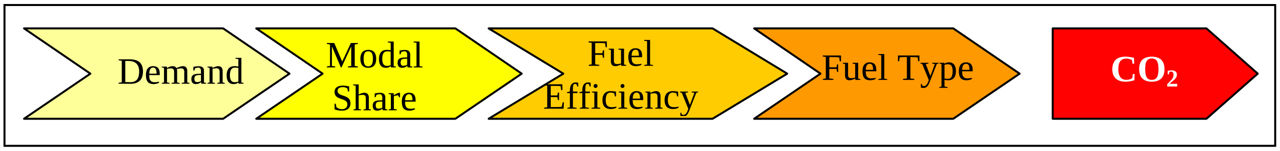

Figure 1.6

Demand

How to manage demand has been a challenge to researchers and policy makers, since measures have to be implemented to run counter to human nature. Freedom to travel is one of the freedoms deemed necessary for the pursuit of happiness. Although telecommuting and teleconference ability may rid of us the need to travel by road or air to some extent, we run the risk of losing touch. The need to have face-to-face contacts will never go away. There are ways to sway human decisions one way or another. As human beings are incentive-driven, giving incentives or disincentives has the potential to have an impact on human behavior. A variety of programs that have been introduced have, intentionally or unintentionally, affected the use of motor vehicles.

Taxes on fuels and tolls, in many cases introduced to finance construction and maintenance of road infrastructure, dampen the demand for mobility especially when they are set at high rates. Europe and Japan are known for their high tax rate policy. Toll roads are seriously discussed as a way to manage congested traffic in and around big cities in the U.S., a country known for its "free-way" network. Taxes on fuels and tolls also encourage people to switch to more fuel efficient vehicles or public transportation.

On the other hand, international air transportation has generally been exempt from fuel taxes as the ICAO Convention[36] and bilateral agreements provide for exemption of fuel from national or local duties or charges. Recent European proposals to levy a tax on jet fuel to finance development aids to fight poverty in developing countries sparked vocal opposition through aviation communities.[37] In the ICAO, an idea to use taxes to fight climate change was voted down as it was considered an inefficient and high-handed measure. Instead, an emission trading scheme is being discussed as the most efficient measure to internalize externalities caused by air services. An emission trading scheme will encourage airlines to operate more efficiently and when the cost of buying allowances is passed on to consumers, it will potentially curb demand for air transportation services, especially more elastic leisure demand. We will further discuss an emission trading scheme later.

Modal share

Railroads, ships and public transit are more fuel efficient modes of transportation than automobiles and aircraft. Public transit can have a strong appeal to drivers tired of sitting behind the wheel during morning and evening rush hours where it is available, affordable, and reliable. Despite capacity constraints of rail and port infrastructures, railroads and ships can be more environmentally friendly alternatives to trucks. Given these situations, there is the potential to use other modes of transportations in addressing climate change inducing gas emitted from motor vehicles.

However, no such viable alternatives are available for air travelers and time-sensitive goods traversing across a continent or ocean. They have to rely on aviation for them to be transported to their destinations. The only exceptions are short haul routes.

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[36] Article 24.

[37] This proposal did not receive EU-wide acceptance, and individual countries levy a tax on tickets rather than fuel to finance developmental aid.

Aviation services can disappear on short haul routes where they have to compete with high speed rail services. But it is often the case that it is more costly to build high speed train networks linking major cities than airports.

Fuel economy

Improving fuel economy holds a key to curbing the growth of CO_2 emissions from both motor vehicles and aircraft. In this area, both aircraft and motor vehicles have made a great stride. Steady technological improvements have made that possible. Hybrid technology can save a lot of gas as the car can save in its battery a part of kinetic energy it loses when slowing down, and use the stored electricity when accelerating without using gas. For example, while the regular Toyota Camry runs 28 MPG in EPA fuel economy, Toyota Camry Hybrid 2007 achieves 39 MPG, about 40 percent improvement in fuel use.[38] The share of hybrid cars is growing as automakers put out a wider variety of hybrid cars in the market. Aircraft design to achieve greater aerodynamics and lighter weight and engine improvements have improved fuel efficiency in past years. The IPCC estimates that aircraft fuel efficiency has improved by 75 percent in the past 40 years.[39] The IATA states that new aircraft are 70 percent more fuel efficient than 40 years ago and 20 percent better than 10 years ago.[40]

There is a big difference in the way to achieve higher standard of fuel economy in the two industries. In the automobile manufacturing industry, governmental fuel economy standards and research and development by manufactures both have played a role in pushing up fuel economy while aircraft and its engines have been improved without a government-set standard. We will explore this issue later. IATA aims to achieve a further 50 percent improvement in fuel economy of aircraft by 2020, notching up the previous goal of a 10 percent improvement by 2010.[41]

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[38] http://www.fueleconomy.gov/.
[39] IPCC, "Aviation and Global Atmosphere: Summary for Policymakers" (1999).
[40] http://www.iata.org/whatwedo/environment/fuel_efficiency.htm.
[41] http://www.iata.org/whatwedo/environment/fuel_efficiency.htm.

Adopting a fuel efficient manner of operation can make a lot of difference in achieving greater fuel efficiency. Drivers can save up to 5 to 33 percent of gas by applying certain methods of driving.[42] The IATA estimates pilots can save jet fuel by up to 6 percent through operational improvements.[43]

One big difference between road transportation and air transportation is the role other stake holders can play to help airlines reduce CO_2 emissions from aircraft. Aircraft can fly only on routes designated by authorities. They cannot necessarily fly their aircraft on the shortest course or without delay due to a number of reasons including air space restrictions for security or military reasons, local noise concerns, inadequate air traffic management infrastructures that need updating, and airport or air route congestions. Better air traffic management can reduce CO_2 emissions by up to 12 percent, according to the IATA estimate.[44] This greater fuel efficiency improvement will never occur without coordinated actions among governments, air traffic control service providers, and airport authorities.

Type of Fuel

There is a wide variety of alternative fuels for road transportation. Some of them were tested and proved effective in reducing CO_2 emissions. Diesel engines have been proved to be more efficient than gas engines. Although diesel cars produce other emissions harmful to humans, for example NO_x and PM, they achieve greater fuel efficiency than conventional gasoline cars. According to a METI estimate, diesel cars can save gas by 24 percent, compared to gasoline cars of the same make. Ethanol blends are gaining traction due to concerns over high gas prices. Buses that run on CNG are not rare on the road today. Although no single alternative fuel is likely to replace gasoline as the main fuel to run motor vehicles, a wide variety of fuels are already marketed. On the other hand, no viable alternative to jet fuel is available for airlines today. Jet fuel is unique in its high BTUs. Alternative fuels used in automobile engines have too low

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[42] http://www.fueleconomy.gov/feg/driveHabits.shtml.
[43] http://www.iata.org/whatwedo/environment/fuel_efficiency.htm.
[44] http://www.iata.org/whatwedo/environment/fuel_efficiency.htm.

BTUs to be suitable for jet aircraft. Synthetic fuels and bio-fuels are developed and tested in laboratories. But none of them is at the marketing stage. Today airlines cannot reduce CO_2 emissions from aircraft by switching to other types of fuel. Further research and development is much needed in this area.

Conclusion

On balance, it is more difficult to cut back on CO2 emissions in aviation than in road transportation as fewer options are available to aviation than for motor vehicles. Alternative fuels and the possibility of a modal change are limited in aviation. Measures to address CO2 emissions from aircraft have to be centered on more efficient use of jet fuel. Even in this area, without cooperation from actors other than airlines, desirable efficiency gains will not materialize. The aviation industry has been loath to an idea of using economic instruments to help achieve a socially desirable outcome. As the possibility to introduce an emission trading scheme is debated, they may or may not warm up to an idea of paying their dues to mitigate the environmental burdens that their operations have brought on.

These constraints do not justify an argument that aviation should be exempt from the global effort to rein in rising CO_2 emissions. They reinforce the idea that there is no panacea or magic wand to guide their way out of the issue that may grow into the biggest concern to face international aviation in the twenty first century. We should waste no time in mobilizing any practical measures available to slow and, if possible, contain the growth of CO_2 emissions from aircraft. We will explore in the chapters to follow some of the areas of potential improvements in fuel efficiency.

Chapter 2. CO_2 Emissions Reduction in Aviation (David Greene, Hiroki Hashimoto, Bengt-Olov Nas, Sumio Shioda, Katsuhiro Yamaguchi)

2.1 Reduction of Aviation CO_2 Emissions by Technical, Operational and Economic Measures

What Airlines Can Do

Aviation CO_2 can be reduced by several different measures.

1. Improved technology development for new aircraft and engines
2. Alternative Fuels
3. Improved Air Traffic Management (ATM) systems
4. Operational procedures
5. Market-Based Option like Emissions Trading System (ETS)

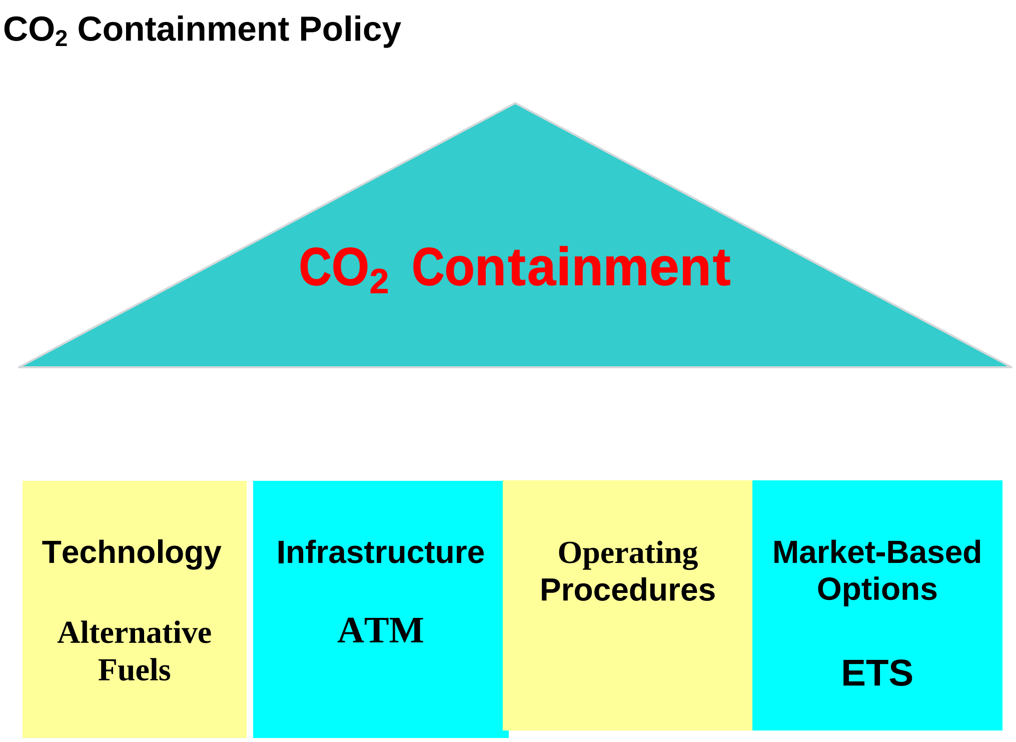

Figure 2.1

All different measures are complementary and not contradictory to each other.
Which of the measures are under airline control?
This portion of the report will address the airlines’ role in these measures.

Development of Improved Technology for New Aircraft and Engines

The manufacturing industry and research establishments mainly control the development of new technology. Airlines have typically gained in reduced operating expenses from lower fuel burn and maintenance costs as airlines have introduced new aircraft in the fleets. The customers, however, also typically influence the new aircraft and engine designs. The manufacturers usually convene "Airline Advisory Boards" early in the design phase. This stage may be before a program is launched and the basic technology is known and practically just being applied. The airlines involved in the advisory process look at many different aspects in addition to the environmental parameters. As the environmental performance and the climate change issues have become more important, airlines put more pressure on the manufacturers regarding improvement in fuel efficiency over other features. However, the decision what to develop and offer the airline market rests with the manufacturers.

New technologies are introduced in different categories of aircraft with relatively long intervals in between. The same technology or aircraft program is typically in production for 15-20 years. The development can, therefore, from an airline perspective be characterized as a "stepwise" technology development and not one in continuous improvement. Over time, fewer new programs have been developed as the industry has consolidated. This has resulted in longer periods between new programs. The stepwise improvement in fuel burn has typically been in the order of 15-20 percent, which equates to an average of 1-2 percent decrease per year. See Figure 2.2 below.

Technology intervals

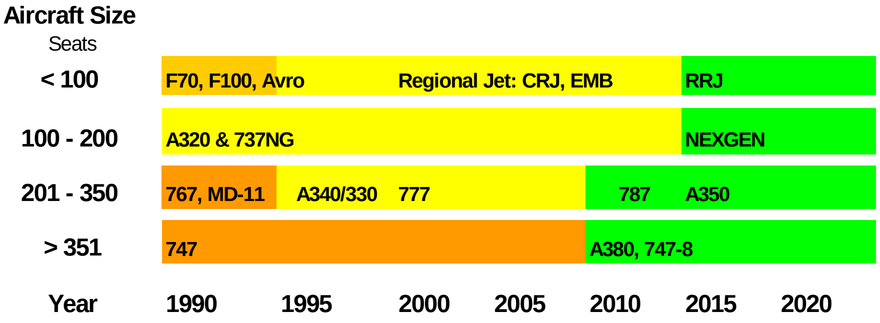

Figure 2.2

IATA has estimated the future commercial fleet fuel efficiency based on the ICAO/CAEP Fleet forecast. In 2005 the fleet average fuel efficiency based on statistics was 40 liter / Revenue-Ton-Kilometer (RTK). In 2020 IATA estimates that the Fleet will have improved its efficiency to 30 liter / RTK. See Figure 2.3 below. The improvement will come from introduction of new aircraft and to some extent higher load factors, but at the same time doubling the number of aircraft in the fleet. The absolute fuel burned and CO_2 emitted will, however, also double in spite of the efficiency improvement.

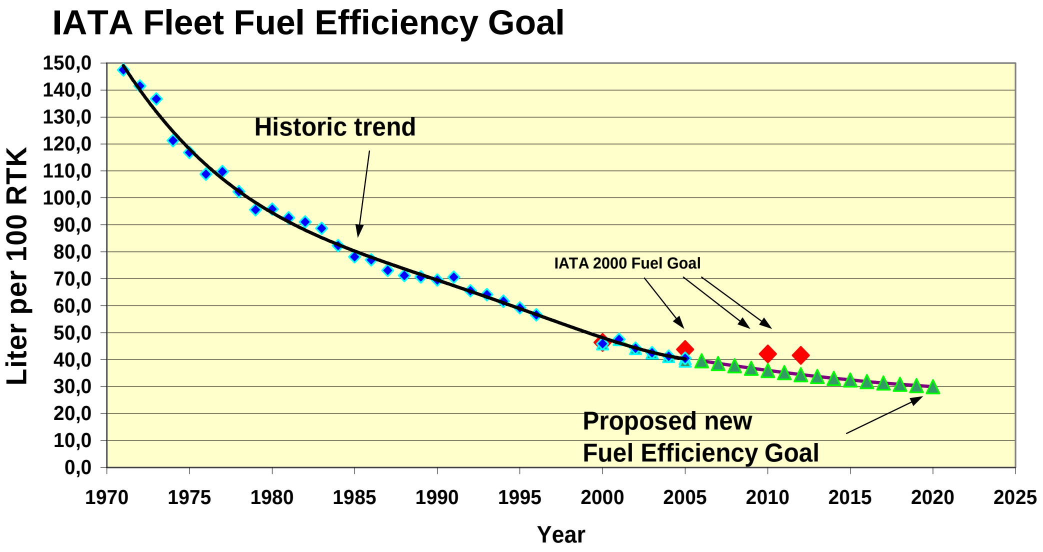

Figure 2.3

Once an airline has decided on a new aircraft type the decisions regarding environmental performance are set for quite a long time. If the airline replaces older and less efficient equipment, the global situation changes only by the incremental addition by the new aircraft if the old aircraft are continued to operate by another airline somewhere in the world. Commercial passenger aircraft are typically in service for 25-30 years and all cargo aircraft 30-40 years.[45]

Alternative Fuels

Alternative Fuels based on a biomass that would provide a carbon neutral operation, are being discussed as a requirement of CO_2 reduction. The process is technically well known, the Fischer Trops process, but the cost to produce and the issue of bio source are far from resolved in the near term. Airlines can only put more pressure on fuel suppliers and the research community to speed up the development.

Improved ATM system

There is a significant potential in improved Air Traffic Management and Systems.[46] The responsibility is with the national authorities and system providers. The inefficiencies may cause even more waste of fuel and time in the future due to the expected growth of traffic unless the improvements are implemented. Airlines have for some time requested the required investments and political willingness to take out the inefficiency of today's ATM/ATS. Airlines can only keep the pressure on the authorities on this issue.

Operational procedures

Optimizing the operational procedures on fuel efficiency is mainly controlled by the airlines. The procedures airlines use are established with a priority on safe operation.

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[45] See Modeling and Traffic and Fleet Forecasts summarized in International Civil Aviation Organization, Forecasting and Economic Analysis Support Group, and Steering Group of the Committee on Aviation Environmental Protection Reports, Montreal, January, 2001.

[46] International Civil Aviation Organization, *Operational Opportunities to Minimize Fuel Use and Reduce Emissions.* Montreal: ICAO Circular 303 AN/176, February 2004.

Secondly, the procedures are designed to be as efficient operation as possible. Efficiency can not only be fuel efficiency but also cost efficiency. Regarding CO_2 efficient procedures, they are also cost efficient and that is why there is no contradiction between cost and environment in this case. The ICAO Circular[47] addresses the principals of fuel saving, which will generally also minimize aircraft emissions.

The operational opportunities and techniques for minimizing fuel consumption are summarized as follows:

a) fly the most fuel-efficient aircraft type for the sector;
b) taxi the most fuel-efficient route;
c) fly the most fuel-efficient route;
d) fly at the most fuel-efficient speed;
e) operate at the most fuel-economical altitude (flight level);
f) maximize the aircraft's load factor;
g) minimize the empty weight of the aircraft;
h) load the minimum fuel to safely complete the flight;
i) maintain clean and efficient airframes and engines;

In addition to the ICAO circular SAS, for example, operates according to the following procedures:

j) use low flap settings for takeoff and landing;
k) have ground power readily available at all ground stops;
l) taxi with one or more engine(s) shut down;
m) loading aircraft at an Aft CG position.

To be able to execute the majority of flights in an as fuel-efficient way as possible, the operation needs to have the objectives in mind from a systems approach. One key parameter in enabling fuel-efficient operation is punctuality. The network planning in terms of schedule, aircraft type and turn around times needs to consider that the execution

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[47] Ibid.

can be performed smoothly and regularly. The Dispatch considers the actual situation for a flight in terms of weather conditions and optimizes the flight plan. Optimization of a flight considers the shortest Equivalent Still Air Distance (ESAD), optimum cruising altitudes and cruise speeds. Based on best forecast of weather and wind minimizing the reserve fuel for an alternate airport and contingency fuel reduces aircraft weight and fuel burn due to weight. Standard Instrument Departure (SID) and Standard Approach (STAR) procedures may in some cases add significantly to the flight track distance and specifically the approach procedures can either save or waste a lot of fuel. The optimum descent and approach is performing a so called Continuous Decent Approach (CDA), which means that the aircraft is descending from cruising altitude on idle engine thrust until final approach when landing gear and landing flaps are extended. The Air Traffic Control (ATC) typically requests aircraft to line up in the approach queue at the same altitude. In such a case, the aircraft is required to descend much too early and fly at a constant level for some time, which needs more power, and increased fuel burn.

Today, aircraft are equipped with Flight Management Systems (FMS). The FMS includes a Flight Management Computer (FMC), which is loaded with the aircraft performance data and a flight profile optimization program. The optimization is normally based on operating cost via a Cost Index (CI). The CI considers fuel cost versus time related costs. If time dependent costs are neglected and the CI is set to only consider fuel cost the flight profile is optimized for lowest fuel burn.

To be able to execute fuel-efficient operations, the pilots need to be motivated and managed to follow the procedures. Communication and training is key to bring full understanding among the crews of the objective and to successfully achieve active fuel saving.

SAS has an active fuel saving process being implemented considering the implication on the different systems and processes affecting a flight. The aircraft and engines need to be kept in clean and good maintenance conditions. Engine wash can restore EGT margin and fuel burn performance. The empty weight of the aircraft needs to be kept as low as possible given the cabin configuration and service level onboard. Catering and loose equipment weights should also be kept to a minimum.

SAS has, in cooperation with the Swedish CAA, initiated a new approach technique called the "Green Approach" (Figure 2.4). The aircraft are equipped with a data link communication system enabling early communication providing better visibility at the ATC of the aircraft position, ETA and optimum descent path such that the approach and landing can be sequenced for an optimized descent and approach. More than 1500 approaches to Stockholm Arlanda airport with SAS 737 has on average saved 100 kg fuel per flight.

SAS "Green" Approach project

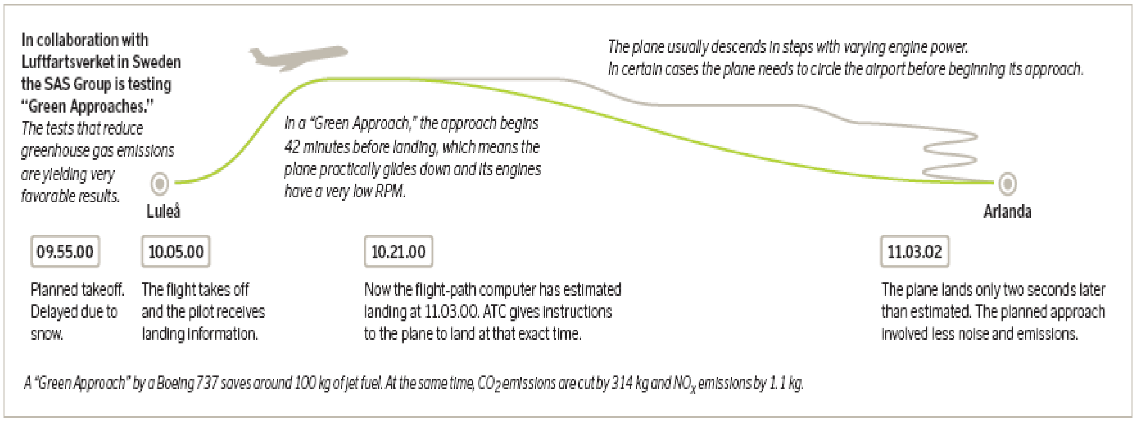

Figure 2.4

IATA has reviewed several airlines' practices and concluded that there is a variation among operators how efficient the airlines are. Today IATA considers that there is a span of 5 percent to 10 percent of potential improvements in the operations.

Market Based Options e.g. Emission Trading System (ETS)

Emissions abatement costs in aviation are quite high and much higher than in many other sectors. For considerable time aviation will be depending on the current carbon based fuel.

Since the Climate Change and CO_2 contributions are global issues, abatement of CO_2, where it is more cost efficient than in the aviation industry, can lead to absolute reduction of CO_2 while the demand for air service is still maintained. Studies in ICAO and in the European Union (EU) have indicated that an ETS has the potential to control CO_2 emissions in a cost efficient way.

The EU has recently tabled proposed legislation to include aviation in the EU ETS. Airlines are currently in discussions with EU and its member states regarding the design of the aviation related elements. Airlines can provide vital information and data to assist the EU in designing an efficient ETS while still maintaining a healthy development of air services.

2.2 Possibility of Future CO_2 Emissions Reduction by Improving Aircraft and Engine Design

Introduction

Aircraft manufacturers and engine manufacturers are improving aircraft and engines for not only for reduction of carbon dioxide emissions but also for reduction of aircraft noise and air pollutants (such as nitrogen oxide); this section focuses on the possibility of CO_2 emissions reduction.

