High Speed Transport and Climate Change – a new Challenge

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Abstract

Air traffic has become the fastest growing segment of transport. Since 1950 use of commercial aviation has grown more than seventy-fold. Prospective analyses indicate that this trend is likely to continue. According to a special report on aviation by the IPCC [IPCC, 1999] in 1992 the related emissions accounted for only about 3.5% of the total climate impact of all anthropogenic emissions.

However, in 2020 Swiss international air traffic's share on total anthropogenic green house gas (GHG) emissions up to a third of the total Swiss anthropogenic GHG emissions. The terrorist attacks in 2001 make an adjustment of the existing growth scenarios necessary. Starting with a sharp decline in 2001, air traffic will recover and may even grow stronger than originally predicted to finally achieve an average yearly growth of 3,5% between 2001 and 2005. The results presented in this paper indicate that the expected growth of air traffic may to a great extend offset the positive impacts of the Swiss climate protection scheme (CO_2-bill).

Table of Contents :

1. Introduction

1.1 Growth of Worldwide Air Traffic

Airplanes allows travelers to reach almost any spot on this planet within a day's time. Traveling by air has become not only the fastest, but also one of the cheapest ways of traveling. Fast progress in technology, low energy costs and international tax exemption have made this extraordinary development possible.

Air traffic has become the fastest growing segment of transport in developed countries. According to the International Air Transport Association (IATA), commercial aviation has grown more than seventy-fold since the first jet airliner took off in 1949. In 1998 airlines worldwide had a total fleet of about 18,000 aircraft operating over a route network of approximately 15 million kilometers and serving nearly 10,000 airports. More than 1,600 million passengers were carried by the world's airlines and over 29 million tones of freight were transported by air, representing approximately 40% (by value) of the world's manufactured exports.

1.2 Impact on Environment and Climate

But air traffic has had an increasingly negative impact on the environment. In spite of substantial efforts undertaken by aircraft industry and carriers to improve airplane technology, aviation's share of the worldwide fuel consumption for transport reached about 12% by the end of the twentieth century. However, according to the Special Report on "Aviation and the Global Atmosphere" issued by the International Panel on Climate Change (IPCC) [IPCC, 1999], the related emissions in 1998 accounted only for about 3.5% of the total climate impact of all anthropogenic emissions. This seemingly low share was one of the reasons to exclude international air traffic from the Kyoto Protocol.

However, we get quite a different picture when we look at the relevance of aviation in a highly developed country like Switzerland. A study in the framework of the Swiss National Research Program "Traffic and Environment" [NFP41-M25, 2000] which interpreted Swiss air traffic statistics in 1998 came to the conclusion that the emissions from air traffic are already responsible for about 13% of the total anthropogenic CO_2 emissions in Switzerland. By 2020, this share might rise to 20%.

The climate impact of all greenhouse gas (GHG) emissions of aircraft might be even higher. According to the above-mentioned report on "Aviation and the Global Atmosphere" by the IPCC, the impact of all GHG emissions from air traffic at high altitudes might have a considerably higher impact on the climate than similar emissions on ground level. Considering this increased impact, air traffic could already make up to about 18% of climate impact of GHG emissions in Switzerland. In a business-as-usual scenario, aviation's share of the total climate impact may rise to almost a third within the next 20 years. Chapter 3.3 presents these figures in detail.

1.3 Air Travel - victim of its own success?

The challenge that air travel represents for climate change is also taken into account by the project "Sustainable Mobility", a member project of the Word Business Council of Sustainable Development and the MIT Technology and Policy program. On its homepage (www.wbcsdmobility.org) it recently published an article under the title "Rising to the carbon challenge" (22 February 2002). The article concludes among other aspects the following:

"The second Grand Challenge to be addressed by the Sustainable Mobility Project goes beyond the auto industry, which is the focus of the first Challenge" and "Other transport modes present an even bigger challenge, especially air travel. Hydrogen fuel or renewable energy such as solar can be conceived of for surface vehicles. But there is little prospect for the use of alternative fuels in air transportation even on a 2030 time horizon. In any case, it is not just carbon dioxide emissions from aircraft that create concerns. The IPCC (International Panel on Climate Change) has identified other emissions, such as condensation trails from jet engines, as potentially worrisome, although their impact is not yet well understood."

"Air travel is a victim of its own success; if air travel grows at the rate projected, its emissions will become an even bigger issue."

1.4 Implications worldwide and for Switzerland

This paper summarizes the implications of the growth of air traffic implies for greenhouse gases emissions both worldwide and in Switzerland. Special attention is paid to the CO_2 of the Swiss Climate Protection Scheme (CO_2- bill) and the potential consequences of continuous growth of aviation. The CO_2 reduction target of Switzerland is to reduce emissions by 10% in 2010 compared to 1990. The paper shows that even if Switzerland achieves to fulfil the reduction target, the expected increase of CO_2- emissions of the international air traffic may to a great extent counterbalance the positive impact of the broad range of measures taken to reach the reduction goal.

The paper also gives an overview on the possible measures to reduce the relevance of air traffic to the climate. Apart from potential technical innovations to increase the efficiency of aviation, measures to compensate the emissions, to decrease the demand for air traffic as well as measures to shift the demand to other means of highspeed transport are in discussion. Here, one interesting option is the potential of new, energy-efficient High Speed Transport systems as the proposed "Eurometro" to replace short- and mid-range air transport.