Trends for improving of fuel efficiency

The technology of aircraft and engines advanced greatly from the 1950's to today. Improvement of fuel efficiency advanced greatly, too. This advancement was achieved by various technical innovations such as improvement of aerodynamics, decreases in aircraft weight, and improvement of engine design.

According to an IPCC special report[48]a typical time-history for a medium-range commercial aircraft from technology development to the end of airline service life would be as follows:

1. Technology development preliminary/final design through aircraft certification testing = 5-10 years
2. Successful production run = 15-20 years
3. Aircraft lifetime = 25-35 years
4. Total time span (i) through (iii) to retirement of aircraft series = 45-65 years
5. Time span (ii) through (iii) to retirement of aircraft series = 40-55 years

Given this, it will take a long time before any particular kind of aircraft is completely replaced. This shows that a new fuel efficient aircraft gives the effect only little by little in reduction of CO_2.

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[48] Intergovernmental Panel on Climate Change, *Aviation and the Global Atmosphere: A Special Report of IPCC Working Groups I and III in collaboration with the Scientific Assessment Panel on the Montreal Protocol on Substances that Deplete the Ozone Layer.* Geneva, Switzerland, 1999.

Moreover, according to the IPCC special report, historically, these improvements have averaged 1-2 percent per year for new production aircraft. Aircraft, airframe, and propulsion production fuel efficiency improvements from the 1950s to today and projected to 2015 and 2050 are summarized in Table 2.1.

Table 2.1: Percentage production fuel-efficiency improvements (ASK kg^{-1} fuel).

Time Period	Airframe	Propulsion	Total Aircraft
1950-1997	30	40	70
1997-2015	10	10	20
1997-2050	25	20	45 (40-50)

According to Figure 2.5, the average growth rate of fuel consumption is lower than the average growth rate of traffic demand. This shows that new fuel-efficient aircraft have been brought on-line. The difference between the average growth rate of fuel consumption and average growth rate of traffic demand has become small. This indicates that the development of aircraft with greater fuel-efficiency is difficult.

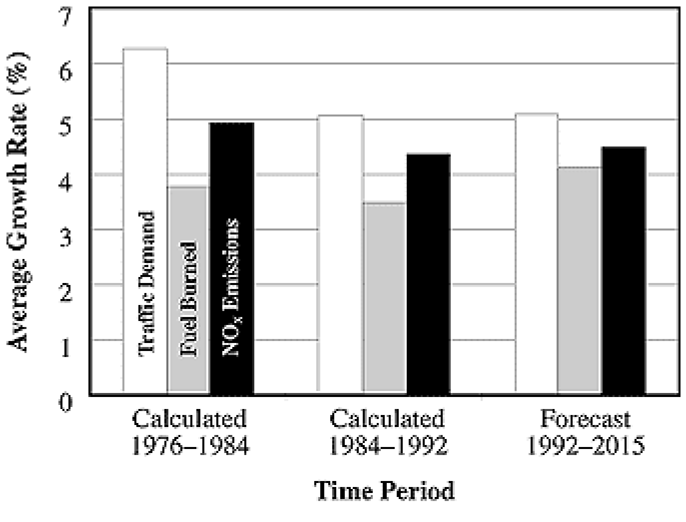
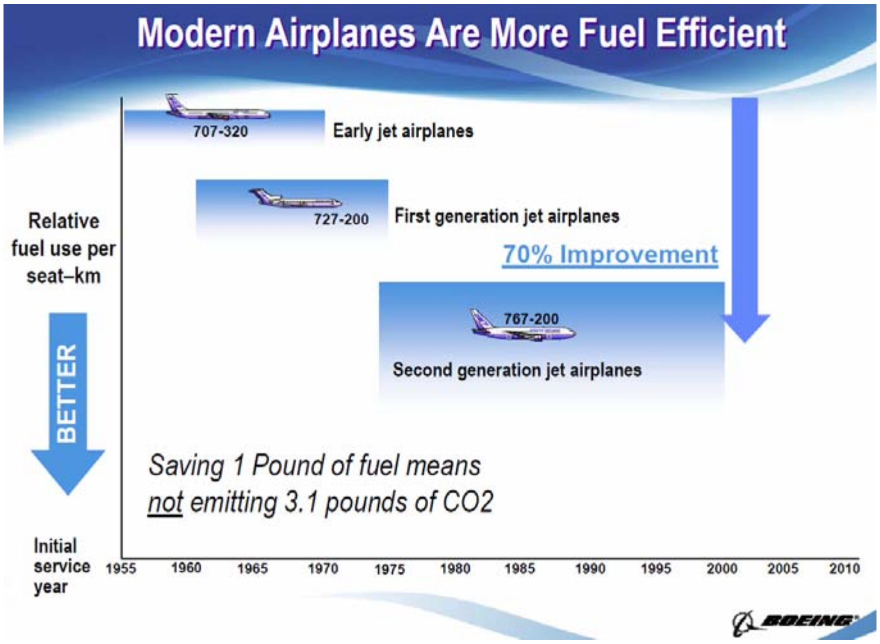


Figure 2.5 Comparison of Growth Rates for Civic Traffic, Fuel Consumption and NO$_x$ Emissions

According to the presentation by Boeing at second study group meeting, as for the Boeing 767, the fuel efficiency is improved 70 percent compared with Boeing 707 -320. This is the same as the IPCC report (Figure 2.6).

Figure 2.6: Fuel Efficiency of Aircraft being Developed Now



Modern Airplanes Are More Fuel Efficient

Saving 1 Pound of fuel means
not emitting 3.1 pounds of CO2

According to the presentation by Boeing at second study group meeting, Boeing 787 an aircraft similar to the Boeing 767 can reduce CO_2 by 20 percent compared with Boeing 767, also the Boeing 747-8 can reduce CO_2 by 15 percent compared with Boeing 747. On the other hand, because the A380 of Airbus did not have aircraft similar to Boeing’s, fuel efficiency of A380 compared with fuel efficiency of A330 that was used to estimate data on the fuel efficiency.

A380 consumes fuel of 2.9 liters per passenger per 100 kilometers. On the other hand, A330 consumes fuel of 3.4 liters per passenger per 100 kilometers. Because the size of aircraft is different, it is difficult to compare fuel efficiency. However, the A380 will enable to reduce CO_2 by 20 percent compared with the A330.[49]

Target of fuel efficiency in the future

The European Commission is planning a "Clean Sky" JTI (Joint Technology Initiative) in the "7th Framework Programme for Research (FP7)". The "Clean Sky" JTI is a 7-year research programme plan for European Air Transport industry that will radically improve the impact on the environment while strengthening and securing European aeronautics industry's competitiveness. The target of this research programme was set up with ACARE (Advisory Council for Aeronautics Research in Europe). In 2020 ACARE goals are 50 percent reduction of CO_2 emissions according to drastic reduction of fuel consumption.[50]

The reduction in the target for Airbus is same target as ACARE. Airbus is aiming at the efficiency improvement of 20-25 percent, of 15-20 percent and of 5-10 percent respectively by improving the aircraft, by improving the engines and by improving ATM.

In the U.S.A, the National Science and Technology Council reported that long-term technology goals of the report are to enable a 25 percent reduction in CO_2 by 2007 and 50 percent by 2022.[51]

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[49] Airbus, *2005 Environmental, Social, and Economic Report.* Toulouse, France: Airbus, 2005.

[50] Advisory Council for Aeronautics Research in Europe, *European Aeronautics: A Vision for 2020.* Brussels: ACARE, January, 2001.

[51] National Science and Technology Council (NSTC), Subcommittee on Transportation Research and Development, *National Research and Development Plan for Aviation Safety, Security, Efficiency and Environmental Compatibility.* Washington, DC: NSTC, September, 1999.

2.3 Regulatory Standards for Greenhouse Gas Emissions From Aircraft

Regulatory standards for pollutant emissions and fuel economy have been successfully applied over the past 50 years by nations around the world to improve air quality and reduce petroleum use by motor vehicles. For mitigating pollutant emissions from transport vehicles, regulatory standards have been the policy of choice. However, regulatory standards have not been applied to energy use by heavy trucks, ships, and planes because it was believed that market forces driven by higher fuel prices would efficiently induce the adoption of energy efficient technologies. Regulatory standards have been used to control pollutant emissions from aircraft and could be applied to control emissions of greenhouse gases from aircraft, as well.

Aspects of Greenhouse Gas Emissions from Aircraft

Regulating greenhouse gas emissions from aircraft raises new issues. First, greenhouse gas emissions standards for aircraft would not be solely concerned with CO_2 emissions and energy efficiency. While the overwhelming majority of greenhouse gas emissions from road vehicles are in the form of carbon dioxide, CO_2 may be less than half of aviation's climate impact (37% according to IPCC). Contrails and NO_x emissions leading to ozone formation also contribute a substantial amount (more than 60% according to IPCC).[52] Regulatory standards have been successfully developed and applied to aircraft emissions of NO_x, CO, unburned hydrocarbons and smoke by ICAO.[53] The importance of non-CO_2 emissions from aircraft raises the issues of trade-offs among aircraft GHG emissions. While such trade-offs increase the complexity of emissions regulations, there is precedent for dealing with such trade-offs in smog-forming emissions from automobiles.

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[52] Penner, J.E., D.H. Lister, D.J. Griggs, D.J. Dokken and M. McFarland, eds., 1999. *Aviation and the Global Atmosphere: A Special Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK.

[53] International Civil Aviation Organization (ICAO). 1999. "Statement from the International Civil Aviation Organization (ICAO) to the Tenth Session of the UNFCCC Subsidiary Body for Scientific and Technical Advice (SBSTA), Bonn, May 31-June 11, 1999.

Second, unlike the markets for automobiles (and possibly even heavy road vehicles), aviation fuel prices appear to be effective in encouraging aircraft manufacturers to adopt the latest energy efficient technologies, both for propulsion and airframes, and to use those technologies to reduce fuel burn rates. Fuel costs typically account for 20-25 percent of total aircraft operating costs. Reducing fuel costs has been a driving influence for the development of more fuel efficient aircraft. Lee et al. have estimated that the overall energy intensity of the U.S. aircraft fleet decreased by more than 60 percent from 1971 to 1998, an average rate of about 3.3 percent per year. The rate of engine efficiency improvement was approximately 1.1 percent per year.[54] All this was achieved in the absence of any regulatory measures requiring energy efficiency improvement. Thus, including aircraft emissions in an overall greenhouse gas trading scheme, or similar financial instruments, would appear to be an effective means of inducing both aircraft manufacturers and air transport firms to reduce GHG emissions.

Third, the fossil carbon content of aviation fuels could be reduced by blending with fuels derived from biomass. Carbon-neutral biomass can be used to produce low-carbon aviation fuels. Although alcohols derived from biomass are not well-suited to aviation use due to their low energy density and combustion properties, biomass can be converted to suitable distillate fuel via gasification and synthesis, and with the addition of lubricity-enhancing additives.[55] Indeed, it could be argued that because there are other low-carbon alternatives for road and water transport, aviation fuel would be the highest and best use for biomass.

Fourth, improvements in energy efficiency reduce CO_2 emissions but may increase the radiative forcing effects of other aircraft emissions. Increasing temperatures and pressures is critical to improving the thermodynamic efficiency of turbine engines, yet it generally leads to increased formation of NO_x. Increasing engine efficiency may

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[54] Lee, J.J., S.P. Lukachko, I.A. Waitz and A. Shafer. 2001. "Historical and Future Trends in Aircraft Performance, Cost and Emissions," *Annual Review of Energy and Environment*, vol. 26, pp. 167-200, Annual Reviews, Palo Alto.

[55] Saynor, B., A. Bauen and M. Leach. 2003. "The Potential for Renewable Energy Sources in Aviation", Imperial College Centre for Energy Policy and Technology, London, August 7, 2003, www.iccept.ic.ac.uk.

lead to increased contrail formation because the reduction in exhaust temperature is generally greater than the reduction in H_2O emissions, resulting in increased relative humidity of the exhaust plume.[56]

Why Regulations versus Market-based Instruments?

Certainly, greenhouse gas emissions from aircraft are an environmental externality and some form of government intervention to reduce their impact is required. Whether regulatory standards might be preferable to market-based policies for mitigating aircraft GHG emissions rests primarily on the possibility that regulatory standards might be more effective in bringing about reduced emissions.

Perhaps the chief advantage of a regulatory approach would be the ability of ICAO to set international standards. Regulatory standards for aircraft GHG emissions administered by an international agency such as ICAO would avoid the boundary problems faced by national or even regional mitigation policies. All the world's aircraft would be equally affected, a potentially critical advantage. International regulatory standards for conventional pollutant emissions by aircraft were implemented by ICAO in 1981 as Annex 16 to the Convention on International Civil Aviation. These standards are not binding on signatories to the Convention but consistency with the standards is strongly encouraged.[57] The international nature of air transport provides a strong economic incentive for harmonization and a high degree of compliance has been achieved. GHG emissions standards set by ICAO would likely affect both Annex 1 and non-Annex 1 nations.

Regulatory standards would most likely apply to aircraft and not the manner in which the aircraft were operated. Operational factors, such as aircraft size, load factors, routing and ground operations, have accounted for about one-fifth of past aircraft

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[56] Lee et al., 2001.

[57] Ibid.

efficiency improvements.[58] On the other hand, aircraft modifications in accord with regulatory standards are responsible for essentially all past reduction in conventional pollutant emissions. Motor fuel or carbon taxes could be used as a complementary policy to regulatory standards to encourage operational measures to reduce fuel use per passenger-km or ton-mile.[59]

Regulatory standards also set clear, unambiguous performance goals for aircraft manufacturers. Market-based policies require manufacturers to translate market signals into appropriate performance goals. Whether performance-goal-driven research, development and design are more effective than the market-driven processes remains an open question. However, uncertainty about the precise effects of aircraft emissions on climate change hinder the formulation of effective regulatory and non-regulatory approaches alike. A workshop by the U.S. Federal Aviation Administration concluded, "There is currently no study in the peer reviewed literature that can be cited to justify, based on the scientific understanding of the impact of aviation emissions, the possible choices of metrics suitable for trade-off application."[60] On the other hand, a full understanding of the trade-offs among aircraft emissions may not be necessary to formulate practical regulatory standards for emissions whose impacts are sufficiently understood (e.g., CO_2 and NO_x).

Existing Approaches

To date, ICAO has not established greenhouse gas emissions standards for aircraft and those nations that have directly addressed the issue have preferred trading schemes or voluntary agreements. The European Commission's proposal to include aircraft in the EU Emissions Trading System reflects its believe that GHG reductions from aviation can be achieved more efficiently by this approach than by imposing a tax or surcharge, or by

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[58] Ibid.

[59] ECON. 2005. "The Political Economy of the Norwegian Aviation Fuel Tax", COM/ENV/EPOC/CTPA/CFA(2005)18/FINAL, Environment Directorate, Center for Tax Policy and Administration, OECD, Paris.

[60] Federal Aviation Administration (FAA). 2006. "Workshop on the Impacts of Aviation on Climate Change: A Report of Findings and Recommendations", Executive Summary, June 7-9, Cambridge, Massachusetts, August 2006, Joint Planning and Development Office, Washington, D.C.

creating a separate emissions trading system for aviation alone. "[T]he best way forward, from an economic and environmental point of view, lies in including the climate impact of the aviation sector in the EU emissions trading scheme."[61]

The Government of Canada opted for a voluntary agreement with the nation's Air Transport Association.[62] The agreement sets a non-binding target of a 24 percent reduction in emissions over 1990 levels and establishes and action plan for government and industry, as well as annual reporting of progress.

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[61] European Commission (EC). 2006. "Impact assessment of the inclusion of aviation activities in the scheme for greenhouse gas emission allowance trading within the community", Commission Staff Working Document, COM(2006) 818 final, SEC(2006) 1685, Brussels.

[62] Transport Canada. 2005. "Agreement to Reduce Greenhouse Gas Emissions in Aviation Signed", http://www.tc.gc.ca, no. H150/05, June 29, 2005.

Chapter 2.4 Measures by Airport and Air Traffic Management Improvement

Airports and air traffic control (ATC) serve as basic infrastructures for air transport. There are important opportunities in these areas for mitigation of CO_2 emissions. It should be noted that because the aircraft operators often face difficulty or do not have direct control over these areas, infrastructure providers need to take their initiative in improving efficiency. IPCC stipulates various operational strategies to mitigate CO_2 emissions from air transport and identifies 6-12 percent possible efficiency gains from ATC initiatives and additional 2-6 percent from other operational improvements.[63] In this portion of the report, the current situation and new opportunities in infrastructure related options are explored.

Measures at airports

There are two major areas for efficiency improvement at airports. First is to promote "greening" of aircraft power units (APU/GPU) and ground service equipment (GSE) at airports. This equipment is used to facilitate various preparatory activities involved in aircraft operation at airports. These include energy supply to parked aircrafts, aircraft towing, cargo and supplies loading/unloading, etc. For instance, a survey at Osaka Airport (Itami), a major domestic airport in Japan, indicates that CO_2 emission from APU/GPU and GSE are 22 percent and 7 percent respectively of the CO_2 originating from the airport (Figure 2.7).[64] Minimizing usage of APU by utilizing GPU for power supply to parked aircrafts could result in CO_2 emission reduction by up to 37 percent. Aircraft tractors and other vehicles operating in and out of airports could also be targets for increasing fuel efficiency. Although the impact on CO_2 emission may be marginal at individual airports, such an effect could more or less be achieved in airports around the world, thus the accumulated effect may be substantial.

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[63] IPCC, 1999, "Aviation and the Global Atmosphere," Cambridge University Press.

[64] Civil Aviation Bureau, 2003, "Eco-airport environmental survey – Osaka International Airport," Ministry of Land, Infrastructure and Transport (in Japanese).

The financial burden to install central electricity distribution GPU system could be quite high. Since CO_2 emission reduction effect is relatively clear, there is a possibility of utilizing CDM under the Kyoto Protocol for installing GPU systems at airports in developing countries. As of May 2007, no case of CDM has been reported.

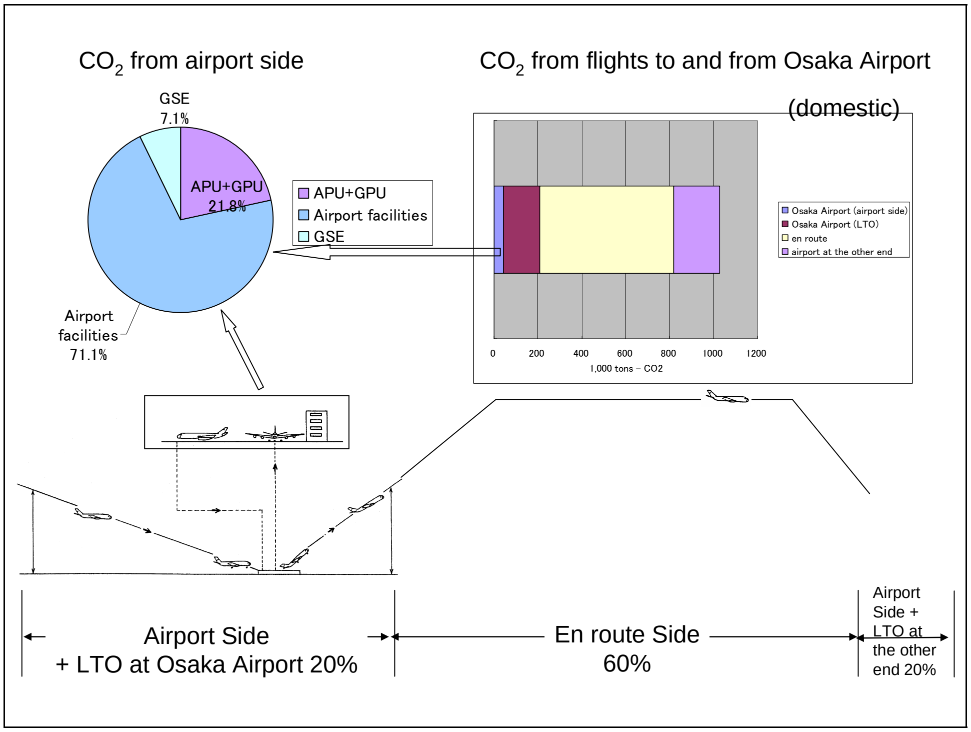

Figure 2.7 CO_2 Emission at Osaka Airport

Second is to improve efficiencies in the landing and take-off (LTO). Impact of LTO on total operation depends on the flight length. In short-haul routes, share of LTO could be relatively high. For instance, CO_2 emission from LTO at Osaka Airport and Narita International Airport is estimated to be 16 percent and 7 percent respectively of the total emission from flights to and from that airport.[65] Considerable excessive fuel burn is necessary for lining up for take-off at congested airports. There is also inefficiency from hovering aircraft waiting to land at congested airports. Optimization of take-off and landing requires both safety and efficiency goals to be met. There are air traffic management (ATM) measures to increase capacity and enhance efficiency for take-off

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[65] Impact of LTO would depend on the stage length. Average stage length of Osaka Airport flights is relatively short at approximately 650km, whereas that of Narita International Airport is 5,200 km.

and landing such as Area Navigation (RNAV) and Continuous Descend Arrivals (CDA), which would be dealt in the following section.

Even if the optimal system is deployed, traffic demand at some major airports is often over-capacity. In such airports, landing slot caps with efficient allocation policy is effective not only for on-time operation but also for reducing CO_2 emissions. The challenge is how to allocate landing slots in an economically efficient manner. Benchmarking, congestion pricing, and other market-based options for landing slot allocation should be explored.[66]

Measures to improve efficiency of air traffic control

Basic Issues

Challenges for ATC in improving efficiency is quite complex. ATC is tasked to optimize safety, capacity and efficiency at the same time, in a four-dimensional setting. Two basic issues are addressed:

One is on route structure. Air routes are designated by states often without taking full account of efficiency. The bulk of the 6-12 percent air traffic inefficiency cited in IPCC is associated with indirect air routes.[67] According to Scandinavian Airlines (SAS), there is more than 10 percent to be gained in less fuel burned and equivalent time, and other costs to be saved by improving ATM system. International routes often detour airspace blocked for other purposes such as military use. Bysouth (2005) suggests specific routes that could be improved.[68] While ICAO has been actively promoting CNS/ATM and performance-based systems to improve efficiency, it has basically left air route designation to contracting states.[69][70] ICAO should take initiatives to review specific issues associated with air routes in conjunction with IATA, IFALPA, etc. ICAO should

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[66] Apart form operational measures at airports; a totally different opportunity exists at airports regarding carbon offset. Since airport is the point of embarkation and disembarkation for passengers, it could serve as a kiosk for providing carbon offset programs.

[67] IPCC, 1999.

[68] Peter Bysouth, Assistant Director, IATA Asia Pacific, "The role of infrastructure providers in a liberalised environment," Proceedings at the ICAO Symposium, "Liberalization of Air Transport in Asia/Pacific," 25-27 May 2005, Shanghai, China http://www.icao.int/icao/en/atb/ecp/symposium_05/Proceedings.pdf.

[69] ICAO, 2002, “Global Air Navigation Plan for CNS/ATM Systems,” ICAO Doc 9750 AN/963.

[70] ICAO, 2004, “Operational Opportunities to Minimize Fuel Use and Reduce Emission” ICAO Cir 303 AN/176.

identify possible short-cuts and recommend contracting states to revise existing routes. In order to undergo such initiatives, special task forces should be established in ICAO regional offices to synthesize reports on possible air route improvements.

The second is on congestion. In major routes today, such as the North Pacific route, lack of capacity hinders aircraft to choose the optimal path and altitude on enroutes. Introduction of RVSM and satellite-based navigation systems needs to be accelerated.

There are considerable delays in today's regional airspace. Major ATC providers have introduced Air Traffic Flow Management (ATFM) to reduce holding when aircrafts are approaching the airport to land.[71] RNAV should be accelerated to increase capacity. Combination of CDM and RNAV in high capacity air space is a challenge for further CO_2 mitigation.

Specific measures to mitigate CO_2 emissions through ATM improvements

Some examples of the benefit from ATM system improvement are shown as follows.

Example 1: RNAV procedures

- Area Navigation (RNAV) is a method of navigation which permits aircraft operation on any desired flight path (within the coverage of navigation aids or within the limits of the capability of self-contained aids, or a combination of these)
- RNAV allows for the more efficient use of airspace while reducing flight delays and decreasing fuel consumption and promotes reduced fuel usage through more efficient climb and descent gradients, shorter ground tracks, and reduced delays.
- Implementing RNAV Q route into high altitude of the western coast of US, FAA has estimated 8 million dollars of fuel savings annually from early Q routes due to about 20 miles shorter per flight than conventional routes.
- Annual benefits by implementing RNAV Standard Instrument Departure (SID) procedures are estimated at $15 to 30 million at ATL and DFW in 2005.[72] Delta

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[71] EUROCONTROL and FAA, 2000, "Environmental Benefits Associated with CNS/ATM Initiatives."

[72] Testimony (Feb. 2006) before the Committee on Transport and Infrastructure Subcommittee on Aviation.

Airlines, which is the largest carrier in ATL, has already said that it expects to realize annual cost savings of approximately $16 million resulting from a combination of factors, including a reduced taxi time, reduced flying distance on arrivals, earlier climb achievement and reduced flying distance on departures. American airlines estimated annual cost savings of up to $15 million in DFW.

- ICAO PBN (Performance Based Navigation) manual, which gives practical guidance to contracting states, air navigation service providers and airspace users on how to implement RNAV and RNP applications, was published this spring and it is expected to promote to implement more efficient routes and procedures based on aircraft performance all over the world.

Example 2: RVSM (Reduced Vertical Separation Minimum)

- RVSM reduces the vertical separation between flight level (FL) 290 and 410 from 2,000 ft. to 1,000 ft. The additional FL enables more aircraft to fly more fuel efficient profiles while maintaining the safety of flight.
- US domestic RVSM (DRVSM) was implemented in January, 2005 and a first year fuel savings of $393 million has been calculated for DRVSM. FAA estimates fuel savings to airlines of approximately $5 billion through 2016. ($8.8 billion after re-calculation of benefits)
- As a result of RVSM implementation in Japanese airspace (Fukuoka FIR) in September, 2005, the average Flight Level (FL) was increased by 285ft for domestic flights and by 483 ft. for international flights. Based on the assumption that an increase of cruise altitude by 2,000 ft. would generally save fuel burn by approximately 3 percent, both domestic and international flights in Fukuoka FIR saved fuel burn approximately by 0.4 percent to 0.7 percent.[73]
- After RVSM implementation in Korean airspace (Inchon FIR), the average FL went up by approximately 530 ft. and it was considered to lead to 0.8 percent fuel saving.[74]
- RVSM is now implemented in almost all the world's airspaces.

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[73] ICAO, 2006 "Report of the 29th Meeting of the ICAO RVSM Implementation Task Force (RVSM/TF/29)."

[74] Ibid.

Example 3: CDA (Continuous Descent Arrivals)

- Definition of CDA is not harmonized. It is defined in USA as “a flight procedure where the vertical profile of an arrival has been optimized”. It can be descended continuously from high altitude to the airport at engine idle or near idle.
- CDA reduced the average fuel consumption as a result of UPS CDA trial at SDF (Louisville International Airport). Average fuel saving for B767 was 350 lbs. per flight and one for B757 was 100 lbs. per flight.[75]
- Due to a wide range of existing aircraft types, ATC believes that CDA may reduce airspace capacity and it would not be applicable to busy airports. Therefore, more advanced ATM, such as 4-D trajectory based operation taking each aircraft performance into account, may be required for congested airports.

Regional and international ATM system is improving and offering fuel saving gradually. Although fuel saving from individual flight may be marginal, accumulated benefit could be significant. Therefore, continuous improvement of the ATM system is necessary to reduce fuel burn in a faster manner than the growth of aviation demand. Lately, NGATS (Next Generation Air Transportation Systems) in the USA and SESAR (Single European Sky ATM Research) in Europe have been initiated to improve safety, capacity and efficiency for the future air traffic. Stakeholders need to work together to solve the challenges including funding of these programs.

Recommendations:

- ICAO and IATA should jointly investigate problems causing inefficient flight operations resulting from ATC thoroughly, make a recommendation on listed items to be improved, and make requests to ATC service providers through contracting states for these improvements.
- For discussion of expanding financial and technical support to the developing countries in the field of ATS, a Special Task Force should be established under the Air Navigation Planning and Implementation Regional Group of each ICAO

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[75] Sandy Liu, FAA, 2006 “Continuous Descent Arrivals (CDA) Workshop #2 Presentation.”

region.

- Based on best practices for efficient operations to be made in ICAO, a checklist should be made and excellent aircraft operators which perform above a certain level should be certified by ICAO, and the results would be announced.

Chapter 3. CO_2 Emissions Reduction by Introducing Market Mechanisms (Emission Trading Scheme: ETS) (William Cowart, Miranda Schreurs, Iwao Matsuoka, Kenichi Takahashi)

3.1 Current Discussions and Challenges over the ETS in ICAO and EU

Emission Trading Scheme

An Emission Trading Scheme (ETS) is an efficient system. Therefore, it is an efficient tool to internalize external diseconomies such as CO2 emissions. Partiality among participants or problem for practicability may arise by the emissions allowance allocation, but ETS gives strong incentive that makes aircraft operators reduce CO2 emissions from aircraft and, thereby, stimulate further discussions.

Emission Trading for Aviation in Europe

Background

The EU Emission Trading Scheme (ETS) began on January 1, 2005 between the most energy intensive sectors such as iron and steal industry, and electric power industry. Currently almost half of total CO_2 emissions from EU have been traded in EU-ETS.

In September 2005, The Commission on aviation and climate change launched the Special Aviation Working Group which consisted of 13 member countries, 5 aviation groups, ACI and 3 international institutes, to discuss incorporation international aviation into EU-ETS. In December 2005, European Council on environment endorsed Supportive Conclusions and ordered the commission to submit legislative proposal by the end of 2006. The Special Aviation Working Group conducted feasibility study on fuel taxation, emission charges, and emission trading regarding international aviation and also conducted impact assessments for economical measures and other political options. Then an option on the communication was submitted in April 2006. The result of a market based option studied in ICAO CAEP was also taken into account. A legislative proposal for a directive of the European Parliament and the Council was approved at the Commission on December 20, 2006. It will take one to three years to complete the legislative process.

Outlines

- Across all sectors of the EU economy, and not only within the industry and energy sectors, policies and measures should be implemented in order to generate the substantial reductions needed.
- Aircraft operators are identified as accountable entities of international aviation in EU-ETS and emissions from all flights arriving at and departing from EU airports should be included in EU-ETS.
- To increase the cost-effectiveness of the scheme, aircraft operators should be able to use CERs and ERUs from project activities to meet obligations to surrender allowances up to a harmonized limit.
- Aircraft operators will have to monitor their emissions of carbon dioxide and report emissions to the competent authority of its administering Member States.
- Aircraft operators will be able to buy allowances from other sectors in EU-ETS and use project credits from JI (Joint Implementation) and CDM (Clean Development Mechanism) activities under the Kyoto Protocol.
- The scheme will take effect in relation to aviation from 2010 when aircraft operators will be required to start monitoring and reporting emissions. From 2011, emissions from the aviation sector will be subject to a cap

Challenges

The current proposal to incorporate international aviation into EU-ETS has some problems such as:

- Regarding geographic scope, to apply that scheme without agreement may have extraterritorial consequences.
- Each country must have different way to set CO_2 emissions reduction targets in international aviation. However the EU proposal deals with each country as same. There are differences among countries regarding the way to set CO_2 reduction targets

ICAO Guidance on Emissions Trading for Aviation

Background

In 2004, on the basis of proposals from the Council, the last session of ICAO Assembly reviewed the consolidated statement of continuing ICAO policies and practices related to environmental protection and adopted a revised version in the form of Resolution A35-5. Resolution A35-5 consists of an introductory text and appendices A through I concerning specific subjects. Appendix H and I are related to aircraft engine emissions. Appendix H is for Environmental impact of civil aviation on the atmosphere, and Appendix I is for market-based measures regarding aircraft engine emissions. In Appendix H, concerns about global warming and scientific uncertainty are described and pointed out, and the Assembly requests the Council to continue to cooperate closely with, and to assist the UNFCCC and its subsidiary bodies to address global warming issues. The Assembly also requests the Council to continue to develop the necessary tools to assess the benefits associated with ATM improvements, and to promote the use of the operational measures outlined in ICAO guidance as a means of limiting or reducing the environmental impact of aircraft engine emissions. Appendix I states the needs to develop market-based measures for protecting the environment as policy tools that are designed to achieve environmental goals at a lower cost and in a more flexible manner. And the Assembly requests the Council to continue to develop guidance for Contracting States on the application of market-based measures aimed at reducing or limiting the environmental impact of aircraft engine emissions. Also, the Assembly encourages Contracting States and the council, taking into account potential impacts on the developing countries, to evaluate the costs and benefits of the various measures addressing aircraft engine emissions in the most cost-effective manner. And to adopt actions regarding voluntary measures, emission-related levies and emission trading. Regarding emission trading, the Assembly requests the Council to place a particular focus on two approaches; providing guidance and reporting.

The Emissions Trading Task Force (ETTF) was established under the Committee on Aviation Environmental Protection (CAEP) in 2004. ETTF prepared a draft guidance document for CAEP/7 in June 2006 in accordance with the Assembly request. However due to diverging views for geographic scope among participants in CAEP Steering Group, it was not endorsed and requested to the Council to consider the issue. In 2006 the Council issued its guidance to CAEP in order for it to finalize the Guidance on Emissions Trading for Aviation

Outlines

The guidance on Emissions Trading addresses the aviation-specific options for the various elements of trading systems, such as trading entities, emission gases to be covered, geographical scope, monitor and reporting, and legal considerations. It should be noted that it cannot be expected to provide the level of detail necessary to assist ICAO member states in addressing every unique issue that might arise technical or political situations at particular states. It should also be noted that this guidance may need to be revised as the world of emissions trading develops over time because it is given the limited practical experience that currently exists in emissions trading.

Accountable Entities

- This element is to identify the responsible entities for emissions from international aviation under the scheme.
- Aircraft operators, Fuel suppliers, Air navigation service providers, Airport operators and Aircraft manufacturers are identified as potential entities.
- In the guidance, aircraft operators are recommended as the accountable entity.

Emission Sources

- This element is to determine at which level of aggregation of aircraft emissions obligations under a scheme should be applied and whether the scheme should include a de minimis threshold.
- The type of activity (i.e. commercial or general aviation) and the volume of activity (i.e. number of flights, ATK (available tonne-kilometers), or amount of emissions) are considered to determine inclusion in emissions trading. And aircraft weight, number of operations or aggregate air transport activity can be identified as options of basis on de minimis threshold.
- It is recommended that the obligations should be applied on the basis of the total aggregated emissions from all covered flights performed by each aircraft operator

included in the scheme.

Emission Species

- This element is to determine which aviation emissions gases are covered by the scheme.
- Several gases such as Carbon Dioxide (CO_2), Methane (CH_4), Hydro Fluorocarbons (HFC) are considered as the primary direct greenhouse gas emission of aircraft.
- The guidance recommends starting with CO_2 only.

Geographic Scope for international aviation

- Geographic scope for international aviation was much complicated because emissions occurring outside the territory of the State can be addressed and there were strongly diverging views due to the diversity of the view from Contracting States. Three elements was discussing in the ETTF.
- First is the international routes covered by that scheme, second, the point of application, for example whether emissions allowances are surrendered upon take-off or landing, third, which operators are included in the scheme.
- The guidance recommends that mutual agreement and alternative to mutual agreement should be considered to integrate international aviation emissions from aircraft operators of other Contracting States into their emissions trading scheme.

Trading Unit

- This is element to determine how integrate international aviation emissions in a scheme in consideration of the current Kyoto accounting system. And these six options to introduce international aviation into a trading scheme are discussed in the guidance.
- The first two options use only Assigned Amount Units (AAUs), which is an allowance that grants the holder the right to emit one tonne of CO_2, and four other options use a combination of AAU and separately defined aviation allowances.
- Contracting States will need to make a choice about which option to pursue taking into account economic efficiency, environmental integrity, and equity and competitiveness issues.

Allowance distribution

- This is element to determine an efficient and equitable method for distributing emissions allowance between aircraft operators, using a benchmark parameter.

- Benchmarks for distributing emissions allowances to the air transport sector should be designed to reward previous investments in new technology and provide incentives to operate the most emissions efficient aircraft in the most efficient way into the future.

Monitoring, Reporting, Verification and Enforcement

- This is an element to determine appropriate methods to monitor, report and verify aircraft operator emissions to ensure the proper functioning and integrity of the scheme, taking into account the administrative cost.
- Options for monitoring and reporting are calculation based on the actual trip fuel and estimation based on actual flight data should be considered.
- Regarding options for verification, accredited verification entity should carry out a predefined verification procedure.

Challenges

The ICAO guidance on emissions trading for aviation has some problems such as:

- Regarding geographic scope in the guidance, the guidance recommends both mutual agreement and alternative to mutual agreement and it could be interpreted in various ways.
- The guidance is not of a regulatory nature and is just guidance for use by Contracting States, “as appropriate”, to incorporate emissions from international aviation into Contracting States’ ETS. Therefore, several different schemes can be established for international aviation.

3.2 An Overview of Several Emission Trading Systems and the Lessons They Provide

There is a growing body of experience in the United States and internationally with emission trading systems (ETS). On the whole, existing systems suggest that there is an important role to be played in pollution control by ETS, but a system's effectiveness depends on the nature of the pollutant, the system's design, the range and kind of facilities covered by the system, and the ability of a central authority to effectively monitor facilities' emissions and compliance with the rules of the trading system. Depending on the nature of a pollutant, emission trading systems can prove preferable to strictly command and control approaches to pollution control as they provide firms with greater flexibility in determining when and how to reduce a pollutant. There are, however, some environmental justice issues with ETS that must also be considered.

Emission trading systems are often referred to as cap and trade systems. They have as their main purpose the control of a pollutant through the allocation of permits (also known as allowances) to polluting firms. Each permit represents the amount of the pollutant that a facility may emit. Firms are not allowed to operate unless they have sufficient permits to cover the pollutants they discharge. Firms that do not comply are subject to heavy fines.

The underlying logic behind emission trading systems is that because a central authority limits the number of allowances in the system, allowances take on value. Essentially, the permits put a price on the right to pollute. Market signals, thus, can help a firm determine whether it is more cost effective to continue polluting or to reduce their pollution load thereby reducing the number of allowances they must obtain to operate. As long as the price of the allowances is high enough, this approach pushes firms that can most cost effectively reduce pollution to do so.

In the language of cap and trade systems, a cap refers to a maximum emission (or production) level beyond which total emissions (or production) are to be prevented. The units (e.g. firms, facilities, power plants) governed by an emission trading system are either allocated (e.g., based on historical emission levels) or purchased (e.g. through an auction) emission allowances. Caps and the units to be governed by the system are usually determined through some form of political bargaining but with a central authority ultimately determining which firms are to be covered by a system and at what level a cap is to be established.

In an emissions trading system, units can buy emissions and sell emission allowances. A firm desiring to expand its operations (and as a result, its emissions) will need to either improve the efficiency of its existing operations, bringing down emissions in the process so that it can expand its operations and stay within the level of emission allowances it holds or obtain emission allowances by buying them from another firm. Firms that can save money by cutting their emissions and selling the permits (also known as emission credits) they hold will choose to do so.

In order to reduce pollution over time, the ETS usually builds in some kind of mechanism that will lead to a reduction in the number of allowances in the system. This can either be done by a central government lowering the level of the cap over time or through a "retirement" system whereby a certain percentage of allowances are taken out of the system with each trade that occurs. Over time, this pushes up the price of remaining permits. Non-system actors, such as non-governmental organizations may also choose to purchase permits in order to retire them from the system. Alternatively, a corporation may choose to retire a share of its emission allowances, donating them, for example, to a non-profit organization. The end effect is to drive up the cost of polluting giving firms a greater incentive to reduce their pollutant emissions.

An alternative to the cap and trade model is a baseline and credit approach. In this kind of system, no total cap is established. Instead, credits are created when a firm brings its pollutant below a baseline (e.g. emission levels at time X). These credits can than be sold to other firms that are exceeding their own baseline.

Already in the 1960s, when the United States began developing national environmental pollution control regulations, economists were making a case for the efficacy and flexibility of emission trading systems. It was not until the 1970s and 1980s, however, that emission trading systems began to be employed by the United States. Europe began experimenting with emission trading systems in the 1980s and 1990s. Below various emission trading systems and the innovations they have led to are briefly introduced.

Emissions Trading Systems

The Environmental Protection Agency's Emission Trading Program under the Clean Air Act Program to Improve Local Air Quality (1974)

Developed in the 1970s, the U.S. EPA's Emissions Trading Programs were the first in the world to incorporate emissions trading systems in an effort to address air pollution. There were several programs developed. A "netting" system allowed new large sources to be exempted from review procedures if existing emissions elsewhere in the same facility were adequately reduced. In 1976, an "offset" program was added to the system. Companies wanting to establish a new facility in an area that was not in compliance with the national ambient air quality standard could do so if they could reduce existing emissions at another facility within the non-attainment area by at least the same amount at the new facility would emit. A bubble system was also formulated. This allowed a firm to aggregate all of its emissions from its various facilities when calculating compliance with emission levels. Finally, a banking system was started that allowed firms to obtain credits for future use when they took actions that reduced their emissions below a specified standard. While pioneering in its approach, the program was not been widely used as it was voluntary and highly complex in its design. It required extensive reporting and compliance procedures limiting firms' ability/willingness to employ the system. According to one assessment, the programs "constitute the first official recognition of the potential value of emissions trading, but the disappointing experience with these programs is the primary reason for the early reputation of emissions trading as a theoretically desirable but largely impractical concept."[76]

Lead Trading Program

In 1973, the U.S. EPA initiated a "phase-down" program to bring the levels of lead in gasoline down to 0.5 grams per gallon by 1980 in large refineries and by 1982 in small refineries. Refineries could average their total (both leaded and unleaded) output to reach the 0.5 standard. In 1982, the standard was changed to 1.10 grams per leaded gallon but eliminated the provision that allowed averaging.[77] At the same time, the EPA introduced a lead trading program for gasoline refineries. A refinery could exceed the lead content limit in its own gasoline if it purchased an equivalent number of allowances from another refinery that had reduced its lead content below the level required by the EPA.

A major innovation with this system was its allowance of banking. In 1985 the EPA further tightened its lead content rules. For mid-1985 the level was set at 0.5 grams per leaded gallon and for 1996 at 0.1 grams per leaded gallon. To accompany this change in the regulation, starting in 1985, refineries were allowed to bank credits that they accumulated for meeting the phase down requirement early and use them in subsequent years. The program was extensively used from 1985-87, when it was terminated because lead phase down was complete. The EPA estimated that savings attributable to the program were significant and the phasedown of lead was sped up by the trading program.

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[76] A. Denny Ellerman, Paul L. Joskow, and David Harrison, Jr., "Emissions Trading in the U.S.: Experience, Lessons, and Considerations for Greenhouse Gases," Pew Center on Global Climate Change. www.pewclimate.org/global-warming-in-depth/all_reports/emissions_trading/emissions_execsumm.cfm.

[77] EPA Press Release, "EPA Sets New Limits on Lead in Gasoline," March 4, 1985.

Trading in the Right to Produce and Consume Ozone Depleting Substances under the Montreal Protocol

One of the first international ETS was created by the Montreal Protocol on the Control of Substances that Deplete the Ozone Layer. The Montreal Protocol created schedules for the phase-down (and in some cases phase-out) of several ozone depleting substances (ODS), including chlorofluorocarbons (CFCs). The phase-down and phase-out schedules were different for industrialized and industrializing countries. When the system was introduced there were only 17 ODS producers in the world. By 1997 there were 79 producers (57 of which were in developing countries).[78]

Under the Montreal Protocol a provision was added to allow "industrial rationalization" of ODS production and consumption rights. Essentially, this created an international emissions trading system. The goal was to encourage a more cost efficient reduction of the production and use of cholorofloUrocarbons, consistent with the phase out plan established by the protocol. Firms that could most cost effectively reduce their production or consumption of ODS had an incentive do so and then sell their ODS production or consumption rights to another firm (possibly in another country) that needed them.

In the United States the government established ODS limits for all ODS producers based on their 1996 ODS production levels. The limits declined over time in accordance with the Montreal Protocol phase out schedule. Firms that wished to produce or use CFCs had to have an "allowance" issued by the U.S. Environmental Protection Agency. For every domestic trade that occurred, the EPA retired one percent of the amount of ODS represented by the allowance from use. This was done to ensure that trading would lead to greater reductions than would occur without trading.

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[78] Organization for Economic Cooperation and Development, "Lessons from Existing Trading Systems for International Greenhouse Gas Emission Trading, Annex I Expert Group on the United Nations Framework Convention on Climate Change Information Paper, ENV/EPOC(98)13/REV1, August 3, 1998.

The U.S. EPA recorded 172 trades in 1992 of which only one was international. In 1994 there were 147 trades of which nine were international. By 1995 the number of trades started to decline, however, as production was declining based on the Protocol's phase-out time line. Monitoring was conducted by national governments based on records of ODS production, imports, and exports. In the United States all trades had to be reported to the EPA before they occurred. International trades required the notification and approval of all relevant authorities of the different countries concerned. The U.S. EPA, for instance, would only allow an international purchase by a U.S. firm to occur if the embassy of the selling firm's country declared that the country had reduced its production rights by the amount transferred.[79] The ODS trading system reduced the administrative costs of implementing the Montreal Protocol.

In the European Union, the European Commission allocated production quotas to ODS producers based on their historic production levels. European producers were allowed to trade within the European Union or with any other party to the Montreal Protocol as long as their combined production quotas did not exceed their combined quota limits. A similar system was put in place establishing ODS consumption quotas. Trade with non-parties to the Montreal Protocol was prohibited.

Developing countries often lacked the necessary monitoring capacity to comply with the emission trading rules of the Montreal Protocol. To aid them in their monitoring efforts, the Montreal Protocol's Multilateral Fund provided funds to help them establish National Ozone Units. Trade between non-European Union countries had to be reported and approved by the United Nations Environmental Programme's Ozone Secretariat.

While there was some abuse of this system and some illegal trading, on the whole, the system appears to have functioned reasonably well. Countries found in non-compliance by the Implementation Committee that was established under the Montreal Protocol were first provided with technical and financial assistance to help bring them into compliance but when this did not function could either be issued cautions or

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[79] Ibid.

ultimately be suspended from the Montreal Protocol. Suspension would mean the loss of access to the ODS market of other Parties and lose the right to financial support.

NO_x Trading Scheme under NO_x Ozone Transport Commission

The 1990 Clean Air Act Amendments established the Ozone Transport Commission (OTC) to help states in the Northeast and Mid-Atlantic region to meet the National Ambient Air Quality Standard for ground-level ozone. Initially, the OTC's focus was on achieving year-round, region-wide emission limits based on Reasonable Available Control Technology.

Then in 1994, the OTC states took the initiative and signed a Memorandum of Understanding formulating a multi-state cap and trade program (the NO_x Budget Program) to control NO_x emissions and address regional transport of ozone. The program set a regional "budget" (a cap) on NO_x emissions from power plants and other large combustion sources during the time of year when these states tend to be out of compliance (May 1 through September 30). The program covered 1,000 large combustion facilities. Under the program's cap and trade provisions, each state allocated emission allowances to their combustion sources in accordance with the portion of the regional budget allocated to the state.[80] Each allowance permitted a source to emit one ton of NO_x during the ozone season. Firms could sell unused allowances or bank them for future use. Regardless of the number of allowances held by a source, it was not allowed to emit at levels that would violate emission limit requirements. The program was a collaborative state/federal partnership. The states established the program requirements and emission budgets and then the EPA administered data systems used to manage the program and provided technical assistance to the states in tracking allowance transfers, maintaining unit and account information, assisting with monitoring, and preparing annual reports. The program was highly successful, leading to a significant reduction in NO_x emissions in the Northeast and Mid-Atlantic regions. According to the OTC, the

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[80] Ozone Transport Commisssion, "NO_x Budget Program, 1999-2002 Progress Report," http://www.epa.gov/airmarkets/progress/docs/otcreport.pdf.

trading program and the earlier Reasonably Available Control Technology requirements brought ozone season emission to approximately 60 percent below 1990 level emissions by the early 2000s. The Budget Program, moreover, was found to be cost effective.