2 The worldwide View: a potential Challenge

2.1 Growth Estimates

2.1.1 Growth Rate Scenarios

Air traffic is one of the fastest growing industries worldwide. Between 1970 and 2000, the total worldwide Revenue Passenger Kilometres (RPK) increased nearly six-fold to reach around 3,2 trillion km. [IPCC, 1999] During that period, the annual growth rate of demand was at 7,3% on average. Projections of the future development are inherently uncertain, and the larger we choose the period of prediction, the wider gets the range of uncertainty.
IPCC has compiled a set of scenario resulting from different sources to predict future demand in air traffic. (Summaries adopted from [IPCC, 1999])

- **FESG:** The Forecasting and Economic Support Group of ICAO developed the long-term traffic scenarios Fa, Fc and Fe. Most of the considered traffic demand incorporated a market maturity concept. Under this concept, historical traffic growth rates in excess of economic growth are considered unlikely to continue indefinitely, and traffic growth will eventually approach a rate equal to GDP growth as the various global markets approached maturity.
- **DTI:** The DTI projection for air traffic and emissions for 2050 (Newton and Falk, 1997) has been developed from the DTI traffic and fleet forecast demand model, in conjunction with data from the ANCAT/EC2 inventory.
- **EDF:** has produced projections of total traffic demand, fuel use, and emissions through 2100 (Vedantham and Oppenheimer, 1994, 1998). The EDF projections use a logistic model to simulate the stages of demand growth in aviation markets, focusing particularly on demand growth in developing countries (where aviation has only recently become a commonplace travel mode). Two sets of aviation demand scenarios—base level and high-level—describe traffic under each of the six IPCC 1992 scenarios (IS92a through IS92f) for global

expectations of gross national product (GNP), population, and emissions (Leggett et al., 1992). Data produced are regional and global totals.

- **MIT:** This study constructed scenarios based on the simple yet powerful assumption that time spent and share of expenditures on travel remain constant (Zahavi, 1981), on average, over time and across regions of the globe (Schafer and Victor, 1997). The aviation portion of high-speed travel is not explicitly characterized. Results of this model projection therefore cannot be used directly in evaluations of the effect of aviation on the atmosphere, nor can they be directly compared to other long-term projections of emissions from aviation. However, up to now only in Japan trains supply a substantial part of highspeed traffic.

	Fa	**Fc**	**Fe**	**DTI**	**Eab**	**Edh**	**MIT**	
Description	Reference Scenario developed by ICAO Forecasting and Economic Support Group (FESG)	FESG low-growth scenario	FESG high-growth scenario	DTI traffic and fleet forecast (excl. Military)	Environmental Defense Fund Scenario, base-level	Environmental Defense Fund Scenario, high-level	MIT study of long-term future mobility	
Projected RPK 2020 (10^12)	6,55	5,07	8,30		7,73	13,63	12,97	
Projected RPK 2050 (10^12)	13,93	7,82	21,98	18,1	23,26	33,66	37,49	total demand for high-speed-transport
Ratio of Demand (2000-2050)	4,35	2,44	6,87	5,66	7,27	10,52	11,71	
Projected CO_2-Emissions 2050 (Gt)	1,37	0,82	2,15	1,98	3,19	4,47	-	
Ratio of CO_2-Emissions (2000-2050)	2,19	1,31	3,45	3,19	5,13	7,17	-	
Reduction of specific fuel burn	49,7%	46,4%	49,7%	45,6%	29,5%	31,8%	-	

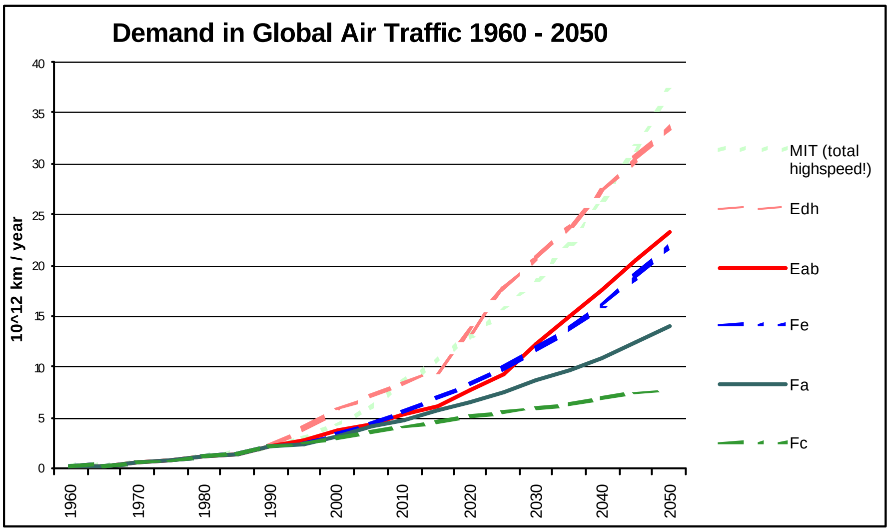
Table 1: Different air traffic growth scenario
RPK = Revenue Passenger Kilometres

Table 1 provides an overview of the mentioned scenario. For this paper, Fa and Eab will be used as reference scenario, whereas Edh represents a high growth scenario.

2.1.2 Projections of demand

Several factors play a crucial role in the future development of air traffic. On the one hand, demand in highspeed transportation depends on the growth rate of the GDP and the growth rate of population. On the other hand, maturity of markets will eventually set limits to the development of demand. The question, to what extent and how quickly developing countries will catch up with the industrialized countries in terms of demand for highspeed transportation is hereby very important. (See 2.1.4 for further considerations). Finally, other external barriers as well as unexpected events like the terrorist attacks on the US may have an additional impact on the demand for air traffic. (See 2.1.3 for further discussion). All these factors bear an inherent uncertainty.
Figure 1 presents the mentioned scenarios.