The NO_x Budget Program was replaced in 2003 by the NO_x Budget Trading Program in response to the EPA's call for State Implementation Plans (SIP) to reduce the transport of ozone over broader geographic regions. The program expanded the number of states involved in trading, thereby expanding the electric power and industrial combustion sources covered by the program. Under the NO_x SIP call program reductions were mandated in two phases. The first phase that went into effect in 2003 required further reductions in NO_x emissions (of approximately 35-40%) from the states that had been involved in the earlier NO_x Budget Program and in 2004 of designated facilities in the new states covered by the program.

1990 Clean Air Act Amendments: SO_2 Allowances

Perhaps the best known example of an emissions trading system is the SO_2 emissions trading system established by Title IV of the 1990 Clean Air Act Amendments. The 1990 Clean Air Act required total U.S. emissions of SO_2 to be capped at around nine million tons per year. This was to be achieved through a two phase process, the first starting in 1995 and the second in 2000.

In the first phase, the EPA assigned emissions limits to 263 of the most SO_2 emissions intensive generating units at 110 power plants operated by 61 electric utilities. The EPA allocated each utility a certain number of allowances based on its heat input during the baseline period (1985-87). Phase two extended the program to other fossil-fuel electricity generating facilities with total SO_2 emissions to be capped at approximately nine million tons (an average of about 1.2 pounds of SO_2 per million Btu). The overall impact of the program is expected to bring emissions down to about half of what they were in 1980.[81]

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[81] A. Denny Ellerman, Paul L. Joskow, and David Harrison, Jr., "Emissions Trading in the U.S.: Experience, Lessons,

Sources were issued tradable allowances. Each represented the right to emit one ton of SO_2. Facilities had to surrender an allowance for every ton of SO_2 emitted. Allowances that were not used could be traded or banked for future use. A small percentage of allowances (2.8 percent) were withheld from units and withheld for distribution through an annual auction to encourage trading and to make sure allowances were available for new electricity-generating units. The revenues from the auction were returned on a pro rata basis to the firms from which the allowances were withheld.

There was a particularly sharp reduction in SO_2 emissions in 1995, one year after the program went into effect. The reason for this was that firms had a strong incentive to reduce emissions beyond what was required and bank their use for future periods when marginal abatement costs were expected to rise (especially after 2000 with the start of Phase II of the program).

This program is considered one of the most successful examples of emissions trading and suggests that emissions trading can lead to sharp reductions in emissions at lower costs than would be the case with less flexible command and control regulations.

The European Union's Carbon Emissions Trading System

In its effort to find cost effective ways to reduce emissions, the European Union (EU) decided to implement the world's first international carbon ETS. The system covers all 27 member states. Norway also cooperates with the program. The Directive mandated a system covering over 10,000 installations representing approximately 40 percent of CO_2 emissions in the power sector (facilities over 20MW), oil refining, cement, glass, ceramics, iron and steel, paper and pulp sectors. Each member state was required to set carbon allocation permits to companies operating in their own territories. Companies exceeding their CO_2 emission quotas would have to buy additional permits to cover their larger emissions. Companies making energy efficiency improvements or switching fuel

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and Considerations for Greenhouse Gases," Pew Center on Global Climate Change. www.pewclimate.org/global-warming-in-depth/all_reports/emissions_trading/emissions_execsumm.cfm.

sources could profit by selling off permits they no longer needed. In 2004, a Linking Directive was passed linking the joint implementation and clean development mechanisms of the Kyoto Protocol to the ETS. With this Directive companies can obtain credits by reducing emissions in developing countries and then using them within the ETS. The ETS was introduced in January 2005 and member states provided their allocation plans in May, which the Commission reviewed and approved after revisions.

At the national level, there were often lengthy domestic debates regarding emissions allocations and reduction targets. Within Germany, for example, there were harsh debates between the Environment and Economics ministers regarding what the reduction targets for the first (2005-2007) and second (2008-2012) periods should be.

The first year's assessment of the ETS suggested there were still many problems. Most importantly, it came to be realized that most countries had issued too many allowances for industry (at times at levels that were higher than actual emissions). This provoked a crash in the emerging carbon trading market. The price for one ton of CO_2 fell 63 percent from €30 to €11 from April 15 to May 15, 2005.[82] The market crashed again in April 2006 (to €8.3), when the actual figures for 2005 emissions came out, providing proof for the over-allocation, particularly in France and Germany.[83] The UK had the opposite problem. Having approved too few allowances, it appealed to the Commission for a change of plan, but it was refused. This forced UK industry to buy 30 million tons of extra allowances.[84]

The European Commission has been closely examining national allocation plans for the second phase of the ETS set to begin in 2008. The Commission is eager to see the system function well and this will require making sure that excessive allocations are not made again in the second phase of the program.

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[82] Spongenberg, Helena, "EU States Gave Too Many Pollution Permits, Say Environment Groups", *EUObserver.com*, May 15, 2005. http://euobserver.com/9/21594.

[83] Morrison, Kevin, "Lower Pollution in EU Sees CO2 Permits Fall 30%", *The Financial Times*, Aprili 27, 2006, p. 21.

[84] Euroactive, "Question Marks" http://www.euractiv.com/en/sustainability/question-marks-eu-co2-trading-scheme/article-155349?_print.

Chicago Climate Exchange

The Chicago Climate Exchange (CCX) is North America's only, and the world's first, greenhouse gas (GHG) emission registry, reduction and trading system for all six greenhouse gases (GHGs).

CCX is a self-regulatory, rules-based exchange designed and governed by CCX Members. Members make a voluntary but legally binding commitment to reduce GHG emissions. Those who reduce more than their targets can sell or bank their surplus allowances. Emission allowances are issued to emitters based on their emission baseline and an emission reduction schedule established by the CCX. The program also permits offset exchanges, so that a firm that would otherwise exceed its target can offset those emissions by making reductions through qualified offset projects (sequestration, destruction, or displacement of greenhouse gas emissions). In Phase I of the program (2003-2006), members committed to reducing by 1 percent a year below their baseline for a total of 4 percent by 2006. Phase II (2007-10) extends the CCX reduction program through 2010. It will require all Members to reduce GHG emissions 6 percent below baseline by 2010. The baseline was set at average annual emissions from 1998-2001 or the single year 2000.[85] Beginning in 2003 corporations began voluntarily trading ghg emission allowances on the Chicago Climate Exchange.

The goals of the program are to: 1.) facilitate the transaction of greenhouse gas emissions allowance trading with price transparency, design excellence and environmental integrity, 2.) build the skills and institutions needed to cost-effectively manage greenhouse gas emissions, 3.) facilitate capacity-building in both public and private sector to facilitate greenhouse gas mitigation, 4.) strengthen the intellectual framework required for cost effective and valid greenhouse gas reduction, and 5.) help inform the public debate on managing the risk of global climate change.

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[85] Chicago Climate Exchange, http://www.chicagoclimatex.com/content.jsf?id=72.

In June 2007, the U.S. House of Representatives has voted to become a member of the CCX offsetting the emissions it itself generates.[86]

Company Efforts

There are also many intra-company emission trading models. In 2000, TransAlta, a Canadian firm, for example, launched plan to eliminate greenhouse gas emissions by 2024, partly through emissions trading. In 2004, they announced the purchase of 1.75 million tons of greenhouse gas candidate Certificate Emission Reductions from Chilean agricultural company, Agrosuper. Their offset projects include: gas recovery, energy efficiency, ruminant methane, landfill and coal mine gas to electricity, forestry, soil sequestration

BP launched an internal cap and trade system spanning 150 business units in more than 100 companies. Each unit was assigned a quota of emission permits. The program cut greenhouse gas emissions by 10 percent below 1990 levels, eight years ahead of schedule. BP was the first company to make a trade with the United Kingdom's Emission Trading System.

Royal Dutch Shell developed a pilot internal emissions trading system (2000-2002). The system allowed trading among group entities in Annex 1 countries. It covered 33 million metric tons of CO_2 equivalents from 22 separate sites. It has since established an Environmental Products Trading Business and entered UK Emissions Trading Scheme. Key Shell UK upstream production facilities now have a greenhouse gas emissions cap. Shell Trading, with Nuon, executed the first trade in EU CO_2 allowances in 2003.

DuPont is a member of the Chicago Climate Exchange and International Emissions Trading Association. In 2002, it donated 120,000 tons of CO_2 emission credits

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[86] "House Passes Kirk Amendment to Offset Greenhouse Gas Emissions," June 22, 2007, http://www.house.gov/appls/list/press/il10_kirk/House_Passes_Kirk_Amendment_to_Offset_Greenhouse_Gas_Emissions.html.

to Salt Lake City Organizing Committee allowing the Winter Olympics to be carbon neutral, by off-setting their emissions.[87]

Trends Related to Emission Trading Schemes and Lessons Learned

There is now close to three decades of experience with emission trading systems. Several trends are visible and various lessons have been learned.

1.) Due to their general cost-effectiveness, emission trading systems are increasingly being used to address a wide variety of environmental problems. First, used voluntarily to address local air pollution problems in the United States, emission trading systems have been used to control numerous kinds of pollutants (e.g. lead, SO_x, NO_x, chlorofluorocarbons, carbon dioxide, municipal waste,) and environmental quality and resource issues (e.g. water based nutrient trading, quota based fisheries management). The key to emission trading schemes' general success is that they provide industry with a more cost-effective means of reducing pollution than is often the case with traditional regulatory approaches. The reason for the greater cost-effectiveness of market-based approaches is that they provide firms with greater flexibility as to how to reduce or control emissions, and also, in some cases, when to make cuts (e.g. this year or three years later).

2.) Initially a predominantly U.S. phenomenon, emission trading systems have spread to many parts of the world (e.g. New Zealand's fishing quota trading system, China's experimental sulfur dioxide trading system).

3.) The Montreal Protocol was the first international agreement that had emissions trading tied to it. Since this time, trading systems are becoming more common as implementation mechanisms for pollution control within international environmental agreements.

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[87] Information from the Pew Climate Center, http://www.pewclimate.org.

4.) Although the United States led in the development of emissions trading systems, other parts of the world have led in the development of carbon trading systems. The United Kingdom launched the world's first economy-wide emissions trading system in April 2002, and in 2005, the European Union launched the world's first international carbon emissions trading system. Other countries have announced plans to launch their own carbon emission trading systems (e.g. Australia) or are experimenting with voluntary schemes (e.g. Japan Voluntary Emissions Trading Scheme started in 2005). There is growing interest in carbon trading in the United States as well (e.g. the Conference of New England Governors and Eastern Canadian Premiers is exploring the idea of a regional greenhouse gas emissions trading scheme and California's Governor Arnold Schwarzenegger discussed with former Prime Minister Tony Blair the possibility of eventually forming a bilateral emissions trading system between them). Germany has announced plans to pursue a linking of the EU emissions trading scheme with a scheme being planned for California. There are already links between the EU's emission trading scheme and Norway and Switzerland.

5.) There is growing awareness that emissions trading is likely to be a major element of future greenhouse gas emissions control efforts. There is growing competition among financial firms and countries to gain a part of the growing carbon emissions trading industry. A July 6, 2007 *New York Times* article calls carbon trading "the new big thing" and notes that the market is already worth $30 billion and could grow to $1 trillion within a decade.[88]

6.) There are now hundreds of companies that have experimented with emissions trading within their own firms and operations. Corporate acceptance of emissions trading (as an alternative to purely regulatory approaches to pollution control) has grown substantially.

7.) The design of emission trading systems is crucial. There are now numerous kinds of emission trading systems, the two best known being cap and trade schemes and base-line emission schemes.

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[88] "In London's Financial World, Carbon Trading is the New Big Thing," *New York Times*, July 6, 2007.

8.) While voluntary schemes tend to be preferred by industry, mandatory schemes appear to have more impact in reducing emissions.

9.) Emission trading systems are primarily in operation in industrialized countries. Enhancing experience with emission trading systems in developing countries will be crucial to the functioning of these systems. There are growing signs of interest in emissions trading in developing countries. India's parliament, for example, will soon consider whether to allow its Multi-Commodities Exchange to trade in carbon credits. Several exchanges already exist, e.g. the European Carbon Exchange, the Chicago Carbon Exchange, the Asia Carbon Exchange. As noted above, China is experimenting with a sulfur dioxide trading system. Nevertheless, familiarity with emissions trading is still limited in many parts of the world. This suggests there will be a strong need to assist developing countries with the development of emission trading schemes and monitoring and verification systems.

10.) There have been numerous important innovations with emission trading systems. These include the development of banking (allowing firms to keep excess emission reduction credits for future use to encourage rapid reductions in emissions early on in a program), offset systems (permitting firms to offset their own emissions by making emission reductions elsewhere), multiple pollutant trading schemes, etc.

11.) While the general experience with emissions trading leans toward the positive, there have been problems with various schemes. The 1974 Environmental Protection Agency's Emission Trading Program under the Clean Air Act Program to improve local air quality has not been as successful as other programs. This appears to be because the system was voluntary and perhaps more importantly, too complex for industries to easily adopt the system. The European Carbon Emissions Trading System got off to a rough start because of the over-allocation of carbon allowances to firms at the national level. This highlights the importance of getting the system design right at the beginning. It may also speak to the importance of pilot emission trading schemes that can be used to work out the kinks in a system.

12.) Offset programs can be very attractive to firms that must comply with emission caps established by a market-based pollution trading scheme or existing in parallel to such a scheme. It is crucial that a system be established that verifies that offsets are “real” and would not have happened regardless. This is also true with efforts to link the clean development mechanism and joint implementation (two mechanisms formed under the Kyoto Protocol to provide firms in developed countries with an opportunity to gain credits towards their own emission reduction requirements by making emission cuts in developing countries or transition economies).

13.) Development of a carbon emissions trading system scheme for the international airline industry could be a cost effective way for the industry to reduce greenhouse gas emissions (or perhaps more realistically given the growth projections for the industry, to reduce greenhouse gas intensity). This system will be unique in many ways, given that the industry deals with a mobile, as opposed to a stationary pollution source. International travel raises many important questions about emission reduction requirements (assuming these are uneven internationally) and emission reduction credits. This suggests that while important lessons can be learned from existing systems, new innovations will be required. The industry will also need to aid developing countries in the development of emission trading expertise.

Useful Data Sources on Emissions Trading

- Chicago Climate Exchange
- European Climate Exchange
- International Emissions Trading Association
- Pew Center on Global Climate Change
- Natsource

- Partnership for Climate Action (Environmental Defense)
- Europa

3.3 International Aviation: Quantitative Analysis of the Impact of a CO_2 Cap-and-Trade System

Recent advances in climate science have confirmed and refined our previous understanding of anthropogenic impacts on the earth's climate. These advances were most recently summarized by the Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (FAR) in February, 2007. Current atmospheric concentrations of greenhouse gases (GHGs), particularly carbon dioxide, methane, and nitrous oxide, significantly exceed pre-industrial measurements determined from sampling of ice cores going back thousands of years.

The FAR forecast near-term warming trends of about 0.2˚C per decade, consistent with recent observations. The scenarios forecast a range in sea-level rise by the end of the 21st century between 0.18 and 0.59 meters. The expected full impacts of the warming over the next century will depend on the magnitude of these trends. The FAR concludes that increases in the areas affected by droughts, the intensity of tropical cyclones, and incidence of extreme high sea levels are *likely*. The frequency of heavy rainfall events (or the proportion of rainfall occurring during heavy rainfall events), and the frequency of heat waves and warm spells are *very likely*. Finally, an increase in the number of warm days and nights – and corresponding decrease in the number of cool or cold days and nights – over most land areas, is *virtually certain*.

The aviation sector is receiving rapidly increasing attention with regard to its Greenhouse Gas (GHG) emissions. Currently representing a small (~2 percent) portion of global CO_2 emissions, the industry's rapid emissions growth, the very substantial proposed reductions in total global emissions, and the likely significant impacts of non-CO_2 GHGs combine to stimulate this apprehension.

Carbon dioxide (CO_2) produced as a result of burning aviation fuel is by far the largest and most straightforward climate change influence from aviation. Other impacts of aviation on net radiative forcing, however, are complex, both in terms of understanding the science and in formulating appropriate policy responses. Besides CO_2 concentrations, aviation can affect atmospheric concentrations of ozone and methane, and influence cloud formation, all of which affect radiative forcing. NO_x emissions from aircraft are the result of incomplete combustion and are potentially quite significant with regard to climate change. Complex atmospheric physics and chemistry in the upper atmosphere contribute to tropospheric ozone formation, but also cause NOx emissions to reduce atmospheric concentrations of methane. However, it is unclear, for example, whether the positive radiative forcing from ozone formation from NOx is fully offset by the negative radiative forcing from methane reduction.

The Kyoto protocol, under which participating countries agreed to fixed percentage reductions in GHG emissions below 1990 levels by 2012, was negotiated under the UNFCCC. The countries of the European Union committed to a reduction of 8%, as a block. In response to its Kyoto commitments, the European Commission developed an EU-wide strategy under the European Climate Change Program (ECCP), beginning in 2000. This program brought together a number of working groups focusing on different sectors or mechanisms. In the transport sector, the primary component of the Commission's Kyoto strategy was a negotiated voluntary agreement with the European Automobile Manufacturing Association (ACEA) to reduce CO_2 emissions to 140 grams per kilometer by model year 2008.

Until December 2006, when the European Commission issued a directive including aviation in its Emissions Trading System (EU-ETS) beginning in 2011, the aviation sector had largely been excluded from these formal mitigation efforts. The inclusion of aviation in the EU-ETS is a logical progression of consensus that has been developing in both the aviation and climate communities since the publication of the IPCC special assessment in 1999. The International Civil Aviation Organization General Assembly endorsed the development of an open trading system and called for the development of guidelines for the structural and legal basis off such a system.

Purpose and Objectives

This analysis has been developed for the quantitative analysis of an International Aviation Emission Trading System. The study examines the impacts of a cap-and-trade Emission Trading System (ETS) for aviation, very similar to the one already being adopted within the European Union, if one were to be additionally adopted in Japan, the United States, China, and/or globally. The primary impacts to be examined are regarding the change in CO_2 emissions, changes in airline operating profits, and changes in airline ticket prices. In addition to the quantitative analysis of a cap-and-trade system measured against benchmarks of absolute emissions, qualitative discussion of the impacts of a GHG-intensity based cap-and-trade system is presented.

Uses and Application

Several previous studies have analyzed the effects of the upcoming imposition of the European Union Directive regarding aviation emissions and requirements for emission allowances and trading. This study will also directly inform discussion regarding the E.U. ETS for aviation. More broadly, the modular and multi-regional nature of the model also permits analyses to be extended to one or more additional regions of the world. (The delineation of the markets is limited, however, to flights within or between the E.U., Japan, the United States, China, and the rest of the world. Further, the model is adaptable to cover different permutations of domestic and international markets.)

The study will, therefore, help to inform policy debate on a wide variety of different scenarios regarding aviation emissions cap-and-trade systems. Given that no other studies have been identified that explicitly address aviation greenhouse gas issues outside the EU, this study should provide an important stepping stone to more detailed analyses of these issues should they be more concretely addressed by ICAO and/or any consortium of countries outside the EU. However the time and resources for this study were limited compared to other recent studies, and it, therefore, provides but a foundation for more detailed modeling. Given the ever-increasing likelihood of action by one or more Kyoto ratifying countries (or even signatories such as the US, given the prevalence of current proposed legislation), this study should provide groundwork for more in depth analyses of the impacts of related GHG measures.

Scope

The work undertaken for this study spanned the following major areas:

- *The international aviation* market – passenger demand, supply provided, load factors, operating costs, and revenues across 16 major world aviation markets;
- *Aircraft fleet and technology* – fuel efficiency of the world aircraft fleet by aircraft type, consequential CO_2 emissions, deployment of the world aviation fleet across markets, and fleet turnover and uptake rates;
- *Airport operations, air traffic operations, and air traffic control management systems* – advances in technology and operating practices that would result in fuel efficiency improvements;
- *Outside costs and factors* – Fuel prices, CO_2 prices (using European Union Allowance prices as a proxy) and coverage of non-CO_2 emissions.

Approach

The broad approach to the study was comprised of the following elements:

- *Literature Review and Data Collection*—A brief review of expected trends in the aviation market, aircraft technologies, air traffic management systems (ATM), airport operations, and fuel and CO_2 prices was conducted. Special attention was given toward estimating emission rates over time from aircraft under the conditions of the above factors, primarily using a fleet inventory approach. Publications regarding the possible implications of the EU-ETS on international aviation were reviewed, and corresponding data collected in these areas.

Large datasets were purchased and/or collected, primarily including a customized version of the SAGE database for 2000-2005, ICAOdata, Eurostat, and various ICAO, IATA and other forecasts, reports and other publications. Substantial data quality control ("scrubbing"), compilation, and manipulation was conducted

- *Model Development*—A robust, modular spreadsheet model was developed to incorporate the individual elements described above in the scope, and their interactions. Each of these elements was included with separate inputs and outputs adjustable for each market, and interaction between each of the markets regarding all factors. Interactions with a single "rest of world" market were also included. Attempts to additionally model the impacts of a GHG intensity-based cap-and-trade system were not able to be incorporated within the study constraints. Data availability and time and resource constraints also limited some elements of model detail and the modeling time frame–2020 was considered the outer end of forecasting reliability, although results were extrapolated to 2025 for informational purposes.

- *Model Runs, Sensitivity Analysis and Results*— Initial model runs were conducted with baseline inputs in order to conduct quality control. Individual and sets of inputs were then systematically varied to ensure model robustness and realistic results. Sensitivity analyses were also conducted to generate results for multiple key scenarios based on permutations of markets included, allowance allocation and other key factors. Results include a baseline, the impact of the EU-ETS system, and key scenarios (e.g., based on alternative assumptions and inputs).

- *Report Compilation* - Several reports and presentations were prepared, including:

- Interim report summary;

- Interim report presentation;

- Draft final report;

- Final summary report; and

- Final report.

Model Development

The elements of the scope described above were broken into smaller model elements, and were assembled into the framework described below using a modular design that allows individual input adjustments, calculation and relationship definitions for each parameter. This model structure allows for various time lags/leads and multiple feedback loops to reflect the interaction between variables and the proposed decision hierarchy (i.e., short-term versus long-term decisions, which decisions are dependent on which others – rather than simply correlated). This framework also allows for feedback to reflect realities of time effects by modeling each forecast year sequentially, with feedback including simultaneous, lagged, and anticipatory elements.

The strength of the model is in its flexibility and facility for conducting scenario evaluation and sensitivity analyses. This is critical as a number of important elements of the design, scope, and coverage of the ETS are not yet determined and could still vary dramatically. For the hypothetical other markets that may come under a cap-and-trade system in the future, these elements are not at all defined and thus require a flexible modeling system. Other variables also may fluctuate considerably, although these are not necessarily policy variables for decision makers.

The overall decision hierarchy and relationship flow commences with the longest-term factors, which are least dependent on smaller fluctuations, and flows to the shortest-term behavior decisions most affected by earlier decisions. Nonetheless, this is recognized as not being a strict hierarchy, and decision-making and behavioral factors do flow in each direction between parameters, with different time frames. Additionally, it should be noted that each of these relationships is defined only to reflect those factors that would cause a change from the baseline or business-as-usual case, not in the underlying factors behind each factor. For example, passenger demand is fundamentally driven in large part by GDP and income, which is not modeled here as it is assumed held constant across scenarios. Fares are thus the parameter considered in the model to determine changes from the passenger demand baseline.

- *International Aviation Market.* The central case scenario in the model addresses international travel in the Japan-Europe, Japan-U.S., Europe-U.S., and E.U.-E.U. aviation markets. Additionally, coverage of China as a separate market was included as an option (albeit with less reliable data), and the “rest of world” (R.O.W.) was included both for its interaction with other markets and for domestic and international aviation within it. The primary elements considered include the underlying demand growth rate, competitiveness of the market (number of airlines per origin-destination pair), aircraft fleet mix and age, operating cost and revenue factors. In total, up to 16 different markets could be addressed:

- CHINA-Domestic
- CHINA-R.O.W.
- EU-CHINA
- EU-EU
- EU-JAPAN
- EU-R.O.W.
- EU-US
- JAPAN-CHINA
- JAPAN-Domestic
- JAPAN-R.O.W.
- JAPAN-US
- R.O.W.-Domestic
- R.O.W.-R.O.W. (International)
- US-CHINA
- US-Domestic
- US-R.O.W.

- *Aircraft technology*. Primarily covered with regard to fuel consumption, using a fleet turnover model at the global level and a regional distribution model, both by 62 individual aircraft types (representing 98 percent of available seat-kilometers (ASK) and all aircraft types with a 0.1 percent or higher market share. An “other” category combined the remaining 340 aircraft types (aggregated from 785 listed in SAGE), which together represented less than two percent of ASK. This element implicitly includes both technological advances in these areas and uptake rates through order bookings and fleet turnover. Aircraft fuel efficiency varies in accordance with fuel prices and emissions costs; uptake is also expedited by increases in demand above the baseline (necessitating more new aircraft).

- *Airport operations*, a*ir traffic operations and air traffic control management systems*. Their emission reduction effects, uptake rates by market, and possible changes in their uptake rate and effectiveness due to ETS and other factors are included through a combined set of penetration and effectiveness rates. Region-specific coverage due to the number and share of airports and local conditions was examined qualitatively to confirm the appropriateness of the baseline. These parameters were modeled in an aggregated manner, and were defined by the origin and destination region, rather than by individual market origin-destination pairs.

- *Outside costs and factors.* Fuel prices, CO_2 prices, and coverage of non-CO_2 emissions are included using sensitivity analyses. Fuel prices and CO_2 prices are both modeled as being affected by increases in aircraft supply (i.e., increased demand for fuel and for CO_2 emissions allowances), which in turn decreases demand due to fare increases (to the extent costs are passed along by airlines – another decision variable included in the model). Thus, feedback (interaction and rebound) effects are addressed in the model for these factors.

Parameter Assumption Ranges and Values

A series of parameter inputs were developed for this analysis. Both from the broader literature and from earlier studies of the effects of the EU ETS on aviation, a wide range of values were found for many of the parameters. In addition to uncertainty about what baseline forecast values for the parameters should be, there is perhaps even greater uncertainty about the sensitivity of the parameters to changes from the baseline. Thus, while specific values were selected for the baseline and central case scenario, ranges of reasonable values were also established in order to conduct sensitivity analyses.

Key findings and selected values for parameters are summarized below:

Aircraft fleet and technology

Over the past 20 years, the fuel efficiency of the in-use aircraft fleet has improved faster than that of the vehicle fleets of other transportation sub-sectors. According to the International Air Transport Association, new aircraft are 70 percent more fuel efficient than 40 years ago, and 20 percent more fuel-efficient than ten years ago. Further, aircraft tend to cycle out of the fleet with regularity and frequency. Thus, aircraft fuel efficiency is expected to continue to improve rapidly in the future, enhanced, potentially, by price signals from a trading regime filtering through the market.

Measures to improve technical efficiency would not only reduce CO_2 emissions from aircraft, but also water vapor as well. NASA has estimated that a reduction in NO_x emissions of 65 percent over the 1996 ICAO LTO limit is possible using near-term technologies.[89] As a non-CO_2 multiplier is used to represent the water vapor, NO_x and other emissions, this implicitly adjusts these emissions proportionally to fuel use in those scenarios where the non-CO_2 multiplier is applied.

Aircraft fuel efficiency will improve from a combination of engine efficiency, aerodynamic efficiency, and structural improvements (aircraft weight). Consistent with historic trends and projections in the literature, a figure of a 1.3 percent annual improvement in the in-use fleet’s fuel efficiency is used for the central case baseline scenario.

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[89] NASA, 2007, http://www.nasa.gov/pdf/55403main_20%20AT.pdf.

These fuel efficiency gains will be somewhat sensitive to changes in fuel prices and analogous CO_2 emissions costs. However, additional fuel efficiency gains will be constrained by safety, technology and capital cost trade-off factors. Thus, a conservative -0.2 elasticity of fuel efficiency with respect to fuel prices for the central case. Further, this elasticity is applied with a time lag of three years. This lag is used because of 1) longer time requirements to introduce new designs and shift production 2) somewhat more rapid ability to shift the fleet mix of new orders and of retirements, and 3) the ability of airlines and aircraft manufacturers to anticipate many of these price changes (e.g., 5 to 7 year lead time information that EU aviation cap-and-trade system will be implemented).

Airport operations and air traffic control management systems

Operational improvements from airport operations and air traffic control management systems can reduce airplane vehicle kilometers traveled, streamline LTO maneuvers, and reduce the amount of time the engine is operating in non-flight operations, thereby reducing fuel consumption. The three main goals of operational improvements are:

- increase the proportion of time spent at cruise altitudes from power-up to power-down;

- decrease the differential between actual airborne hours and minimum flight hours for any given flight stage; and

- maximize aircraft occupancy for a given level of demand.

Collectively, inefficiencies in these three criteria are estimated to be responsible for about 12 percent greater CO_2 emissions than would occur if ATM procedures could meet these goals.[90] Such efforts generally involve a combination of technological, procedural, and institutional changes:

- Technological changes in ATM include the use of more sophisticated technologies, such as Precision Runway Monitors and/or Simultaneous Offset Instrument Approach, to reduce delays for aircraft in flight.

- Procedural changes in ATM – facilitated by more sophisticated IT applications – can facilitate more widespread use of Reduced Vertical Separation Minima (RVSM), which allow aircraft to cruise at higher altitudes[91] or Continuous Descent Approach (CDA) techniques to minimize fuel burn (and noise) on aircraft descent and landings by allowing aircraft to remain at higher altitudes on approach longer and to power down engines more linearly.

- Finally, institutional changes, such as better integration of ground and air traffic control, can help ensure more comprehensive, gate-to-gate strategies to minimize fuel consumption.

Combining the results of several studies, for the central case scenario it is assumed that it will typically take approximately 25 years for full implementation of these systems to occur (with significant variation across regions). At full implementation, these systems would together contribute a 20 percent effectiveness rate for reducing fuel consumption.

Operational changes by airports and or air traffic control are not directly sensitive to emissions trading regimes that focus exclusively on aircraft operators, though such regimes would cause operators to put pressure on airport administrations to proceed with such changes more rapidly. An elasticity of 1.0 for the technology uptake rate with regard to fuel prices / CO_2 costs is used to represent such pressure. As with aircraft fuel efficiency, a three-year lag is applied to represent the combination of technological and financial constraints with anticipatory capabilities.

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[90] Intergovernmental Panel on Climate Change Special Report: Aviation and the Global Atmosphere , by Joyce E. Penner and David Lister and David J. Griggs and David J. Dokken and Mack McFarland, pp. 384. ISBN 0521663008. Cambridge, UK: Cambridge University Press, June 1999.

[91] A rule of thumb used is that an increase in cruise altitude of 2000 feet saves about 3 percent of fuel.

Economic signals

Economic signals can positively affect the above two strategies – that is, influence the rates of technology and airport/ATM operational changes – as represented by the elasticities above. For example, they may change the pace at which airlines replace their aircraft, thereby cycling new technology into the fleet faster. In the longer run, airlines would have an incentive to push for technological and operational changes, to make different fleet distribution choices, and to renew their fleets faster than they otherwise would have, as cost-saving measures to passengers to win them back. While such pressures would not affect the efficiency gains possible from operational or technological change, they would be expected to influence the rate at which such changes occur through technology uptake and market penetration.

Economic signals can also have more direct influence on overall emissions levels by influencing the level and structure of both supply and demand. For example, they might change the calculus for passenger assessment of modal preference for short-haul flights, inducing more use of rail or bus. Likely a more important factor is that passengers will shift their trips from long-haul flights to closer destinations, whether by airplane or other mode (for leisure travel), or will forego a given trip (for business travel). It is noted that these price signals are the dominant factor affecting this analysis because we are modeling only the changes in demand from a baseline, rather trying to estimate the absolute level of demand (such as forecasting the baseline), where factors such as GDP and income would play a much more important role.

On the supply side, profitability will be the most important factor in determining changes in capacity provided for this study, and represents in a fashion shifts in the supply and demand curves. While this is fairly straightforward with regard to the point-to-point service of low cost airlines, it is more complex for the hub-and-spoke networks of other airlines, where load factors and profits interact among numerous individual links in the network. Because of the aggregation of activity into large markets for this study, the use of aggregate profitability was considered the most appropriate and feasible way to determine supply shifts at the broad market level.

Passenger Demand

Growth in demand for passenger air travel is usually projected at between four and five percent per year globally (ranging from 2.5 to 7 percent per year in individual major international and domestic markets) for the next 20 years, absent demand restraint measures.[92] [93] While there is the potential for change in aviation demand forecasts beyond the impacts of the ETS, for example, the extent of liberalization and open skies, the base scenario is to use current ICAO forecasts. Such projections put pressure on the technical, operational, and economic mechanisms discussed in the previous chapter, to find at least that much efficiency improvement per year just to hold emissions to current levels.

Adjustments from this baseline are made using the standard application of price elasticities to demand. Prudence suggests using the median values among those studies meeting best-practice standards. Aggregating the elasticities from Table 3.1 below, a central case value of -1.1 was utilized for the combined short-haul/domestic own-price elasticity and -0.75 for the long-haul/international market, or -0.87 fully aggregated.

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[92] Assembly Resolutions in Force (as of 8 October 2004), Doc 9848, Published by authority of the Secretary General International Civil Aviation Organization. Available at www.icao.int/icao/en/atb/epm/A35_5_en.pdf (last accessed 8 August, 2007).

[93] Report to the United States Congress: AVIATION AND THE ENVIRONMENT - A National Vision Statement, Framework for Goals and Recommended Actions, by Ian Waitz, Jessica Townsend, Joel Cutcher-Gershenfeld, Edward Greitzer, and Jack Kerrebrock, Massachusetts Institute of Technology, December 2004.

	All studies			Studies meeting best-practice criteria		
	1st quartile	Median	3rd quartile	1st quartile	**Median**	3rd quartile
Own-price: Long-haul international business	0.48	0.27	0.20	0.48	**0.27**	0.20
Own-price: Long-haul international leisure	1.65	0.99	0.54	1.70	**1.04**	0.56
Own-price: Long-haul domestic business	1.43	1.15	0.84	1.43	**1.15**	0.84
Own-price: Long-haul domestic leisure	1.47	1.12	0.89	1.23	**1.10**	0.79
Own-price: Short/medium-haul leisure	1.75	1.52	0.89	1.74	**1.52**	1.29
Own-price: Short/medium-haul business	0.80	0.73	0.61	0.78	**0.70**	0.60
Income Elasticity	0.84	1.39	2.17	0.81	**1.14**	2.05

Table 3.1[94]

Other parameters

Minor feedback, or rebound, effects also occur with other elements of the model. For example fuel prices are modeled as changing from the baseline value depending on the demand for jet fuel. A value of 0.7 is used for this elasticity to illustrate this linkage.

Similarly, the price for CO_2 emission allowances could be fairly sensitive to the demand for these allowances. Other studies have varied from estimating a negligible impact under any realistic scenario, to estimating as much as a five euro increase in

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[94] Gillen, D. W., Morrison, W. G. and Stewart, C. (2004), Air Travel Demand Elasticities: Concepts, Issues and Measurement, Ottawa: Canadian Department of Finance (http://www.fin.gc.ca/consultresp/Airtravel/airtravStdy_e.html).

allowance prices under the most extreme circumstances. Due to the non-continuous, stepwise nature of the marginal cost abatement "curves" and CDM/JI/"hot air" availability of allowances, it is difficult and not precisely appropriate to use elasticities, which imply a continuous function. Absent knowing where on the stepwise function the market will be, however, an elasticity is still used as the best approximation of this feedback effect. A conservative value of 2.0 is used for this parameter to represent the potentially high sensitivity of allowance prices to small shifts in demand. Given the long advance warning regarding the entry of aviation into the ETS and the continually increasing sophistication of the market, the undertaking of additional abatement opportunities is expected to remove almost all of the potential volatility in CO_2 prices that has been trumpeted by some. Thus, given the small size of the aviation sector relative to the entire EU ETS market, the effects of aviation on allowance prices is likely to be quite small even with a conservatively high elasticity.

Based on the EU Directive of December 2006, an initial three percent of allowances are assumed to be auctioned, with the remainder allocated based on the average emissions for 2004-2006. This auction share is set to increase by 10 percent annually for the central case scenario, and this latter factor is adjusted to conduct sensitivity analyses.

The issue of the amount of the additional cost of emissions allowances that can be passed through to consumers is a very complex and sensitive question, and one for which previous studies have used widely varying values. Depending on the specific circumstances described, these values have varied for 0 to 100 percent. A qualitatively-determined median value of 70 percent was selected from the central scenario, with sensitivity analysis showing the importance of this parameter for passenger demand and, especially, airline operating profits.

The price of CO_2 emission allowances is set at 30 euros in the central case scenario. This is consistent with consensus estimates for prices in the 2012 time frame, although there is significant uncertainty further in the future as ETS rules for that period are still under development. Other studies conducted sensitivity analyses using values ranging from 6 to 60 euros.

Aviation greenhouse gas emissions from non- CO_2 sources are recognized as being a potentially very high contributor to radiative forcing. However, there is still significant uncertainty regarding this effect, and it has been tabled for future discussion with regard to aviation cap-and-trade frameworks. This effect is set at zero (i.e., a multiplier of 1.0 to CO_2 emissions) for the central case scenario, while a multiplier effect of 2.0 is most commonly cited as a likely value for this effect, and thus is used for sensitivity analysis.

The entry of the various markets and regions into aviation emissions cap-and-trade frameworks is a great uncertainty outside of the European Union. For the purposes illustrating the effects of such entry, a primary purpose of this study, the central case scenario uses 2016 as the year for Japan and the United States to implement a system similar to and linked with the EU ETS for aviation, and 2020 is used for China and the rest of the world. Effectively identical rules are assumed for all markets based on the current EU Directive.

Results

This section provides a description of the baseline forecast used for the modeling analysis. This baseline is indicative of the aviation economics, operations, and emissions that could be expected in the absence of any emissions cap-and-trade regime. However, the main focus of the section is on presenting the results of various scenarios that have been developed in order to illustrate the impacts of GHG cap-and-trade regimes, as it might be implemented in different forms.

Baseline forecast

Development of a baseline forecast was prepared using forecast data for aviation supply (ASK), demand (RPK), costs, fuel efficiency, and related key parameters. These data were derived from ICAO and IATA forecasts, SAGE, ICAOdata, and Eurostat trendlines, earlier studies of the EU ETS’ impacts on international aviation, and stand-alone studies of potential technology and fuel efficiency improvements. While these baseline forecasts are considered to be generally accurate, alternative forecasts are of course possible. Because the model and scenarios are formulated as differences from the baseline, adjustments to the baseline will have minimal effect on estimating what the effect of various cap-and-trade policies will be.

The baseline forecast revealed that current trends of improving aircraft fuel efficiency and load factors, as well as ATMS, airport operations and related advances will have significant impacts in reducing CO_2 emissions. Notably, from 2011 to 2025 in the baseline forecast, CO_2 emissions per passenger-km will fall by 17 percent.

Passenger aviation supply and demand, available seat-kilometers (ASK) and revenue passenger-kilometers (RPK), increase at the consensus ICAO and IATA long-term global average forecast rate of 4.4% annually (this rate varies by specific market and region), with load factors having stabilized at 75.5 percent by 2010. Aircraft fuel efficiency is projected to improve at the historic rate and consensus forecast of 1.3 percent annually.

Operating costs and yields per passenger-km will each fall by nearly 25 percent during this time frame, due to improved fuel efficiency, labor and asset productivity, higher load factors, and similar factors. As per ICAO (2006), because of their linkages and movement in a similar direction, “(i)t is therefore not possible to forecast the operating result with any reasonable degree of certainty.” While ICAO chose to place their baseline forecast for operating profit at 0.5 percent (“barring any unforeseen events”), this study has left the figure at the more historically consistent 0.0 percent since unforeseen events unfailingly do occur eventually.

Central scenario

The central scenario represents the phased-in implementation of aviation cap-and-trade in 2011/2012 for the EU, 2016 for Japan and the United States, and 2020 for China and the rest of the world. It also includes the same assumption as the baseline that there will be a phase-in of auctioning from 2011-2020, no multiplier representing non-CO_2 emissions, a middle position (relative to prior studies) regarding cost pass-through rates

(70 percent of auctioned allowance costs, no pass-through of opportunity costs), fuel economy and fuel price elasticities, and technology uptake rates. Overall, the central scenario represents a conservative estimate of the impact of a gradual, steady introduction of aviation cap-and-trade systems. This is not intended to imply that this is the most likely future scenario, but rather that it is a benchmark to judge other possibilities against.

At the global level, the effects of the central scenario cap-and-trade regimes include a discernible improvement in aircraft fuel efficiency (an additional 1.4 percent globally by 2025) and reduction in CO_2 emissions (3.5 percent annual average by 2025). Operating costs will increase on the order of one percent, with this being partially attained by increasing load factors, while fares and passenger demand remain essentially flat. Among other factors, this is one with a value that cycles over time as there are market dynamics from aircraft order booking delays, etc. regarding capacity that result in cyclical supply/demand mismatches. Thus, airline operating margins may fall in aggregate by approximately one-half of a percent, decreasing profitability, although the long-run ability to pass-through a greater portion of universal costs and/or opportunity costs (not explicitly modeled here) could well obviate this.

It should be noted that the model utilizes time-lagged responses for multiple parameters (for example, ASK or supply can respond significantly only over several years to changes in profits, costs and/or demand), while also attempting to reflect airlines' ability to foresee circumstances such as the imposition of the cap-and-trade regimes and predicted CO_2 prices. The results for some parameters thus show oscillating values as the model tries to converge on equilibriums under dynamic conditions. Rather than looking only at the final year results, many of the results should be viewed with a multi-year moving average or cumulative impact in mind, in order to reflect the order of magnitude of results. However, these fluctuations also help illustrate the uncertainty under which aviation markets operate, and the annual variation in parameters such as yields and profits that has historically occurred.

Central case scenario results for the European Union are quite consistent with the global results, with Europe naturally showing greater results more quickly, being the early adopter. However, the market dynamics and increased operating efficiencies (due to technology uptake, for example) result in less of an impact on operating costs and demand, and hence a slightly lower percentage CO_2 reduction in the far out years (i.e., 2025), even though the cumulative reductions over the time period are greater, as expected. Scenario results for Japan demonstrate the same phenomenon to an even greater extent. ATMS and other technology and operational advances are able to keep operating cost increases contained in the further out years, allowing reduced fares, additional demand growth, and nearly a four percent decrease in CO_2 emissions in the early 2020's. Central case scenario results for the United States show lesser percentage results than other regions, largely due to the greater size and share of its domestic market. Given that the greatest magnitude of these results occurs in the furthest out years, when there is the greatest uncertainty in both assumptions and model results, these post-2020 results should be viewed with appropriate caution.

Delayed Auctioning and Global Participation Scenario

This scenario illustrates the effects of the EU's having to "go it alone" somewhat longer in implementing an aviation cap-and-trade regime, and in all parties delaying the transition from emissions allocations to auctioning. As anticipated, this scenario's assumptions result in emissions reductions being both delayed and smaller than in the central scenario. One important issue to note is that decreases in capacity provided play a relatively larger role in total emissions reductions than do technological efficiency, for this scenario.

Non-CO_2 Multiplier, High Fuel Economy and Technology Sensitivity Scenario

This scenario represents a high global sensitivity to climate change issues, without substantial policy changes being implemented in aviation to further advance the issue. The one key policy decision that is included in the scenario is for non-CO_2 emissions to be incorporated at an assumed level equivalent to CO_2 emissions (i.e., CO_2 emissions are multiplied by two). The scenario models much higher airline sensitivity to the effects of emissions, and thus results in overall GHG reductions somewhat more than double those found under the central scenario. Further, because of the increased technology sensitivity, a greater proportion of the emissions reductions occur due to improved airline operating efficiencies rather than from supply reductions.

Maximum Early and Aggressive Implementation Scenario

An aggressive scenario in terms of both policy implementation and sensitivity assumptions shows dramatically higher reductions in CO_2 emissions without significant changes in airline profitability, passenger demand, or supply provided. It should be noted that most of these increased reductions are the result of greater scenario impacts through the middle years (e.g., 2016-2023) rather than a higher result in the model end year of 2025. Among the most important factors included in this scenario are earlier adoption of the cap-and-trade system (2014 for Japan and USA, 2016 for China and the rest of the world), a non-CO_2 multiplier of 2.0 applied to emissions, and a fuel efficiency elasticity of -0.4 (consistent with a long-term elasticity rather than the three-year lag used here).

This scenario shows a nearly four percent decrease in CO_2 emissions by 2017 and seven percent by 2020, leveling off thereafter. At the same time, the effects on profitability (less than a one percent decrease in margins), and passenger demand and supply (from a one to three percent decrease relative to the baseline) are not too dissimilar from the central case scenario.

These results indicate that while the effectiveness of a cap-and-trade system for aviation is somewhat uncertain, especially as the timing and location of impacts is attempted to be isolated, the policy consequences are not likely to be dire. The one caveat to this conclusion is that if the market for CO_2 emission allowances were to be particularly tight and/or near a price step or inflection point, there could be a significant effect on CO_2 emission allowance prices, having an impact both on the aviation and other sectors. Given that such cap-and-trade systems are extremely unlikely to be implemented without significant notice in a sophisticated market, this possibility is judged to be very small.

To examine data used in this analysis, see the tables in the appendix following the report.

Intensity Targets

Greenhouse gas intensity represents a measure of GHG emissions relative to another parameter; by far the most common is emissions per unit of economic output. At the national (or other governmental) level, GHG intensity is stated as tonnes per dollar of GDP, for manufacturers it is tonnes per unit sold or per sales dollars, for power generators it is tonnes per MWh, etc. In aviation logical intensity measures include tonnes per available ton-kilometer or per revenue ton-kilometer (the latter perhaps being preferable as it accounts for the load factor element of service efficiency and emissions efficiency).

The common rationale for an intensity target is that it reduces uncertainty regarding the cost of compliance with emissions reductions requirements. For example, airlines generally have a better ability to forecast what it will cost them to reduce emissions to 100 tonnes CO_2 per million revenue passenger-kilometers (RPK) (as this is largely based on the single parameter fuel efficiency of the aircraft fleet) than to forecast the cost to keep total emissions below five million tonnes (because this is largely based on both fuel efficiency and total passenger demand, which is harder to predict, meaning two variables must be accurately forecast).

A comparison of emissions reduction approaches may be summarized as:

- Carbon taxes – a tax regime sets the value of emissions reductions, letting the market work out what level of emissions reduction is optimal.
- Emissions caps – typically through a cap-and-trade regime, sets the level of emissions reduction, letting the market work out what the value of those reduction increments will be.
- Intensity targets - typically through a cap-and-trade regime, sets the level of

emissions efficiency, setting the level of emissions reduction for a given quantity of demand and allowing the market to set the cost of achieving this goal.

Most discussions in the aviation community have tended to focus on a cap-and-trade regime, largely because aviation fuels have by convention been exempted from fuel taxation. An absolute emissions cap is the dominant form of cap in current emissions trading, although there is a domestic intensity-based cap-and-trade system in the United Kingdom, and a similar system being advanced towards adoption in Canada.