Fig 1 : Growth Scenario 1960 – 2050
The different Scenarios are characterized in Table 1. The Reference Scenario by the IPCC and ICAO is Fa. However, demand projections of most airplane manufacturers follow more or less Scenario Eab.



In 1970, 551 billion kilometres (RPK) were flown worldwide. In 2000, this figure 2000 was already at around 3,2 trillion [Boeing 2001]. The predictions of the considered scenarios range between a 2,4-fold and a 10,5-fold increase of demand by 2050. FESG scenarios assume that in the future, growth rates of air traffic are unlikely to further exceed world economic growth rates (as was always the case in past years!). The differences between Fc through Fe are therefore mainly a consequence of different predictions of population and GDP growth. EDF focuses on developing countries in particular. EDF's analysis of the history of the U.S. domestic market concluded that there was approximately a 70-year period from start of market expansion to maturity. Therefore, the growth of demand is expected to flatten only in the second half of the century.
The MIT scenario cannot be directly compared to the others, as it includes the total demand in highspeed transport, rather than growth of air traffic only. [Schaefer and Victor, 1998] Moreover, it is questionable whether its method remains valid if applied over a period of 60 years. The share of the demand for highspeed-transport, which will finally still be covered by air traffic, depends also on the implementation of the next generation of (maglev-) trains.

2.1.3 Crisis 2001 – Impact on Air Traffic Demand

After the terrorist attacks in the United States on September 11th, 2001, all carriers suffered severe declines in demand. Three months after the attacks, IATA forecasted a worldwide net loss of USD 7 billion due to cancelled or poorly loaded flights [IATA, 2001]. The question arises, whether scenarios that have been produced before the disaster are still of any significance.
During the Gulf War 1991 the number of passengers transported by aircrafts temporary dropped by about 20%. It took four years for that figure to reach pre-war level again. Recent projections by IATA indicate that after September 11th, too, global air traffic will recover within 3-4 years, under the condition that no further unexpected events occur [IATA, 2002]. Key findings of its 'Passenger Forecast 2001-2005, Special Interim Edition' are:

- The route areas where the five year forecasts average annual growth rate (AAGR) has significantly been downgraded from IATA's original September forecast are: Transatlantic, Transpacific and Europe to the Middle East. These are also the markets to demonstrate the strongest recovery from 2003 onwards.
- The Intra-European route area, the largest of the international passenger markets, is estimated to achieve an AAGR of over 4% over the period 2001-2005, with low-cost carriers continuing to stimulate demand.

- The AAGR for total scheduled international passengers is 3.5%, down from 4.7% in the original 2001 forecast. This growth is made up of a clear decline in 2001, stabilisation in 2002, and then recovery from 2003 onwards. On this projection the annual number of passengers on international scheduled services is estimated to reach 637 million by 2005.

Fig 2 : Demand for Air Traffic before and after September 11th
According to new IATA forecast air traffic will further recover after September 11th, 2001 and finally achieve an average growth of about 3.5% between 2001 and 2005.

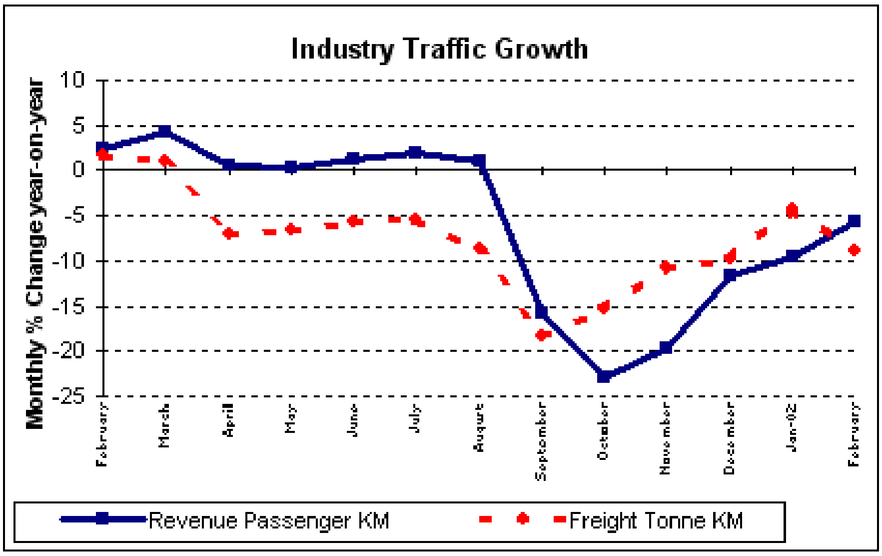
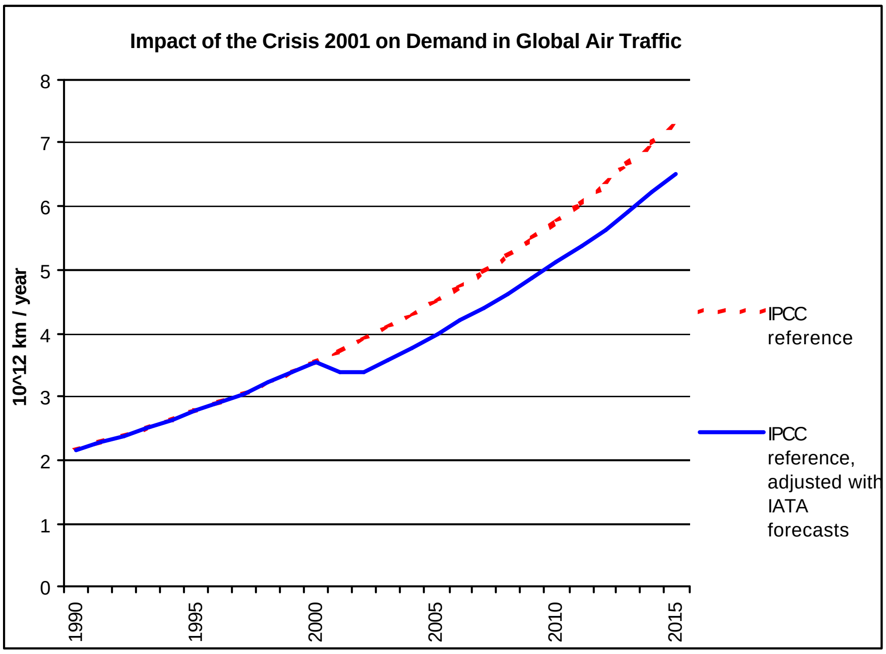