A primary criticism of intensity targets is that they can allow absolute emissions to exceed desired levels. Because scientists can determine – at least to some degree – what level of GHG emissions reduction is needed to mitigate expected climate impacts, but individuals and companies have insufficient inter-generational perspective to determine what the value of those reductions should be, arguably, the cap-and-trade approach adopted by the European Commission is the most appropriate mechanism.

This argument has even been extended to allege that intensity-based caps are not as stringent as absolute caps. This perception has largely been due to some proposals, most notably the Bush Administration's announced GHG intensity targets, that indeed set goals that do little more than follow the existing emissions trendline. However, this same criticism could apply to an absolute cap that is laxly set to follow the trendline. If developed with equal stringency, both regimes will achieve comparable emissions reductions.

As intensity targets are based on output, the more reliable demand forecasts are, the more intensity targets can also effectively function as an absolute emissions cap. Typically, this holds true in the short run (perhaps five years or less), where the desired absolute emissions cap can be determined, but instead of using absolute emissions as the basis for the cap-and-trade regime, the absolute targets for each year are divided by the forecast output/demand (e.g., RPK) in order to determine the intensity targets for each year. As forecasts are likely to be less accurate over longer time horizons, actual emissions with an intensity target are more likely to vary further from the desired absolute emissions over longer time frames. However, they will also provide reduced cost uncertainty, as fluctuations in demand from forecasts will only have an impact on absolute emission caps.

As described above, one important advantage of intensity-based targets is that they reduce uncertainty about emissions costs, as only estimates of the cost to achieve the target of emissions per output is required. This implies that not only total emissions reductions costs, but the cost per unit of output are better known reducing price volatility per unit.

With absolute caps, exceeding a cap of 10 tonnes by one tonne results in an average price increase of 1/11 of the cost per tonne. Exceeding the cap by two results in an increase of 2/12 of the cost per tonne – nearly double the price increase for less than a 10 percent increase in emissions. To the extent that these emissions increases (or decreases) are due to demand changes, they do not reflect a firm's emissions reductions efforts. If the demand increases/decreases are due to exogenous factors (e.g., an improved or declining economy) a firm is penalized/rewarded for factors out of its control.

Even more problematic with absolute caps is the issue of reverse incentives for good or bad performance. Say that in a market with only two airlines, airline A improves its fuel efficiency by 10 percent, cutting not only its emissions but also passing on the cost savings in reduced fares. The competing airline B does not improve its fuel efficiency, resulting in no fare decreases. The more fuel efficient airline A would gain market share due to its reduced fares – we will illustratively use a 10 percent increase in its passengers and decrease in airline B's passengers. Airline A would also attract some new passengers – illustratively five percent – who did not previously fly in this market. Assuming in this example that the airlines adjust service levels proportional to demand changes, airline A's emissions will thus be five percent higher than before despite its fuel efficiency improvements. Airline A must purchase emissions allowances even though it has implemented GHG emissions reduction measures and been more efficient and successful by all other measures. Airline B is under its cap by 10 percent, and thus may sell a corresponding number of emissions allowances despite implementing no emissions reductions – a windfall that increases its margin per passenger even though its total revenue decreases. This argument holds for higher or lower changes in market share. For example, even if all of the demand changes were lower, both airlines may be able to receive allowances to sell, with airline B's allowances being the same if there is no induced demand, or greater than airline A's if there is induced demand. In any case, the margin per passenger is always high for airline B.

Intensity targets account for these shifts in demand, and thus avoid penalizing firms that have greater commercial success or providing windfalls to less successful firms. They also provide direct rewards to firms that implement emissions reductions measures, regardless of their commercial successes or failures. Intensity targets are thus advantageous in allowing firms (or countries) to grow without penalty and to avoid providing windfalls.

It should be noted however, that rebound effects or induced demand, can increase emissions beyond the levels envisioned if not accounted for in setting intensity targets. As mentioned above, aviation emissions reductions will almost entirely come from fuel efficiency improvements, some portion of which will be passed on to passengers in the form of lower fares. Airline price elasticities are high, generally exceeding 1.0 for leisure markets, and thus fare reductions will increase aggregate demand. Because intensity targets allow emissions to increase with demand, this results in higher emissions than projected by the baseline demand forecast times the intensity target. While this same induced demand phenomenon also exists with emissions reductions implemented to meet an absolute cap, there can be no increase in absolute emissions, and the induced demand must be addressed by additional efficiency improvements or the purchase of allowances. Thus, intensity-based targets will result in higher emissions than an absolute cap unless a different (higher) demand forecast is used to account for this phenomenon.

Because intensity targets allow growth, they are generally the preferred regime for developing countries. In order to decrease opposition to unilateral cap-and-trade regimes in aviation, such as that of the EU, an intensity-based regime would be preferable. Further, an intensity-based cap-and-trade system is more likely than an absolute cap to be implemented in additional aviation markets, especially in developing countries. If intensity targets have stringency equivalent to the desired absolute emissions targets, environmental concerns can be largely met.

In order to conduct trading with an intensity-based cap-and-trade regime, each organization’s emissions difference from the intensity target must be multiplied by its units of output, thus calculating an absolute number of tonnes to be purchased or sold. For example, if an airline provides 200 million RPK and has a target of 100 tonnes of CO_2 per million RPK, and achieves 90 tonnes/RPK, then it has earned a credit of 200 * (100-90) = 2000 tonnes of allowances that it may sell (or possibly bank). The reverse holds true with regard to exceeding targets and purchasing allowances.

An intensity-based cap-and-trade regime can be established within a single sector with little difficulty. However, it becomes more problematic to implement across sectors. One element is that while intensity targets reduce cost uncertainty within a sector, as the technology to achieve emissions reductions is likely to be relatively consistent across firms. Once the market is broader, however, the certainty element with regard to abatement costs becomes less relevant if they are higher than other sectors. In these cases, the market price for allowances will be less than the abatement costs, and will be the dispositive cost element, as well as being subject to fluctuation. This situation is the likely case for aviation. Nonetheless, the uncertainty reduction from the indexing to outputs is still an advantageous characteristic.

Trading across multiple sectors (as per EU ETS) with an intensity target in aviation, among other sectors, also may have more of a differential effect on firms than an absolute cap. Firms may serve in markets with inherently higher emissions intensities (due to flight distance, aircraft or slot constraints, etc.) and thus have a greater impact by an intensity target than firms not in these markets. With absolute caps allocated to firms, these characteristics are already taken into account as benchmarks are typically based on historical emissions. Of course, such differentiation may not be bad if, for example, it discourages very short flights that may have higher emissions intensity than competing transport modes.

Another concern for aviation with regard to intensity targets is the issue of the transferability of net allowances. Because international aviation is not within national emissions targets of the EU ETS, allowing it to send net emissions allowance to other sectors would increase the total permissible emissions, and thus is barred. Thus, it is generally accepted that aviation will be allowed to be a net purchaser of allowances from other sectors, but not a net seller. With an absolute cap, this is generally not considered an issue, as the rapid growth of the sector and its relatively high abatement costs imply that it will almost certainly be a net purchaser. With an intensity target, it is much more possible that the industry could reduce emissions below its intensity target, and thus have surplus allowances to sell. Banking of these allowances is one possibility, while another is insuring that the targets are consistent with the envisioned absolute cap (e.g., average 2004-06 emissions) to minimize this possibility.

3.4 CDM Project as a Measure for Developing Countries into ETS

3.4a ATM System Improvement as a CDM Project

Introduction

According to the examples of the measures taken by some countries, improvement of the Air Traffic Management (ATM) system is one of solutions to reduce air traffic congestion to meet air traffic demand, and to enable operators to fly on more efficient routes and more optimized altitudes while maintaining an adequate safety level. CO_2 emissions from aircraft flying in the airspace controlled by improved ATM system may be less than that in which the airspace in which ATM system is not improved.

This section will discuss whether ATM system improvement for the developing countries (or non-Annex 1 countries) could be registered as a Clean Development Mechanism (CDM) project under the Kyoto Protocols. Some major requirements to register a certain project as CDM project are as follows:

- The project must have real, measurable and long-term benefits related to the mitigation of climate change (measurable and long-term benefit);
- The project is an add-on to the current situation and reduces emissions more than would have occurred without the registered CDM project activity (additional reduction);
- The project contributes to the sustainable development for the host countries. (sustainability)

Discussion

Measurable and long-term benefits

- It is possible for each operator to measure amount of fuel consumption by using the on-board Digital Flight Data Recorder (DFDR) of each aircraft and to calculate total amount of CO_2 emissions, but those data are not open for public scrutiny and not regularly collected and examined in any organizations including IATA and ICAO so far. Therefore, baseline emissions and project emissions required for registration of

CDM project cannot be calculated.

- The main objectives of improving the ATM system are to increase airport or airspace capacity, to increase efficiency of flight, and/or to address noise and air quality issues from aircraft. In addition, reducing CO_2 emissions is a secondary objective so far. Therefore, capacity of airport and/or area to be improved by new ATM system may have been limited and constrained, and cannot afford to accept additional aircraft without improving the new ATM system and applying new standards for spacing or separation between aircraft or terrain for safety. Once a new ATM system is improved, additional aircraft flying in that airspace and landing in that airport will increase.
- Therefore, CO_2 emissions would be temporarily reduced because of more efficient operations and less fuel consumption for each flight compared with no project, but total amount of CO_2 emissions would increase in mid term or long term because air traffic demand in that area would increase as the airport or airspace capacity increases.

Additional reduction

- The effect of CO_2 emissions reduction per flight is achieved by improvement of ATM system. If the amount of air traffic does not increase, one can say that project is additional, but actually, the amount of air traffic is expected to increase in the future and ATM improvement project produces an increase in the capacity of an airport and/or airspace and the resulting in a CO_2 emissions increase.
- Therefore that project may not additional.

Sustainability

Host countries make a decision as to whether a project contributes to the sustainable development for the host countries or not. Projects well coordinated with host countries may contribute to the sustainable development for the host countries.

Conclusion

From the above discussion on the assumption that improvement of ATM system contributes to increase airport or airspace capacity, improvement of ATM system would temporarily reduce CO_2 emissions, but it might be a cause to increase CO_2 emissions in mid - or long - term and this scenario does not meet the condition to register as a CDM project.

If it is discussed on the assumption that primary objective of ATM System improvement is to reduce CO_2 emissions, different results may emerge. However, that discussion would be unrealistic.

3.4b Potential of GPU Introduction as a CDM Project

Introduction

In this section, CO_2 reduction achieved by introducing ground power units (hereinafter referred to as GPUs) will be evaluated. GPU is a system installed at airports to supply electric power and heated or cooled air to parked aircrafts. Previously, the power necessary for the maintenance or cleaning of parked aircraft or on-board air conditioning systems had been provided by power generated by auxiliary power units (APU) installed in the aircraft. However, the introduction of GPUs will not only improve the environment within the airport (by reducing noise and gas emissions) and cut the amount of kerosene used for APUs, but reductions in CO_2 emissions are also expected because they will use power supplied through specific systems with less CO_2 emission per power generation. This system is, therefore, regarded as a countermeasure against global warming. In many developed countries, GPUs are being introduced at many major airports exclusively for domestic flights, in addition to international airports. However, in developing countries, this system has yet to be introduced except at some major international airports. This section will, in particular, seek to establish whether a GPU introduction project can be established as the first clean development mechanism (CDM) in the aviation field.

There are four following reasons to select the GPU introduction project as a subject of evaluation as CDM:

High versatility

Because the introduction of GPUs is a project that affects the reduction of kerosene consumption of APU, it is also compatible with the EU-ETS, which focuses on the consumption of kerosene.

Short time frame required for introduction

It only takes six to twelve months to introduce a GPU system, including design and construction work. This period is considerably shorter when compared to other kerosene reduction projects, including aircraft replacements, reconsideration of routes, and mitigation of airport congestion.

Relatively small initial investment

Cost for GPU introduction-per-spot is less than 100 million yen in the case of Japan. The initial investment is smaller when compared to aircraft replacements, so it is easier to introduce.

Ease of management as CDM

There are four reasons why CO_2 reduction policies in the transportation field are difficult to gain approval for as CDM projects: they are difficult to manage because they cover mobile objects (difficulty in monitoring); the setting of baseline scenarios is difficult because traffic volume is contingent on other factors; its profitability is low due to the small amount of CO_2 reduction; and it is difficult to set boundaries because it deals with mobile objects. However, because GPU usage is limited to airports, it is quite easy to manage, even though it covers mobile objects, namely aircraft. As a result, the project will be free from two above-mentioned problems, namely the difficulties inherent in monitoring and setting boundaries. Also, as for predicting aviation demand, there is a clear limitation with regard to the upper limit of traffic volume for which aircraft landing and takeoff is possible (number of flights), contingent upon airport capacity and other factors. Furthermore, because many airports in both developing and developed countries are not completely privatized, the number of flights is controlled to a certain extent by the governments of the countries in which the airports in question are located. This situation is similar to that of airport maintenance plans. Therefore, it is considered that future predictions (baseline scenario) are easier to produce than with other modes of transportation. As a result, profitability remains one of the most important conditions in establishing GPU introduction as a CDM project.

However, one must consider the following issues when establishing the GPU introduction project as a CDM project:

Small scale of CO_2 reduction represented by GPU introduction

According to case studies in Japan, the percentage of fuel consumption by GPUs represents only about 2 percent of the total in international flight. Therefore, even if utilized to the fullest extent, it cannot be said to represent a definitive countermeasure against the trend of increasing kerosene consumption in line with increasing demand for air transportation.

Subject of project implementation

In reality, the results of reduction in kerosene consumption achieved with GPU introduction will be reaped by the airlines that own the aircraft in question. Therefore, while there will be no problem if the airline itself introduces GPUs, in the case where an airport introduces GPUs on its own, the entities investing in the GPU system will be different from those receiving the benefits therefrom. Thus, in the case where an airport is the introducing entity, a mechanism for transferring the CER (Certified Emission Reduction) obtained as CDM to the airline in one way or another is required.

At present, international airlines are exempted from CDM

CDM is not approved for aircraft used on international flights. In order to apply the effect of the GPU introduction project to international flights, a separate international mechanism will be necessary. One example of such cases is the introduction of a system to link CER and emission credits under EU-ETS.

Based on the above background information, the GPU introduction project is posited as a CO_2-reduction project in the aviation field, and will be evaluated as to whether it will be established as a CDM project, which is one of the existing economic mechanisms.

Effect of CO_2 Reduction

The effect of CO_2 reduction achieved by way of GPU use by different models of aircraft is evaluated here, based on the result of hearings at major international airports in Japan and literature research on past studies. We would like to explain the evaluation method by using B747-400 as an example.

Table 3.2: List of parameters for the evaluation of CO_2 emission reduction achieved through the introduction of GPUs

Aircraft	B747-400
APU	PW901A
APU fuel flow	863 lbs/h
GPU facility output	140 KVA
CO_2 emission unit	1.415 kg-CO_2/lbs
CO_2 emission unit for electricity grid	0.461 kg-CO_2/kWh

Table 3.2 shows variations used for the evaluation of the B747-400. The PW901A by Honneywell is frequently used as APU for the B747-400. Published figures pertaining to the latest fuel flow at Gatwick Airport is applied here for the fuel flow figure. This is similar to the actual figures collected through hearings on actual fuel flow figures for cases of heavy demand for electric power supply and air conditioning in Japan. GPU power consumption is estimated by referring to the averaged actual figure from Japan. In reality, electric power differs according to the size of air-conditioning facilities installed at airport and the existence of heat accumulation systems. Data for Tokyo, Japan is used for CO_2 emission basic unit for power supplied through a specific system. According to these data, the CO_2 emission reduction expected when GPU is used for B747-400 for one hour is estimated as 1,170 kg. The following models were evaluated as well using the same method. The result is shown in Table 3.3:

Table 3.3: CO_2 emission reduction achieved by using GPUs

B737-200	299 kg-CO_2/h
B767-200	346 kg-CO_2/h
B777 Series	707 kg-CO_2/h
A340	589 kg-CO_2/h
A320	278 kg-CO_2/h

Potential as CDM Project

The GPU introduction project was evaluated for its potential for establishment as a CDM project. As a basic scenario, the assumption is that GPUs are to be introduced in one spot, and aircraft of a consistent size land and takeoff from the point in question. In compliance with CDM criteria, it is assumed that the project period is ten years and that it will be profitable if the internal rate of return exceeds 10 percent. We also made a comparison of the case wherein the price of CO_2 reduced by GPU is considered and the case wherein it is not considered. The subject aircraft herein are B747-400 (large-size model), B767-200 (medium-size model) and B737 (small-size model).

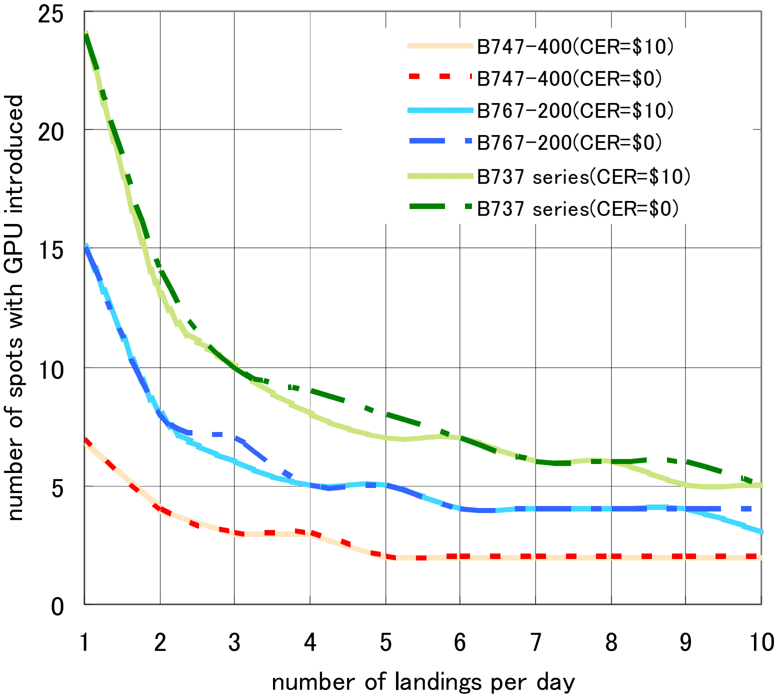
Table 3.4: List of parameters for the evaluation of potential as CDM project

Period of project	16 years
Residual ratio of depreciation	5%
Corporate tax rate	17%
CER allocation	95%
CER guaranteed purchase price	$ 10
Credit period	10 years
Total initial investment	$ 46,000
GPU usage rate	90%

CO_2 emission unit for electricity grid	0.9kg-CO_2/kWh
Kerosene unit price	$ 0.45
Annual cost for maintenance	$ 110,800
Annual cost for maintenance (per spot)	$ 23,700

Table 3.4 shows the set variations. Initial cost of GPU was estimated from hearings in Japan and a report on Zurich Airport. The price of emission credit under the current EU-ETS is used as reference material for setting the price of CO_2. The GPU usage fee was estimated based on usage fees in Japan obtained from hearings as a quoting price.

Figure 3.1: Borderline (IRR>10%) of GPU introduction project becoming a CDM project



The result is shown in Figure 3.1. The curves in this figure show the relationships between number of landings per day at one spot and number of spots with GPU introduced when the internal rate of return of this project is more than 10 percent, one of CDM criteria. As a result of the evaluation, in airports with many landing per day, it is considered that this is sufficiently profitable regardless of the plane size. Therefore, cases befitting introduction as CDM projects will be limited to airports with smaller numbers of landings and takeoffs, such as local airports. However, the curves with the carbon price (CER=$10) and without it (CER=$0) are same in most cases. When the price of CO_2 is taken into consideration, it is true that the profitability increases. However, in reality, internal rates of return actually do not constitute improvements of more than about two percent. As a result, it is indeed possible that such cases do not have potential for establishment as CDM projects in terms of additionality.

Conclusion

It became clear from these estimations that there is a possibility that GPU introduction projects may not be established as CDM projects from the perspective of additionality. However, this does not mean that the profitability of the GPU introduction project itself is insignificant. While results for simple cases only are shown in this section, it is considered that the profitability of GPU introduction projects will prove higher when considering increases in the size of aircraft using the spots in question or increases in aviation demand in the future. In particular, by considering a project period of 15 years, which is equivalent to the lifespan of a GPU, as opposed to ten years, the profitability will further increase. By considering all these factors, a GPU introduction project in reality constitutes something along the following lines, for example: airports first introduce GPU on their own and offer the use thereof to airlines; airports then establish GPU usage fees by projecting the size of CO_2 emission reductions and the price of CO_2, and establish this project as a business model by collecting such usage fees from airlines; and airlines will meet the domestic emission reduction requirements by incorporating said CO_2 emission reduction achieved through their usage of GPUs among their corporate achievements. As a result, although it may not represent a CDM project, it is considered that there is indeed potential that a GPU introduction project will be established as a CO_2 reduction project.

Chapter 4. Conclusion (Policy Options)

1. Need for Action

With increasing international aviation demand, CO_2 emissions from aircraft are expected to increase in the future. The IPCC projects that international air traffic, as measured by revenue passengers km, is expected to grow about five percent a year between 1990 and 2015. ICAO CAEP forecast an average of 4.3 percent annual growth in passenger km for the period 2000 – 2020. The share of CO_2 emissions from international aviation is currently very small. A 1999 IPCC Special Report states that "Aircraft emissions of carbon dioxide represent 2.4 percent of total fossil fuel emissions of carbon dioxide in 1992 or two percent of total anthropogenic carbon dioxide emissions."

However, it is expected to grow rapidly in the future. Even given efficiency gains, total aviation fuel usage is projected to increase by 3 percent per year between 1990 and 2015 according to the IPCC report. In the IPCC 2050 mid-range scenario, aviation carbon dioxide emissions would represent three percent of total anthropogenic carbon dioxide emissions.

Regarding the Emission Trading Scheme (ETS) for international aviation as a strategy against global warming, though currently ETS for international aviation is discussed in ICAO, common ETS guidelines are to be followed only if Contracting Parties agree to enact an ETS as being proposed by ICAO to be adopted at the 2007 Assembly. However, important basics of an ETS such as reduction targets have not been agreed to. It may take some time to reach agreement to enact an ETS between Contracting States.

Fuel-efficiency for aircraft has been improving as compared with the past, but it is not enough to offset the growth rate of CO_2 emissions from international aviation. In addition, reasonable alternative jet fuel to replace kerosene has not yet been developed and it will take some time for its research and development.

Attention should be paid to the fact that international aviation has functions such as intercontinental transportation, which are unable to be replaced by railway and maritime transportation; however, the amount of CO_2 emissions per passenger mile from international aviation is bigger than that from railway or maritime transportation.

Therefore, it is necessary for us to take practical measures for reducing CO_2 emissions from international aviation from now on and lead it to the right direction where sustainable growth for international aviation is secured.

2. Need to Take a Comprehensive Approach

Not only aircraft operators but also other entities such as manufacturers of aircraft and engines, air traffic service providers, and airport authorities are involved in CO_2 generation from international aviation. It is difficult to reduce CO_2 emissions from aircraft effectively without cooperation between all those entities. Therefore, a comprehensive approach emphasizing cooperation among all entities concerned is necessary.

Sharing the common knowledge on the amount of CO_2 emissions from aircraft, in particular, from international aviation in the future, is necessary for effective implementation of this comprehensive approach. If possible, under the auspices of ICAO, a common base year and target year (possibly the end of the period of Post Kyoto Protocol) should be decided. Based on the estimate of future CO_2 emissions from aircraft without additional measures for reduction, considering progress of research and development and measures to be taken in this field in the future, each state should voluntarily announce the CO_2 reduction targets for the target year from the common base year. Regarding setting numerical targets of CO_2 emissions, it is desirable that an emission unit which clearly reflects results of efforts made for CO_2 reduction, rather than emissions quota, is adopted because CO_2 emissions from aircraft operated on international routes will increase greatly, not decrease, no matter what measures are taken and it is more likely to be embraced by developing countries than other targets. A common roadmap which includes the measures to be taken by each entity toward the target year should be developed under the auspices of ICAO based on the voluntary CO_2 emissions reduction targets. And based on the technical progress, measures to be taken by each participating state or stakeholder concerned should be reviewed regularly. Each state should regularly report on the amount of the fuel used by the registered aircraft for international aviation to ICAO, ICAO should review these reports, and the results of the review as well as measures that have been taken by each state should be published. These measures will be the foundation to gauge the progress that aviation communities will make.

Measures described in the following should be discussed as measures to be included in the common roadmap.

(1) Research and Development (R&D)

For promoting development of more fuel efficient aircraft and engines, experts from aircraft manufactures, engine manufacturers and IATA are encouraged to discuss and set common targets for improving fuel efficiency. In this regard, ICAO's work to set a fuel efficiency target should be encouraged.

(2) Alternative fuel

ICAO is invited to follow up research on alternative fuel conducted by other bodies and give recommendations regarding the findings.

(3) Purchase of fuel efficient aircraft

- The aviation industry should consider greenhouse gas emissions reduction contribution from all aspects of aircraft operations, including slot allocations, which enhance fuel efficiency.
- Each state is invited to encourage its operators to introduce more efficient aircraft by any appropriate measures.
- ICAO should conduct a study on a method of aircraft recycling including a funding system to work effectively.

(4) Efficient flight operations

- ICAO and IATA should jointly investigate problems causing inefficient flight operations resulting from ATC thoroughly, make a recommendation on listed items to be improved, and make requests to ATC service providers through contracting states for these improvements.

- For discussion of expanding financial and technical support to the developing countries in the field of ATC, a Special Task Force should be established under the Air Navigation Planning and Implementation Regional Group of each ICAO region.
- The study group applauds ICAO's efforts to disseminate information about best practices employed in the industry and encourage the development of "excellence" checklists as a way of encouraging aircraft operators to adopt these best practices in their own operations.
- IATA´s initiative to foster best practices in fuel efficient operation should also be recognized.

(5) Introduction of environmental governance

- For promoting CO_2 reduction measures to be taken by information disclosure, guidelines for environmental information disclosure for aircraft operators, air traffic service providers, and airport authorities should be developed in ICAO.
- The amount of aircraft fuel consumption or amount of CO_2 emissions, which is not treated in current ICAO Statistics, should be reported from Contracting States. Regarding the data collected by ICAO, the process by company and route should be taken into account.

3. Emission Trading Scheme (ETS)

(1) Evaluation of ETS

An Emission Trading Scheme (ETS) is an efficient tool to internalize external diseconomies such as CO_2 emissions. Emissions abatement costs in aviation are quite high and much higher than in many other sectors. For the foreseeable future aviation will be depending on the current carbon based fuel. Since climate change and CO_2 reduction are global issues, the abatement of CO_2, where it is more cost efficient than in the aviation industry, can lead to absolute reduction of CO_2 while the demand for air service is maintained. Depending on manners of emissions allowance allocation, ETS may cause impartiality or impracticability among the participants concerned. But ETS gives a strong incentive that makes aircraft operators reduce CO_2 emissions from aircraft and, thereby, stimulate further efforts to promote measures suggested in Section 2. Studies in ICAO and the European Union (EU) have indicated that an ETS has the potential to control CO_2 emissions in a cost efficient way. According to the quantitative analysis of the effectiveness of ETS in Chapter 3.3, depending on the allocation and auctioning of emission allowances, there are some effects to reduce CO_2 emissions although the impact on aircraft operators is small and reasonable. Therefore, introduction of ETS should be elaborated.

(2) Evaluation of incorporating international aviation into EU-ETS

The current proposal to incorporate international aviation into EU-ETS has some problems such as:

- regarding geographic scope, to apply that scheme without agreement of the states concerned may have extraterritorial consequences;
- in the absence of a global target, each state may end up setting different CO_2 emissions reduction targets in international aviation. The EU's proposed target may come in conflict with other targets without coordination.

Therefore, the current proposal needs further consultations with other countries before taking effect.

(3) The study group's proposal

When international aviation is incorporated into an ETS, the ETS should be, in our view, based on the following principles:

- the system should be based on agreements of the states concerned and that covers the major nations with large number of fleets;
- the ICAO guidance should be referenced for basic system design.

However, there were two opposing views in the study group as to how to approach emissions from aircraft operated by airlines of developing countries, reflecting different principles under two different sets of international rules and different interpretations as to which principle should override the other.

- The United Nations Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol accept to share a common goal but different responsibilities between developed countries and developing countries to allow developing countries to attain sustainable growth. This different responsibilities principle should be followed in addressing greenhouse gas emissions from international air aviation, because an ETS for international aviation as one of measures for CO_2 emissions reduction would be designed and implemented as a part of a legal framework set by the UNFCC and Kyoto Protocol. Therefore, if developing countries agree to take part in an ETS, common but differentiated responsibilities between aircraft operators belonging to developing countries and developed countries should be pursued.

- The UNFCCC and Kyoto Protocol recognize that international aviation is special and could not be treated in the same way as other sectors. ICAO was asked to study the method of addressing greenhouse gas emissions from international aviation. Therefore, it is reasonable to build an ETS rule based on the concepts that ICAO has espoused. Under the Chicago Convention, international aviation has been ruled by common standards and reciprocal exchange of traffic rights so that airlines of developing countries and developed countries compete with each other under the same conditions. Therefore, all aircraft operators should be treated equally.

But on the other hand, the study group agreed that in order for an ETS to be effective, the ETS should be designed in a way to cover as many aircraft as possible, including those operated by airlines of developing countries. In order to introduce an ETS with as many participating nations as possible, it is proposed that researchers examine a two-step approach, bearing in mind that any international arrangement addressing greenhouse gas emissions from international aviation will be implemented in the post Kyoto Protocol period. The first step is to set a globally common target for emissions intensity (for example, CO_2 emission per available ton kilo-meter) since an emissions intensity target allows growth while it achieves reduction of CO_2 emissions relative to

> the level under the business-as-usual scenario, and it is more acceptable to developing countries than a cap in absolute numbers. Then in the second step, an ETS with an emissions intensity cap will be introduced based on mutual agreement. There are still many questions that need to be answered with this type of an ETS, such as what the impact of the intensity-capped ETS is on CO_2 emissions reduction, how to design a trading of credits with an intensity cap, and how to link with emissions markets with absolute level caps.

At the same time, the study group encourages the development of mechanisms to promote capacity building in developing countries for emissions trading. This should include capacity building related to monitoring, enforcement, and the operations of emissions trading systems. Beyond this, a voluntary CO_2 emissions trading pilot program involving airlines of developing countries should be considered as a means of developing capacity and know how.

Appendix

Detail of Data Analysis from Chapter 3.3

Results Table 1: Central Scenario – Global Results

Global Results

Key Assumptions:	
CO_2 cost (Euros)	30
Fuel cost elast wrt fuel demand	0.7
% Auctioned 2011	3%
Increase auction % per year	10%
CO_2 cost % pass thru	70%
Demand elasticity wrt fares	-1.1
Non-CO_2 multiplier	1.0
Baseline annual fuel econ improve	1.3%
Fuel econ elast wrt fuel price	-0.2
Supply (ASK) elast wrt profit	0.8
Fixed costs per ASK	65%

Region enters cap-and-trade system:	
China	2020
European Union	2011
Japan	2016
Rest of world	2020
United States	2016

ATC, ATMS & Operations		
Start Year	2008	
Full implementation, in years	25	
Uptake elasticity wrt fuel cost	1.0	
Effectiveness	20%	
China	150%	Penetration time relative to world average
European Union	80%	
Japan	65%	
Rest of world	200%	
United States	80%	
Cross-check should = 100%	100.0%	

Baseline

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	6,380,662	5.31	€ 0.0704	€ 0.0704	4,817,400	524,995
2012	6,664,862	5.24	€ 0.0690	€ 0.0690	5,031,971	541,293
2013	6,962,777	5.17	€ 0.0676	€ 0.0676	5,256,897	558,180
2014	7,275,113	5.11	€ 0.0663	€ 0.0663	5,492,711	575,680
2015	7,602,614	5.04	€ 0.0649	€ 0.0649	5,739,974	593,816
2016	7,946,064	4.97	€ 0.0636	€ 0.0636	5,999,278	612,615
2017	8,306,289	4.91	€ 0.0624	€ 0.0624	6,271,248	632,103
2018	8,684,160	4.85	€ 0.0611	€ 0.0611	6,556,540	652,308
2019	9,080,596	4.78	€ 0.0599	€ 0.0599	6,855,850	673,259
2020	9,496,566	4.72	€ 0.0587	€ 0.0587	7,169,907	694,985
2021	9,933,093	4.66	€ 0.0575	€ 0.0575	7,499,485	717,519
2022	10,391,254	4.60	€ 0.0564	€ 0.0564	7,845,397	740,893
2023	10,872,186	4.54	€ 0.0552	€ 0.0552	8,208,501	765,141
2024	11,377,090	4.48	€ 0.0541	€ 0.0541	8,589,703	790,299
2025	11,907,231	4.42	€ 0.0531	€ 0.0531	8,989,959	816,405

Scenario

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	6,380,662	5.31	€ 0.0704	€ 0.0704	4,817,330	524,995
2012	6,664,834	5.24	€ 0.0690	€ 0.0690	5,029,467	541,288
2013	6,961,736	5.17	€ 0.0677	€ 0.0677	5,250,210	558,046
2014	7,271,527	5.11	€ 0.0664	€ 0.0664	5,480,708	575,248
2015	7,594,556	5.04	€ 0.0651	€ 0.0651	5,722,327	592,884
2016	7,931,455	4.97	€ 0.0640	€ 0.0639	5,964,777	610,966
2017	8,278,427	4.90	€ 0.0628	€ 0.0627	6,221,220	628,943
2018	8,638,589	4.83	€ 0.0617	€ 0.0616	6,495,045	647,237
2019	9,014,529	4.76	€ 0.0605	€ 0.0604	6,787,540	666,000
2020	9,408,888	4.70	€ 0.0596	€ 0.0594	7,062,834	685,383
2021	9,808,784	4.63	€ 0.0585	€ 0.0583	7,363,367	703,755
2022	10,226,609	4.56	€ 0.0574	€ 0.0571	7,703,817	722,826
2023	10,670,099	4.49	€ 0.0561	€ 0.0559	8,081,119	743,061
2024	11,145,345	4.43	€ 0.0548	€ 0.0546	8,489,001	764,816
2025	11,656,066	4.36	€ 0.0536	€ 0.0534	8,918,841	788,256

Percent Change

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	0.00%	0.00%	0.00%	0.00%	-0.00%	0.00%
2012	-0.00%	-0.00%	0.05%	0.03%	-0.05%	-0.00%
2013	-0.01%	-0.01%	0.11%	0.09%	-0.13%	-0.02%
2014	-0.05%	-0.03%	0.19%	0.15%	-0.22%	-0.08%
2015	-0.11%	-0.05%	0.26%	0.21%	-0.31%	-0.16%
2016	-0.18%	-0.09%	0.57%	0.43%	-0.58%	-0.27%
2017	-0.34%	-0.18%	0.78%	0.61%	-0.80%	-0.50%
2018	-0.52%	-0.28%	0.93%	0.73%	-0.94%	-0.78%
2019	-0.73%	-0.38%	1.01%	0.78%	-1.00%	-1.08%
2020	-0.92%	-0.50%	1.55%	1.14%	-1.49%	-1.38%
2021	-1.25%	-0.71%	1.79%	1.35%	-1.82%	-1.92%
2022	-1.58%	-0.90%	1.74%	1.31%	-1.80%	-2.44%
2023	-1.86%	-1.07%	1.54%	1.11%	-1.55%	-2.89%
2024	-2.04%	-1.22%	1.27%	0.83%	-1.17%	-3.22%
2025	-2.11%	-1.37%	1.03%	0.58%	-0.79%	-3.45%

Results Table 2: Central Scenario – European Union Results

Europe Results

Key Assumptions:	
CO_2 cost (Euros)	30
Fuel cost elast wrt fuel demand	0.7
% Auctioned 2011	3%
Increase auction % per year	10%
CO_2 cost % pass thru	70%
Demand elasticity wrt fares	-1.1
Non-CO_2 multiplier	1.0
Baseline annual fuel econ improve	1.3%
Fuel econ elast wrt fuel price	-0.2
Supply (ASK) elast wrt profit	0.8
Fixed costs per ASK	65%

Region enters cap-and-trade system:	
China	2020
European Union	2011
Japan	2016
Rest of world	2020
United States	2016

ATC, ATMS & Operations		
Start Year	2008	
Full implementation, in years	25	
Uptake elasticity wrt fuel cost	1.0	
Effectiveness	20%	
China	150%	Penetration time relative to world average
European Union	80%	
Japan	65%	
Rest of world	200%	
United States	80%	
Cross-check should = 100%	100.0%	

Baseline

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	1,589,395	5.65	€ 0.0706	€ 0.0706	1,199,993	131,784
2012	1,659,388	5.58	€ 0.0692	€ 0.0692	1,252,838	135,800
2013	1,732,511	5.51	€ 0.0678	€ 0.0678	1,308,046	139,942
2014	1,808,904	5.44	€ 0.0664	€ 0.0664	1,365,723	144,215
2015	1,888,718	5.37	€ 0.0651	€ 0.0651	1,425,982	148,622
2016	1,972,108	5.30	€ 0.0638	€ 0.0638	1,488,942	153,168
2017	2,059,236	5.23	€ 0.0625	€ 0.0625	1,554,723	157,858
2018	2,150,273	5.16	€ 0.0613	€ 0.0613	1,623,456	162,695
2019	2,245,397	5.09	€ 0.0600	€ 0.0600	1,695,275	167,686
2020	2,344,795	5.03	€ 0.0588	€ 0.0588	1,770,320	172,834
2021	2,448,660	4.96	€ 0.0577	€ 0.0577	1,848,739	178,146
2022	2,557,199	4.90	€ 0.0565	€ 0.0565	1,930,685	183,626
2023	2,670,624	4.83	€ 0.0554	€ 0.0554	2,016,321	189,280
2024	2,789,158	4.77	€ 0.0543	€ 0.0543	2,105,814	195,114
2025	2,913,036	4.71	€ 0.0532	€ 0.0532	2,199,342	201,133

Scenario

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	1,589,395	5.65	€ 0.0706	€ 0.0706	1,199,924	131,784
2012	1,659,360	5.58	€ 0.0693	€ 0.0692	1,251,384	135,795
2013	1,731,897	5.51	€ 0.0680	€ 0.0679	1,304,208	139,860
2014	1,806,834	5.43	€ 0.0668	€ 0.0667	1,358,847	143,958
2015	1,884,091	5.36	€ 0.0656	€ 0.0655	1,415,865	148,071
2016	1,963,732	5.28	€ 0.0644	€ 0.0643	1,475,853	152,195
2017	2,046,000	5.21	€ 0.0632	€ 0.0630	1,539,321	156,341
2018	2,131,807	5.14	€ 0.0620	€ 0.0618	1,606,451	160,597
2019	2,221,801	5.06	€ 0.0608	€ 0.0606	1,676,904	164,997
2020	2,316,405	4.99	€ 0.0596	€ 0.0594	1,750,117	169,559
2021	2,415,689	4.92	€ 0.0585	€ 0.0582	1,826,477	174,273
2022	2,519,752	4.85	€ 0.0573	€ 0.0571	1,907,943	179,145
2023	2,629,290	4.78	€ 0.0561	€ 0.0559	1,993,956	184,254
2024	2,744,601	4.71	€ 0.0550	€ 0.0547	2,083,821	189,612
2025	2,865,890	4.64	€ 0.0539	€ 0.0536	2,176,986	195,229

Percent Change

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	0.00%	0.00%	0.01%	0.01%	-0.01%	0.00%
2012	-0.00%	-0.00%	0.13%	0.10%	-0.12%	-0.00%
2013	-0.04%	-0.02%	0.31%	0.24%	-0.29%	-0.06%
2014	-0.11%	-0.07%	0.52%	0.41%	-0.50%	-0.18%
2015	-0.25%	-0.13%	0.73%	0.58%	-0.71%	-0.37%
2016	-0.42%	-0.22%	0.91%	0.72%	-0.88%	-0.64%
2017	-0.64%	-0.33%	1.04%	0.81%	-0.99%	-0.96%
2018	-0.86%	-0.44%	1.14%	0.86%	-1.05%	-1.29%
2019	-1.05%	-0.57%	1.22%	0.89%	-1.08%	-1.60%
2020	-1.21%	-0.70%	1.33%	0.94%	-1.14%	-1.89%
2021	-1.35%	-0.85%	1.42%	0.98%	-1.20%	-2.17%
2022	-1.46%	-1.00%	1.41%	0.96%	-1.18%	-2.44%
2023	-1.55%	-1.14%	1.36%	0.90%	-1.11%	-2.66%
2024	-1.60%	-1.26%	1.32%	0.84%	-1.04%	-2.82%
2025	-1.62%	-1.35%	1.31%	0.82%	-1.02%	-2.94%

Results Table 3: Central Scenario – Japan Results

Japan Results

Key Assumptions:	
CO_2 cost (Euros)	30
Fuel cost elast wrt fuel demand	0.7
% Auctioned 2011	3%
Increase auction % per year	10%
CO_2 cost % pass thru	70%
Demand elasticity wrt fares	-1.1
Non-CO_2 multiplier	1.0
Baseline annual fuel econ improve	1.3%
Fuel econ elast wrt fuel price	-0.2
Supply (ASK) elast wrt profit	0.8
Fixed costs per ASK	65%

Region enters cap-and-trade system:	
China	2020
European Union	2011
Japan	2016
Rest of world	2020
United States	2016

ATC, ATMS & Operations		
Start Year	2008	
Full implementation, in years	25	
Uptake elasticity wrt fuel cost	1.0	
Effectiveness	20%	
China	150%	Penetration time relative to world average
European Union	80%	
Japan	65%	
Rest of world	200%	
United States	80%	
Cross-check should = 100%	100.0%	

Baseline

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	333,405	7.70	€ 0.0645	€ 0.0645	251,721	28,287
2012	352,139	7.60	€ 0.0632	€ 0.0632	265,865	29,481
2013	371,941	7.50	€ 0.0619	€ 0.0619	280,816	30,726
2014	392,874	7.40	€ 0.0607	€ 0.0607	296,620	32,026
2015	415,003	7.31	€ 0.0595	€ 0.0595	313,327	33,382
2016	438,397	7.21	€ 0.0583	€ 0.0583	330,990	34,797
2017	463,130	7.12	€ 0.0571	€ 0.0571	349,663	36,273
2018	489,280	7.02	€ 0.0560	€ 0.0560	369,406	37,814
2019	516,928	6.93	€ 0.0548	€ 0.0548	390,281	39,422
2020	546,163	6.84	€ 0.0537	€ 0.0537	412,353	41,100
2021	577,077	6.75	€ 0.0527	€ 0.0527	435,693	42,852
2022	609,766	6.67	€ 0.0516	€ 0.0516	460,374	44,679
2023	644,336	6.58	€ 0.0506	€ 0.0506	486,474	46,587
2024	680,895	6.49	€ 0.0496	€ 0.0496	514,076	48,579
2025	719,560	6.41	€ 0.0486	€ 0.0486	543,268	50,657

Scenario

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	333,405	7.70	€ 0.0645	€ 0.0645	251,721	28,287
2012	352,139	7.60	€ 0.0632	€ 0.0632	265,797	29,481
2013	371,913	7.50	€ 0.0619	€ 0.0619	280,632	30,723
2014	392,774	7.40	€ 0.0607	€ 0.0607	296,289	32,015
2015	414,777	7.30	€ 0.0595	€ 0.0595	312,841	33,357
2016	437,987	7.21	€ 0.0589	€ 0.0587	327,676	34,753
2017	461,361	7.10	€ 0.0581	€ 0.0579	343,554	36,067
2018	485,212	7.00	€ 0.0572	€ 0.0570	361,172	37,361
2019	509,845	6.89	€ 0.0562	€ 0.0559	380,934	38,656
2020	535,663	6.79	€ 0.0550	€ 0.0548	403,012	39,979
2021	563,095	6.68	€ 0.0538	€ 0.0535	427,609	41,358
2022	593,847	6.58	€ 0.0524	€ 0.0521	454,757	42,973
2023	628,124	6.49	€ 0.0512	€ 0.0509	482,979	44,792
2024	665,690	6.40	€ 0.0501	€ 0.0498	511,194	46,786
2025	705,855	6.31	€ 0.0492	€ 0.0489	538,979	48,896

Percent Change

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2012	0.00%	0.00%	0.02%	0.02%	-0.03%	0.00%
2013	-0.01%	-0.00%	0.05%	0.04%	-0.07%	-0.01%
2014	-0.03%	-0.01%	0.09%	0.07%	-0.11%	-0.04%
2015	-0.05%	-0.02%	0.12%	0.09%	-0.16%	-0.07%
2016	-0.09%	-0.04%	1.13%	0.81%	-1.00%	-0.13%
2017	-0.38%	-0.19%	1.82%	1.44%	-1.75%	-0.57%
2018	-0.83%	-0.38%	2.29%	1.85%	-2.23%	-1.20%
2019	-1.37%	-0.58%	2.48%	2.00%	-2.39%	-1.94%
2020	-1.92%	-0.82%	2.43%	1.90%	-2.27%	-2.73%
2021	-2.42%	-1.08%	2.12%	1.55%	-1.86%	-3.49%
2022	-2.61%	-1.23%	1.59%	1.02%	-1.22%	-3.82%
2023	-2.52%	-1.35%	1.19%	0.59%	-0.72%	-3.85%
2024	-2.23%	-1.46%	1.09%	0.44%	-0.56%	-3.69%
2025	-1.90%	-1.57%	1.31%	0.61%	-0.79%	-3.48%

Results Table 4: Central Scenario – United States Results

USA Results

Key Assumptions:	
CO_2 cost (Euros)	30
Fuel cost elast wrt fuel demand	0.7
% Auctioned 2011	3%
Increase auction % per year	10%
CO_2 cost % pass thru	70%
Demand elasticity wrt fares	-1.1
Non-CO_2 multiplier	1.0
Baseline annual fuel econ improve	1.3%
Fuel econ elast wrt fuel price	-0.2
Supply (ASK) elast wrt profit	0.8
Fixed costs per ASK	65%

Region enters cap-and-trade system:	
China	2020
European Union	2011
Japan	2016
Rest of world	2020
United States	2016

ATC, ATMS & Operations		
Start Year	2008	
Full implementation, in years	25	
Uptake elasticity wrt fuel cost	1.0	
Effectiveness	20%	
China	150%	Penetration time relative to world average
European Union	80%	
Japan	65%	
Rest of world	200%	
United States	80%	
Cross-check should = 100%	100.0%	

Baseline

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	2,131,180	4.35	€ 0.0775	€ 0.0775	1,609,041	171,633
2012	2,197,890	4.30	€ 0.0759	€ 0.0759	1,659,407	174,717
2013	2,266,826	4.24	€ 0.0744	€ 0.0744	1,711,453	177,868
2014	2,338,067	4.19	€ 0.0729	€ 0.0729	1,765,241	181,086
2015	2,411,696	4.13	€ 0.0714	€ 0.0714	1,820,830	184,375
2016	2,487,798	4.08	€ 0.0700	€ 0.0700	1,878,288	187,734
2017	2,566,462	4.02	€ 0.0686	€ 0.0686	1,937,679	191,168
2018	2,647,781	3.97	€ 0.0672	€ 0.0672	1,999,075	194,676
2019	2,731,849	3.92	€ 0.0659	€ 0.0659	2,062,546	198,262
2020	2,818,767	3.87	€ 0.0646	€ 0.0646	2,128,169	201,926
2021	2,908,638	3.82	€ 0.0633	€ 0.0633	2,196,021	205,672
2022	3,001,567	3.77	€ 0.0620	€ 0.0620	2,266,183	209,501
2023	3,097,668	3.72	€ 0.0608	€ 0.0608	2,338,739	213,416
2024	3,197,055	3.67	€ 0.0596	€ 0.0596	2,413,777	217,418
2025	3,299,848	3.62	€ 0.0584	€ 0.0584	2,491,386	221,510