Figure 2 shows monthly %-changes in traffic growth on a year-on-year basis. If the observed trend continues, at least zero-growth can be expected by the middle of 2002. According to IATA, the regions that suffered most from the decline, will later also show strongest recovery rates. Therefore, as a first approach, in this paper all "adjusted" growth scenario take the IATA forecast into account, no matter for which region a scenario is applied. Starting with a sharp decline in 2001, air traffic will recover and even grow stronger than predicted originally and will finally achieve an average growth of 3,5% per year between 2001 and 2005.
Figure 3 shows the impact of the revised IATA forecast on the IPCC Fa1 scenario. Apparently, original scenario must be adjusted with a time lag of 3 to 4 years.

Fig 3 : Impact of the crisis 2001 on the IPCC reference scenario. *IATA forecasts a time lag of 3 to 4 years for the scenarios to materialize.*



IATA-Forecast	
2001	-4,7%
2002	0,0%
2003	5,8%
2004	5,8%
2005	5,8%

Table 2 : adjusted worldwide growth of global RPK

2.1.4 From Low- to Highspeed: Projections for Different World Regions

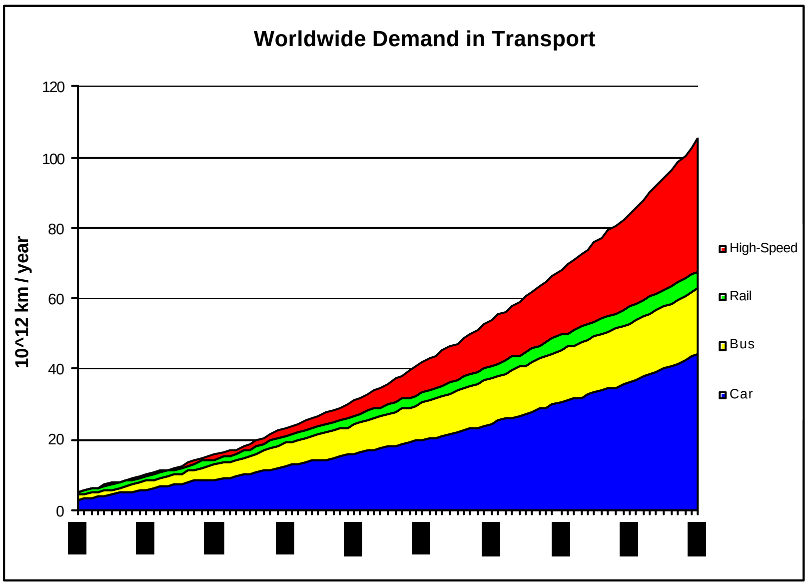
Estimates for growth of air traffic vary between the various routes flown in the world. The Boeing Market Outlook 2001 states: "The share of GDP spent on air travel by countries with high initial travel shares has tended to grow more slowly than the world average. These countries have maturing air travel markets. In contrast, GDP share spent on air travel by countries with low historical travel shares has tended to rise faster than the world average." Growth rates between 2000 and 2020 vary from 3,1% for North America up to 9,3% for China. The figures are presented in table 3 [Boeing, 2001].

Region	Annual Growth 2001 - 2020	Region	Annual Growth 2001 - 2020
No. America	3,1	China	9,3
Europe	4,7	Latin America	7,7
Other Asia-Pacific	5,4	No. America - L. America	4,8
No. Atlantic	3,6	Europe - L. America	5
Europe - Asia	5,3	Northeast Asia	6,7
Transpacific	4,8	Africa - Europe	4,7

Table 3: growth of air traffic in different regions [Boeing, 2001]

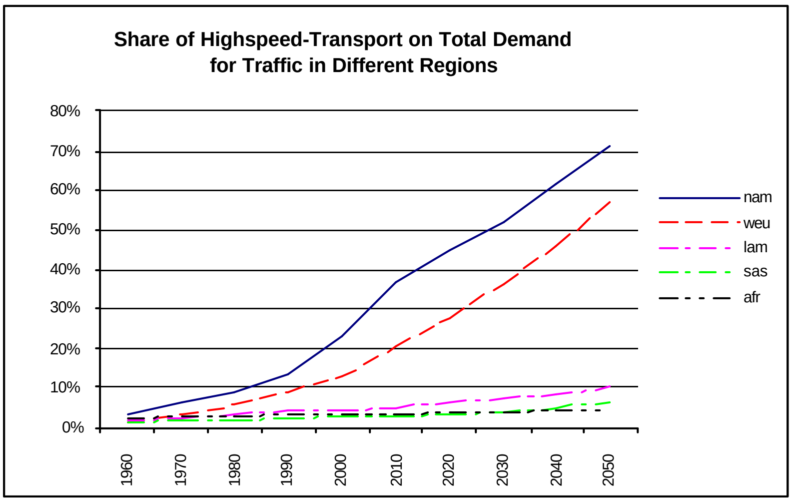
Schaefer and Victor have calculated highspeed growth scenarios for 11 world regions. [Schaefer and Victor, 1998]. On average, a person spends 1.1 h per day travelling and devotes a predictable fraction of income to travel. These time and money budgets are surprisingly stable over space and time. They hold