Scenario

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	2,131,180	4.35	€ 0.0775	€ 0.0775	1,609,041	171,633
2012	2,197,890	4.30	€ 0.0759	€ 0.0759	1,659,109	174,717
2013	2,266,707	4.24	€ 0.0744	€ 0.0744	1,710,649	177,854
2014	2,337,647	4.19	€ 0.0729	€ 0.0729	1,763,801	181,039
2015	2,410,749	4.13	€ 0.0715	€ 0.0715	1,818,726	184,272
2016	2,486,085	4.08	€ 0.0703	€ 0.0702	1,870,018	187,553
2017	2,561,548	4.02	€ 0.0691	€ 0.0690	1,923,519	190,601
2018	2,637,845	3.96	€ 0.0678	€ 0.0677	1,980,512	193,560
2019	2,715,562	3.91	€ 0.0665	€ 0.0664	2,041,597	196,474
2020	2,795,414	3.85	€ 0.0652	€ 0.0651	2,106,898	199,390
2021	2,878,095	3.80	€ 0.0639	€ 0.0637	2,176,773	202,350
2022	2,966,767	3.74	€ 0.0625	€ 0.0623	2,251,519	205,706
2023	3,061,748	3.69	€ 0.0611	€ 0.0610	2,328,291	209,387
2024	3,162,555	3.64	€ 0.0599	€ 0.0597	2,404,988	213,339
2025	3,267,931	3.59	€ 0.0587	€ 0.0585	2,480,657	217,461

Percent Change

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
2012	0.00%	0.00%	0.01%	0.01%	-0.02%	0.00%
2013	-0.01%	-0.00%	0.03%	0.02%	-0.05%	-0.01%
2014	-0.02%	-0.01%	0.05%	0.04%	-0.08%	-0.03%
2015	-0.04%	-0.02%	0.07%	0.06%	-0.12%	-0.06%
2016	-0.07%	-0.04%	0.43%	0.31%	-0.44%	-0.10%
2017	-0.19%	-0.12%	0.68%	0.54%	-0.73%	-0.30%
2018	-0.38%	-0.22%	0.86%	0.70%	-0.93%	-0.57%
2019	-0.60%	-0.34%	0.96%	0.77%	-1.02%	-0.90%
2020	-0.83%	-0.46%	0.97%	0.75%	-1.00%	-1.26%
2021	-1.05%	-0.61%	0.89%	0.65%	-0.88%	-1.62%
2022	-1.16%	-0.70%	0.71%	0.47%	-0.65%	-1.81%
2023	-1.16%	-0.78%	0.56%	0.31%	-0.45%	-1.89%
2024	-1.08%	-0.85%	0.50%	0.24%	-0.36%	-1.88%
2025	-0.97%	-0.92%	0.56%	0.28%	-0.43%	-1.83%

Results Table 5: Delayed Auctioning and Global Participation – Global Results

Global Results

Key Assumptions:	
CO_2 cost (Euros)	30
Fuel cost elast wrt fuel demand	0.7
% Auctioned 2011	3%
Increase auction % per year	5%
CO_2 cost % pass thru	70%
Demand elasticity wrt fares	-1.1
Non-CO_2 multiplier	1.0
Baseline annual fuel econ improve	1.3%
Fuel econ elast wrt fuel price	-0.2
Supply (ASK) elast wrt profit	0.8
Fixed costs per ASK	65%

Region enters cap-and-trade system:	
China	2026
European Union	2011
Japan	2020
Rest of world	2026
United States	2020

ATC, ATMS & Operations		
Start Year	2008	
Full implementation, in years	25	
Uptake elasticity wrt fuel cost	1.0	
Effectiveness	20%	
China	150%	Penetration time relative to world average
European Union	80%	
Japan	65%	
Rest of world	200%	
United States	80%	
Cross-check should = 100%	100.0%	

Baseline

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	6,380,662	5.31	€ 0.0704	€ 0.0704	4,817,400	524,995
2012	6,664,862	5.24	€ 0.0690	€ 0.0690	5,031,971	541,293
2013	6,962,777	5.17	€ 0.0676	€ 0.0676	5,256,897	558,180
2014	7,275,113	5.11	€ 0.0663	€ 0.0663	5,492,711	575,680
2015	7,602,614	5.04	€ 0.0649	€ 0.0649	5,739,974	593,816
2016	7,946,064	4.97	€ 0.0636	€ 0.0636	5,999,278	612,615
2017	8,306,289	4.91	€ 0.0624	€ 0.0624	6,271,248	632,103
2018	8,684,160	4.85	€ 0.0611	€ 0.0611	6,556,540	652,308
2019	9,080,596	4.78	€ 0.0599	€ 0.0599	6,855,850	673,259
2020	9,496,566	4.72	€ 0.0587	€ 0.0587	7,169,907	694,985
2021	9,933,093	4.66	€ 0.0575	€ 0.0575	7,499,485	717,519
2022	10,391,254	4.60	€ 0.0564	€ 0.0564	7,845,397	740,893
2023	10,872,186	4.54	€ 0.0552	€ 0.0552	8,208,501	765,141
2024	11,377,090	4.48	€ 0.0541	€ 0.0541	8,589,703	790,299
2025	11,907,231	4.42	€ 0.0531	€ 0.0531	8,989,959	816,405

Scenario

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	6,380,662	5.31	€ 0.0704	€ 0.0704	4,817,330	524,995
2012	6,664,834	5.24	€ 0.0690	€ 0.0690	5,030,412	541,288
2013	6,962,120	5.17	€ 0.0677	€ 0.0676	5,253,029	558,095
2014	7,272,991	5.11	€ 0.0663	€ 0.0663	5,486,074	575,424
2015	7,598,024	5.04	€ 0.0650	€ 0.0650	5,730,521	593,286
2016	7,937,961	4.97	€ 0.0637	€ 0.0637	5,987,356	611,700
2017	8,293,734	4.91	€ 0.0625	€ 0.0625	6,257,492	630,703
2018	8,666,997	4.84	€ 0.0612	€ 0.0612	6,541,538	650,409
2019	9,059,016	4.78	€ 0.0600	€ 0.0600	6,839,643	670,860
2020	9,470,877	4.71	€ 0.0590	€ 0.0589	7,135,437	692,092
2021	9,896,708	4.65	€ 0.0579	€ 0.0578	7,447,677	713,340
2022	10,339,126	4.58	€ 0.0569	€ 0.0567	7,780,414	735,007
2023	10,800,332	4.52	€ 0.0557	€ 0.0556	8,136,076	757,214
2024	11,283,080	4.46	€ 0.0546	€ 0.0545	8,515,944	780,116
2025	11,790,440	4.39	€ 0.0535	€ 0.0534	8,919,937	803,872

Percent Change

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	0.00%	0.00%	0.00%	0.00%	-0.00%	0.00%
2012	-0.00%	-0.00%	0.03%	0.02%	-0.03%	-0.00%
2013	-0.01%	-0.01%	0.07%	0.05%	-0.07%	-0.02%
2014	-0.03%	-0.02%	0.10%	0.08%	-0.12%	-0.04%
2015	-0.06%	-0.03%	0.14%	0.11%	-0.16%	-0.09%
2016	-0.10%	-0.05%	0.17%	0.14%	-0.20%	-0.15%
2017	-0.15%	-0.08%	0.19%	0.15%	-0.22%	-0.22%
2018	-0.20%	-0.10%	0.21%	0.16%	-0.23%	-0.29%
2019	-0.24%	-0.13%	0.22%	0.16%	-0.24%	-0.36%
2020	-0.27%	-0.16%	0.53%	0.37%	-0.48%	-0.42%
2021	-0.37%	-0.23%	0.73%	0.55%	-0.69%	-0.58%
2022	-0.50%	-0.32%	0.86%	0.66%	-0.83%	-0.79%
2023	-0.66%	-0.41%	0.91%	0.70%	-0.88%	-1.04%
2024	-0.83%	-0.51%	0.90%	0.67%	-0.86%	-1.29%
2025	-0.98%	-0.61%	0.85%	0.60%	-0.78%	-1.54%

Results Table 6: Non-CO2 Multiplier, High Fuel Economy and Technology Sensitivity – Global Results

Global Results

Key Assumptions:	
CO$_2$ cost (Euros)	30
Fuel cost elast wrt fuel demand	0.7
% Auctioned 2011	3%
Increase auction % per year	10%
CO$_2$ cost % pass thru	70%
Demand elasticity wrt fares	-1.1
Non-CO$_2$ multiplier	2.0
Baseline annual fuel econ improve	1.3%
Fuel econ elast wrt fuel price	-0.3
Supply (ASK) elast wrt profit	0.8
Fixed costs per ASK	65%

Region enters cap-and-trade system:	
China	2020
European Union	2011
Japan	2016
Rest of world	2020
United States	2016

ATC, ATMS & Operations		
Start Year	2008	
Full implementation, in years	25	
Uptake elasticity wrt fuel cost	2.0	
Effectiveness	20%	
China	150%	Penetration time relative to world average
European Union	80%	
Japan	65%	
Rest of world	200%	
United States	80%	
Cross-check should = 100%	100.0%	

Baseline

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	6,380,662	5.31	€ 0.0704	€ 0.0704	4,817,400	524,995
2012	6,664,862	5.24	€ 0.0690	€ 0.0690	5,031,971	541,293
2013	6,962,777	5.17	€ 0.0676	€ 0.0676	5,256,897	558,180
2014	7,275,113	5.11	€ 0.0663	€ 0.0663	5,492,711	575,680
2015	7,602,614	5.04	€ 0.0649	€ 0.0649	5,739,974	593,816
2016	7,946,064	4.97	€ 0.0636	€ 0.0636	5,999,278	612,615
2017	8,306,289	4.91	€ 0.0624	€ 0.0624	6,271,248	632,103
2018	8,684,160	4.85	€ 0.0611	€ 0.0611	6,556,540	652,308
2019	9,080,596	4.78	€ 0.0599	€ 0.0599	6,855,850	673,259
2020	9,496,566	4.72	€ 0.0587	€ 0.0587	7,169,907	694,985
2021	9,933,093	4.66	€ 0.0575	€ 0.0575	7,499,485	717,519
2022	10,391,254	4.60	€ 0.0564	€ 0.0564	7,845,397	740,893
2023	10,872,186	4.54	€ 0.0552	€ 0.0552	8,208,501	765,141
2024	11,377,090	4.48	€ 0.0541	€ 0.0541	8,589,703	790,299
2025	11,907,231	4.42	€ 0.0531	€ 0.0531	8,989,959	816,405

Scenario

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	6,380,662	5.31	€ 0.0704	€ 0.0704	4,817,260	524,995
2012	6,664,806	5.24	€ 0.0691	€ 0.0690	5,026,968	541,281
2013	6,960,696	5.17	€ 0.0678	€ 0.0677	5,243,657	557,861
2014	7,268,001	5.10	€ 0.0665	€ 0.0665	5,469,225	574,675
2015	7,586,774	5.03	€ 0.0653	€ 0.0652	5,705,964	591,679
2016	7,917,650	4.96	€ 0.0643	€ 0.0642	5,932,826	608,879
2017	8,252,413	4.88	€ 0.0633	€ 0.0631	6,176,322	624,934
2018	8,596,972	4.81	€ 0.0622	€ 0.0619	6,442,437	640,919
2019	8,955,967	4.73	€ 0.0610	€ 0.0607	6,732,921	657,134
2020	9,334,001	4.65	€ 0.0604	€ 0.0599	6,975,121	673,857
2021	9,704,551	4.56	€ 0.0594	€ 0.0589	7,254,295	687,165
2022	10,092,127	4.48	€ 0.0581	€ 0.0577	7,595,052	701,344
2023	10,509,883	4.40	€ 0.0567	€ 0.0563	7,990,818	717,122
2024	10,967,831	4.32	€ 0.0552	€ 0.0548	8,430,047	735,060
2025	11,471,770	4.25	€ 0.0539	€ 0.0535	8,893,833	755,365

Percent Change

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	0.00%	0.00%	0.00%	0.00%	-0.00%	0.00%
2012	-0.00%	-0.00%	0.10%	0.07%	-0.10%	-0.00%
2013	-0.03%	-0.03%	0.22%	0.17%	-0.25%	-0.06%
2014	-0.10%	-0.08%	0.37%	0.29%	-0.43%	-0.17%
2015	-0.21%	-0.16%	0.51%	0.40%	-0.59%	-0.36%
2016	-0.36%	-0.27%	1.10%	0.82%	-1.11%	-0.61%
2017	-0.65%	-0.53%	1.48%	1.17%	-1.51%	-1.13%
2018	-1.00%	-0.81%	1.73%	1.36%	-1.74%	-1.75%
2019	-1.37%	-1.13%	1.83%	1.42%	-1.79%	-2.39%
2020	-1.71%	-1.47%	2.83%	2.07%	-2.72%	-3.04%
2021	-2.30%	-2.09%	3.21%	2.41%	-3.27%	-4.23%
2022	-2.88%	-2.62%	3.05%	2.29%	-3.19%	-5.34%
2023	-3.33%	-3.11%	2.60%	1.86%	-2.65%	-6.28%
2024	-3.60%	-3.56%	2.04%	1.30%	-1.86%	-6.99%
2025	-3.66%	-3.97%	1.54%	0.79%	-1.07%	-7.48%

Results Table 7: Maximum Early and Aggressive Implementation – Global Results

Global Results

Key Assumptions:	
CO_2 cost (Euros)	30
Fuel cost elast wrt fuel demand	0.7
% Auctioned 2011	3%
Increase auction % per year	25%
CO_2 cost % pass thru	70%
Demand elasticity wrt fares	-1.1
Non-CO_2 multiplier	2.0
Baseline annual fuel econ improve	1.3%
Fuel econ elast wrt fuel price	-0.4
Supply (ASK) elast wrt profit	0.8
Fixed costs per ASK	65%

Region enters cap-and-trade system:	
China	2016
European Union	2011
Japan	2014
Rest of world	2016
United States	2014

ATC, ATMS & Operations		
Start Year	2008	
Full implementation, in years	25	
Uptake elasticity wrt fuel cost	2.0	
Effectiveness	20%	
China	150%	Penetration time relative to world average
European Union	80%	
Japan	65%	
Rest of world	200%	
United States	80%	
Cross-check should = 100%	100.0%	

Baseline

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	6,380,662	5.31	€ 0.0704	€ 0.0704	4,817,400	524,995
2012	6,664,862	5.24	€ 0.0690	€ 0.0690	5,031,971	541,293
2013	6,962,777	5.17	€ 0.0676	€ 0.0676	5,256,897	558,180
2014	7,275,113	5.11	€ 0.0663	€ 0.0663	5,492,711	575,680
2015	7,602,614	5.04	€ 0.0649	€ 0.0649	5,739,974	593,816
2016	7,946,064	4.97	€ 0.0636	€ 0.0636	5,999,278	612,615
2017	8,306,289	4.91	€ 0.0624	€ 0.0624	6,271,248	632,103
2018	8,684,160	4.85	€ 0.0611	€ 0.0611	6,556,540	652,308
2019	9,080,596	4.78	€ 0.0599	€ 0.0599	6,855,850	673,259
2020	9,496,566	4.72	€ 0.0587	€ 0.0587	7,169,907	694,985
2021	9,933,093	4.66	€ 0.0575	€ 0.0575	7,499,485	717,519
2022	10,391,254	4.60	€ 0.0564	€ 0.0564	7,845,397	740,893
2023	10,872,186	4.54	€ 0.0552	€ 0.0552	8,208,501	765,141
2024	11,377,090	4.48	€ 0.0541	€ 0.0541	8,589,703	790,299
2025	11,907,231	4.42	€ 0.0531	€ 0.0531	8,989,959	816,405

Scenario

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	6,380,662	5.31	€ 0.0704	€ 0.0704	4,817,260	524,995
2012	6,664,806	5.24	€ 0.0691	€ 0.0691	5,021,303	541,279
2013	6,958,393	5.17	€ 0.0680	€ 0.0679	5,227,271	557,403
2014	7,259,457	5.09	€ 0.0672	€ 0.0670	5,412,654	573,135
2015	7,556,385	5.00	€ 0.0663	€ 0.0660	5,610,127	586,424
2016	7,852,216	4.91	€ 0.0656	€ 0.0652	5,805,913	598,251
2017	8,140,363	4.81	€ 0.0643	€ 0.0639	6,064,726	607,064
2018	8,446,627	4.71	€ 0.0626	€ 0.0623	6,387,778	617,027
2019	8,789,973	4.61	€ 0.0608	€ 0.0605	6,759,697	629,460
2020	9,194,661	4.54	€ 0.0591	€ 0.0588	7,150,233	647,066
2021	9,659,198	4.46	€ 0.0577	€ 0.0574	7,526,204	668,457
2022	10,182,984	4.40	€ 0.0566	€ 0.0563	7,861,112	694,423
2023	10,726,742	4.33	€ 0.0559	€ 0.0555	8,151,531	719,859
2024	11,257,558	4.25	€ 0.0553	€ 0.0549	8,424,534	742,625
2025	11,756,224	4.18	€ 0.0546	€ 0.0542	8,720,636	761,905

Percent Change

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	0.00%	0.00%	0.00%	0.00%	-0.00%	0.00%
2012	-0.00%	-0.00%	0.21%	0.15%	-0.21%	-0.00%
2013	-0.06%	-0.08%	0.50%	0.38%	-0.56%	-0.14%
2014	-0.22%	-0.25%	1.44%	1.08%	-1.46%	-0.44%
2015	-0.61%	-0.70%	2.15%	1.71%	-2.26%	-1.24%
2016	-1.18%	-1.28%	3.11%	2.46%	-3.22%	-2.34%
2017	-2.00%	-2.13%	3.10%	2.52%	-3.29%	-3.96%
2018	-2.74%	-2.88%	2.49%	1.98%	-2.57%	-5.41%
2019	-3.20%	-3.54%	1.56%	1.08%	-1.40%	-6.51%
2020	-3.18%	-3.93%	0.71%	0.22%	-0.27%	-6.90%
2021	-2.76%	-4.25%	0.28%	-0.27%	0.36%	-6.84%
2022	-2.00%	-4.40%	0.48%	-0.16%	0.20%	-6.27%
2023	-1.34%	-4.69%	1.20%	0.49%	-0.69%	-5.92%
2024	-1.05%	-5.08%	2.13%	1.39%	-1.92%	-6.03%
2025	-1.27%	-5.52%	2.91%	2.18%	-3.00%	-6.68%

Results Table 8: Maximum Early and Aggressive Implementation – European Union Results

Europe Results

Key Assumptions:	
CO_2 cost (Euros)	30
Fuel cost elast wrt fuel demand	0.7
% Auctioned 2011	3%
Increase auction % per year	25%
CO_2 cost % pass thru	70%
Demand elasticity wrt fares	-1.1
Non-CO_2 multiplier	2.0
Baseline annual fuel econ improve	1.3%
Fuel econ elast wrt fuel price	-0.4
Supply (ASK) elast wrt profit	0.8
Fixed costs per ASK	65%

Region enters cap-and-trade system:	
China	2016
European Union	2011
Japan	2014
Rest of world	2016
United States	2014

ATC, ATMS & Operations		
Start Year	2008	
Full implementation, in years	25	
Uptake elasticity wrt fuel cost	2.0	
Effectiveness	20%	
China	150%	Penetration time relative to world average
European Union	80%	
Japan	65%	
Rest of world	200%	
United States	80%	
Cross-check should = 100%	100.0%	

Baseline

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	1,589,395	5.65	€ 0.0706	€ 0.0706	1,199,993	131,784
2012	1,659,388	5.58	€ 0.0692	€ 0.0692	1,252,838	135,800
2013	1,732,511	5.51	€ 0.0678	€ 0.0678	1,308,046	139,942
2014	1,808,904	5.44	€ 0.0664	€ 0.0664	1,365,723	144,215
2015	1,888,718	5.37	€ 0.0651	€ 0.0651	1,425,982	148,622
2016	1,972,108	5.30	€ 0.0638	€ 0.0638	1,488,942	153,168
2017	2,059,236	5.23	€ 0.0625	€ 0.0625	1,554,723	157,858
2018	2,150,273	5.16	€ 0.0613	€ 0.0613	1,623,456	162,695
2019	2,245,397	5.09	€ 0.0600	€ 0.0600	1,695,275	167,686
2020	2,344,795	5.03	€ 0.0588	€ 0.0588	1,770,320	172,834
2021	2,448,660	4.96	€ 0.0577	€ 0.0577	1,848,739	178,146
2022	2,557,199	4.90	€ 0.0565	€ 0.0565	1,930,685	183,626
2023	2,670,624	4.83	€ 0.0554	€ 0.0554	2,016,321	189,280
2024	2,789,158	4.77	€ 0.0543	€ 0.0543	2,105,814	195,114
2025	2,913,036	4.71	€ 0.0532	€ 0.0532	2,199,342	201,133

Scenario

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	1,589,395	5.65	€ 0.0706	€ 0.0706	1,199,854	131,784
2012	1,659,332	5.58	€ 0.0696	€ 0.0694	1,246,691	135,786
2013	1,729,970	5.50	€ 0.0687	€ 0.0685	1,291,063	139,470
2014	1,799,915	5.40	€ 0.0680	€ 0.0676	1,335,124	142,687
2015	1,868,418	5.30	€ 0.0671	€ 0.0667	1,382,714	145,345
2016	1,936,011	5.19	€ 0.0657	€ 0.0654	1,444,166	147,507
2017	2,007,023	5.09	€ 0.0640	€ 0.0637	1,519,919	149,789
2018	2,087,584	4.99	€ 0.0621	€ 0.0618	1,605,826	152,890
2019	2,181,360	4.91	€ 0.0604	€ 0.0601	1,694,212	157,039
2020	2,289,040	4.83	€ 0.0590	€ 0.0587	1,777,339	162,222
2021	2,407,673	4.76	€ 0.0580	€ 0.0576	1,850,476	168,122
2022	2,528,910	4.68	€ 0.0573	€ 0.0569	1,914,762	173,777
2023	2,645,843	4.60	€ 0.0566	€ 0.0562	1,976,626	178,729
2024	2,755,160	4.52	€ 0.0559	€ 0.0555	2,044,769	182,881
2025	2,858,590	4.44	€ 0.0550	€ 0.0546	2,127,301	186,518

Percent Change

	ASK (million)	Avg. Fuel Econ (kg/km)	Op Costs (Euro/RPK)	Fares (Euro/RPK)	Pax Demand (million RPK)	CO2 (tonnes 000's)
2011	0.00%	0.00%	0.02%	0.01%	-0.01%	0.00%
2012	-0.00%	-0.00%	0.57%	0.40%	-0.49%	-0.01%
2013	-0.15%	-0.19%	1.39%	1.06%	-1.30%	-0.34%
2014	-0.50%	-0.58%	2.31%	1.82%	-2.24%	-1.06%
2015	-1.07%	-1.18%	3.08%	2.47%	-3.03%	-2.20%
2016	-1.83%	-1.95%	3.00%	2.45%	-3.01%	-3.70%
2017	-2.54%	-2.71%	2.33%	1.84%	-2.24%	-5.11%
2018	-2.92%	-3.27%	1.38%	0.92%	-1.09%	-6.03%
2019	-2.85%	-3.65%	0.58%	0.09%	-0.06%	-6.35%
2020	-2.38%	-3.89%	0.26%	-0.30%	0.40%	-6.14%
2021	-1.67%	-4.05%	0.56%	-0.09%	0.09%	-5.63%
2022	-1.11%	-4.35%	1.34%	0.62%	-0.82%	-5.36%
2023	-0.93%	-4.75%	2.27%	1.53%	-1.97%	-5.57%
2024	-1.22%	-5.20%	3.02%	2.28%	-2.90%	-6.27%
2025	-1.87%	-5.60%	3.32%	2.62%	-3.28%	-7.27%