Fig 4 : Development of Worldwide demand for different means of transport
This forecast of different travel modes by MIT researchers is based on historic data and on the concept of travel time and travel money budgets per person. They show a clear trend towards an increased demand of high speed traffic resulting form a travel time budget that remains almost constant whle the travel money budget further grows.



for a broker at Wall Street and for a farmer in a Saharan village alike. As a consequence, a person with growing income is likely to switch to more expensive – and therefore generally faster – means of transport. Worldwide development of GDP stands therefore in line with growing demand for highspeed transport. Schaefer and Victor [Schaefer and Victor, 1998] utilized these findings as a basis to calculate scenarios of future demand on different means of transport. Figure 4 shows worldwide demand for transport divided into the different means.
Between 2000 and 2050 total demand for transport is expected to more than triple.
As mentioned earlier, the model does not provide information about the share of air traffic on total highspeed transport.

Fig 5 : The share of highspeed-transport differs drastically between the developping and the industrialized world
nam = Northern America
weu = Western Europe
lam = Latin America
sas = South Asia
afr = sub-Saharan Africa



Schaefer and Victor calculated the same scenarios for 11 different world regions. According to the respective expected growth of GDP, the projections of future means of transport differ dramatically between developing and industrialized countries. Most obvious is the share of highspeed transport, which is shown in figure 5 for five world regions. The scenario indicates that by 2050 about half of the distances travelled in industrialized countries are covered through highspeed transportation, whereas in developing countries highspeed hardly accounts for 10% of the demand.

These findings are also illustrated by figures 6 and 7 that show the per-capita distribution of car, bus, rail and highspeed transport in Western Europe and sub-Saharan Africa. It is important to note that the scale of the axis between the two figures differs dramatically as well: In total, an average Western European is expected to travel nearly 35’000 km per year, whereas an African will travel only about a tenth of this amount.

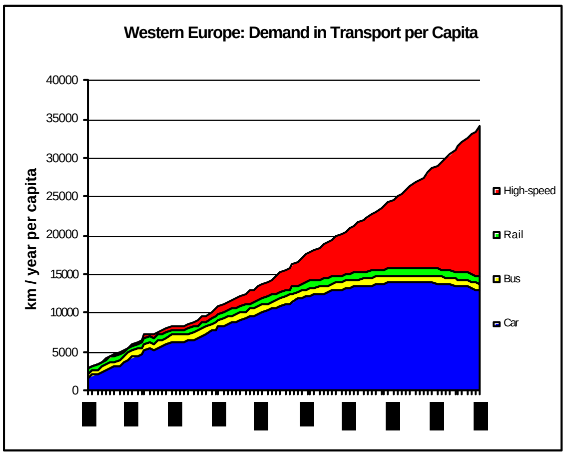


Fig 6: Per-Capita-Demand for different means of transport in Western Europe

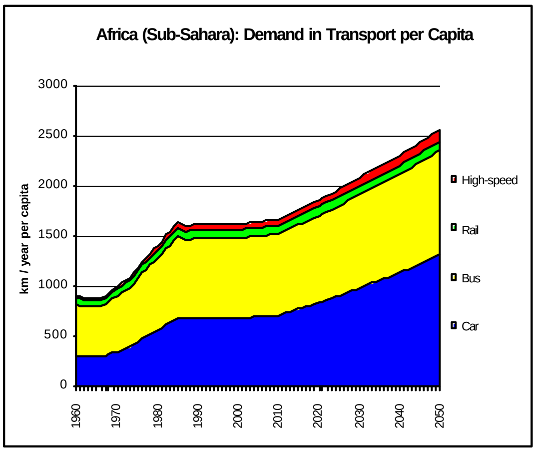


Fig 7: Per-Capita-Demand for different means of transport in sub-Saharan Africa

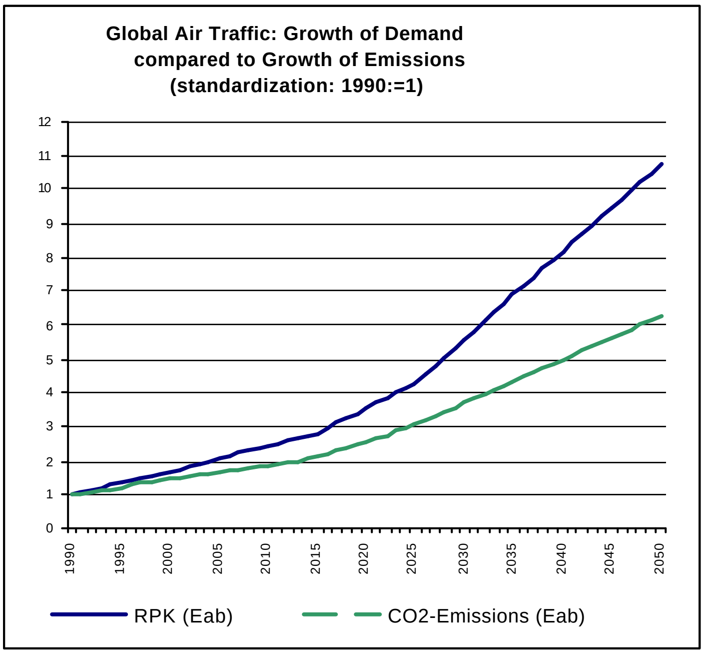
2.1.5 Plausibility of scenarios:

How plausible are these findings for long-term perspectives? Projections over such a long period are always subject to a considerable range of uncertainty, in this case mainly due to the uncertain development of the region’s GDP. For MIT scenarios, a further important problem is the fact that highspeed transport is very sensitive to small adjustments of the time-budget, as well as to political circumstances. Suppose that a person on daily average travels 70 min at 60 km/h by car and 5 min at 800 km/h by plane. The average distance covered daily is 137 km. If the same person now shifts just five minutes of his daily travel-budget from car to plane, the average distance covered increases by 45% to reach 200 km.

2.2 The potential of Efficiency Improvements

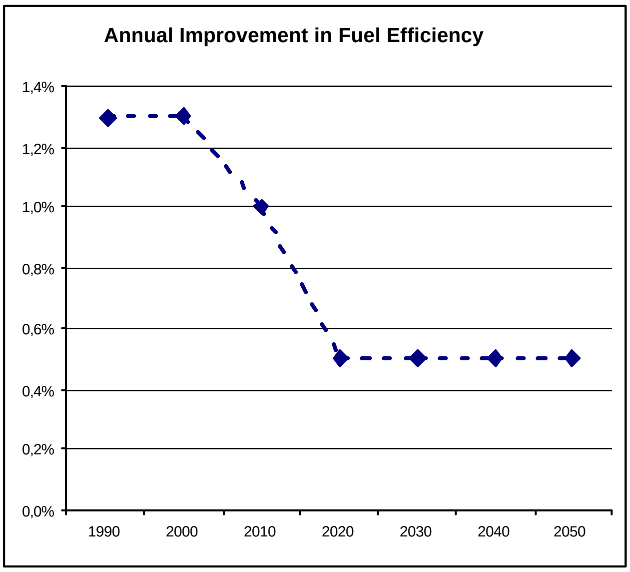
Airplanes constantly gain in efficiency. Newly produced aircraft consume about 70% less fuel per passenger-km than 40 years ago.

Fig 8 : Emissions of air traffic grow slower than its demand. *The graph shows the example of mid-range scenario Eab, assuming an average traffic growth of 4% and an average growth of fuel burn of 3.2% per year.*
The scenario would result in a 10.7 fold increase of air traffic and a 6.6 fold increase of fuel burn and CO_2*- emissions.*



Different studies indicate that during the next 50 years this trend is likely to continue, but at a much lower level. IPCC assumes a reduction in specific fuel consumption of up to 1,9 % yearly.[1] Over the period from 2000 till 2050 this would correspond to a total specific fuel reduction up to 58 % [IPCC, 1999] (see also table 1). These figures are in line with findings of other estimates. [Lee, 2000]

Fig 9 : Ratio of fuel efficiency improvements 1990 – 2050 according to DTI. *Fuel efficiency of airplanes will further increase during the next decades. However, the DTI forecasts indicate that the ratio of improvements could decrease to a lower level.*
(Source : DTI projection in [IPCC, 1999])



However, increase in aircraft efficiency alone will not be sufficient to offset total expected additional CO_2-emissions. Figure 8 shows that growth rates for emissions are smaller than rates for corresponding demand. (illustrated here for scenario Eab, see table 1). (More on emissions-scenarios see 2.3)
Furthermore, scenarios by DTI indicate that improvements in aircraft efficiency might not be an everlasting success story. Figure 9 shows that the annual improvements may drop substantially during the next decades [IPCC, 1999]. This again stresses the challenge of growing air traffic for the climate,

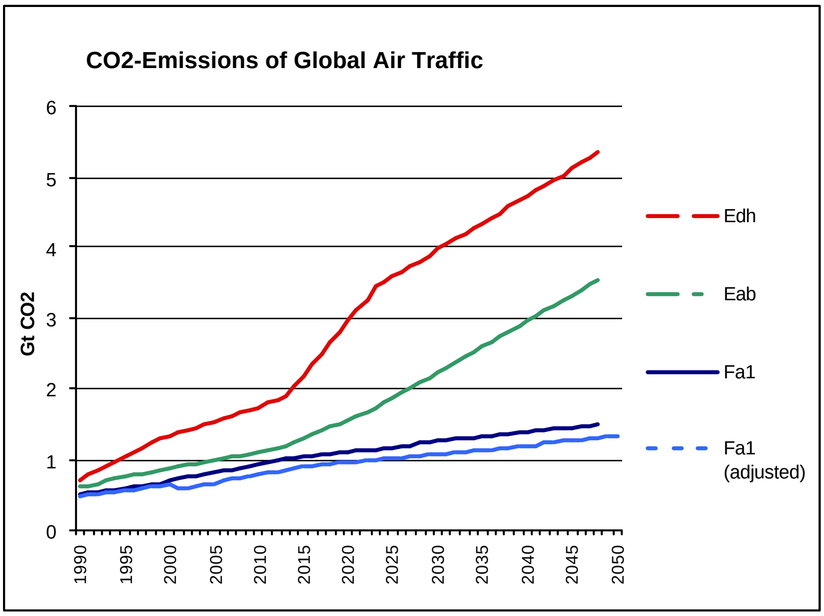
[1] Higher engine and aerodynamic efficiencies contribute 70 % to these reductions. The remaining improvement will be achieved by reduction of structural aircraft weight and changes in operational measures, primarily increased load factor. [Lee, 2000].

as according to IPCC, «there would not appear to be any practical alternatives to kerosene-based fuels for commercial jet aircraft for the next several decades. » [IPCC, 1999]

2.3 CO_2- Emission Scenarios

Based on the scenario on growth of air traffic (see 2.1.1) and the scenario on fuel efficiency improvements (see 2.2) different studies calculate possible future CO_2-emissions of air traffic.
Figure 10 presents the CO_2 emissions of global air traffic according to reference scenario Fa1, Eab and the high-growth scenario Edh. As a consequence of the terrorist attacks 2001, CO_2 emissions of air traffic drop in 2001 and recover again until 2005. Figure 10 also shows the scenario Fa1 adjusted with recent IATA forecasts (see 2.1.3). Compared to the original prediction, the adjusted scenario suggests a time lag in emission growth.
All of these scenarios assume that technological improvements leading to reduced emissions per revenue passenger-km will continue in the future and that optimal use of airspace availability (i.e., ideal air traffic management) is achieved by 2050. If these improvements do not materialize then fuel use and emissions will be higher. [IPCC, 1999]

Fig 10 : Scenario for CO_2-Emission of global air traffic. *Fa1 and Eab are reference scenario, Edh represents a high-growth projection. The time lag shown in the Fa1 adjusted scenario is a consequence of the crisis in 2001.*

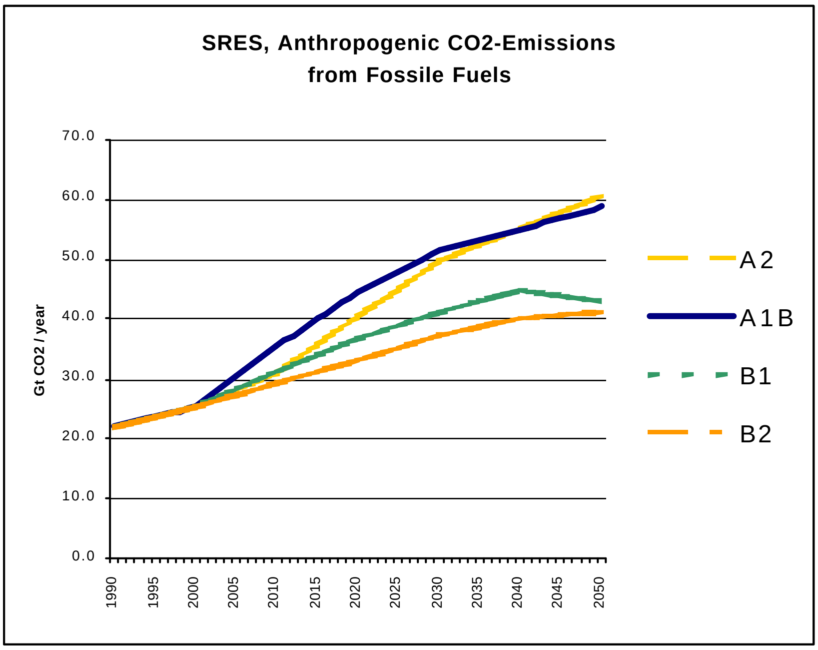


2.4 Impact on the Climate

2.4.1 Carbon Dioxides

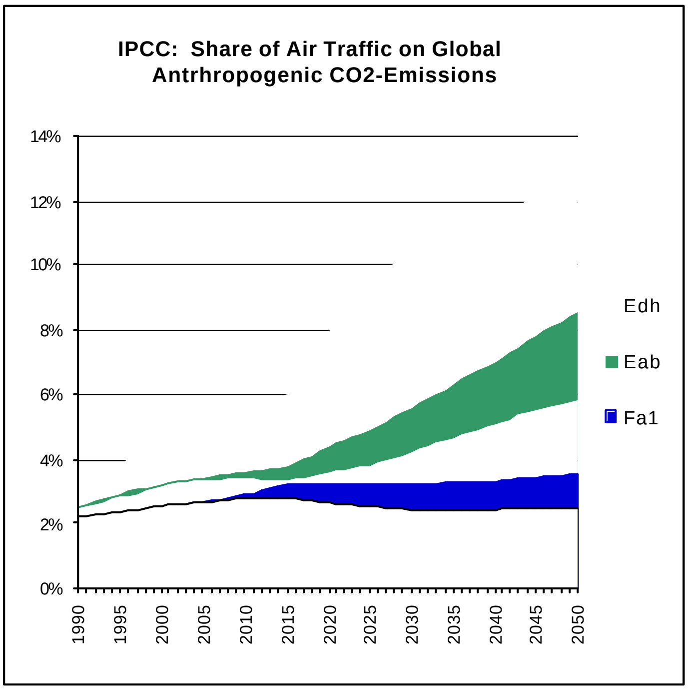
1992 the CO_2-emissions of air traffic represented 2,4% of the total anthropogenic carbon dioxide emissions.

Fig 11 : IPCC "Storylines" of the Special Report on Emissions Scenarios (SRES). *The SRES scenarios are grouped in four storylines A1, A2, B1 and B2, which all represent different possible states of a future world.*
IPCC projects human CO_2-emissions to double or even triple by 2050.



IPCC has developed a series of scenarios to predict trends in future anthropogenic GHG emissions. [IPCC, 2000] These Special Report on Emissions Scenarios (SRES) are grouped in four storylines A1, A2, B1 and B2, which all represent different possible states of a future world. All the storylines consist of several sub-scenarios, one of them being the marker scenario. Figure 11 shows the four marker scenarios within each storyline.

Fig 12 : Share of air traffic on global anthropogenic CO_2-emissions. *The ranges represent the air traffic growth scenario Fa1, Eab and Edh; (see Fig. 10)*
The lower and upper end of each range represent the SRES scenarios A2 (lower end) and B2 (upper end). (see Fig. 11)
By 2050, a range from about 3% up to 13% of global anthropogenic CO_2-emissions could be caused by air traffic.



The share of air traffic on total anthropogenic CO_2-emissions most likely will increase substantially during the next decades. To predict the share, the air traffic emission scenarios Fa1, Eab and Edh are compared with the SRES on total anthropogenic CO_2-emissions. The lower end of the range in each air traffic scenario in Figure 12 represents the share of air traffic within SRES A2 (generally high anthropogenic emissions); the upper end of the range represents the share of air traffic within SRES B2 (generally low emissions).

2.4.2 Greenhouse Gases

The overall climate effects of aircraft are not only the result of its CO_2-emissions. A number of direct and indirect species of aircraft emissions have been identified to affect Climate [IPCC, 1999]:

- Radiative forcing (direct influence): *carbon dioxide*, *water*
- Production of ozone in the troposphere, alteration of the methane lifetime, formation of contrails, modified cirrus cloudiness (indirect influence): *carbon dioxide*, *water*
- Modifying the chemical balance in the atmosphere (indirect influence): *nitrogen oxides, particulates, water vapour*

According to IPCC, the overall radiative forcing by aircraft for all scenarios is about factor 2 to 4 larger than the forcing by CO_2 alone. (This figure does not count the changes in cirrus clouds, because the respective database is very poor.) Table 4 shows these factors for all considered scenarios (without uncertainties). [IPCC, 1999]

It is further estimated that the total anthropogenic GHG emissions have a 1.5 times larger effect on the climate compared to the CO_2 emissions only [IPCC, 1999]. The share of aircraft on the total anthropogenic GHG emissions can therefore be assumed to be about twice as high as the share on total anthropogenic CO_2 emissions. However, recent estimations suggest that this factor might be lower, not because of better performance of aircraft, but because the total amount of anthropogenic GHG emissions probably has been underestimated. Therefore, the figures presented here assume an even more conservative factor and estimate that in the considered scenarios GHG shares are 1,5 higher than the corresponding CO_2 shares.

Under these assumptions, aircraft's share on total anthropogenic GHG emissions could reach between 4 and 12% in 2020. Predictions beyond that are more uncertain. In 2050 the different assumptions indicate shares of between 3,7 and 19,4%.

RF total GHG / RF CO2	Fa	Eab	Edh
2015	3	2,8	3,2
2050	2,6	3,3	3,4

Table 4: Emissions of Global Air Traffic : Warming Potential (Radiative Forcing, RF) of total GHG in relation to CO2 only
Fa: Reference Scenario developed by ICAO
Eab: Environmental Defense Fund Scenario, base-scenario
Edh: Environmental Defense Fund Scenario, high-growth-scenario
(see also Table 1)

Share of air traffic on total GHG emissions	Fa	Eab	Edh
2020, based on A2	4,0%	5,4%	9,8%
2020, based on B2	4,8%	6,6%	12,0%
2050, based on A2	3,7%	8,8%	13,2%
2050, based on B2	5,3%	12,9%	19,4%

table 5: share of air traffic on total anthropogenic GHG emissions

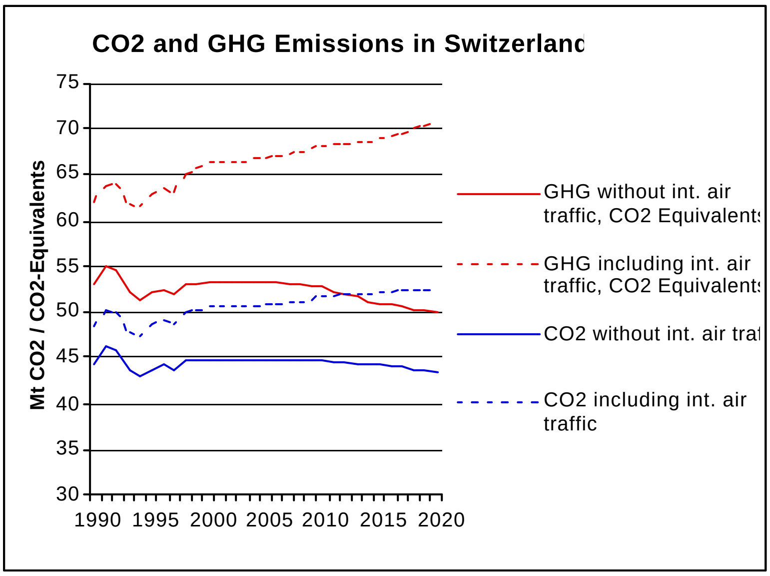
3 The Swiss View: a real new Challenge

3.1 Growth Estimates

The Swiss energy statistics reports CO_2-emissions of between 44 and 46 Mt per year since 1990. The National Communication of Switzerland 2001 states : "The measures contained in the energy legislation and the energy efficiency programs will increase energy efficiency, in particular within the residential sector and in industry. However, due to rapid economic growth, the CO_2-targets set in the CO_2-legislation will not be reached on time. This is particularly the case for the transport sector." [UNFCCC, 2001] The National Communication calculates two emissions scenario: The scenario "with measures implemented" assumes "that the voluntary approach of CO_2-legislation (without CO_2 tax) will not be able to reach the predefined targets." According to the National Communication this is the "most relevant scenario." In fact, for 2020 the emissions are calculated to remain at nearly the level of 1990 (43.5 Mt in 2020). The second scenario "planned measures" includes the achievement of the reduction target, which will only be possible if the CO_2 tax is implemented. According to this scenario, emissions will decrease by 10% until 2010, and another 5% until 2020. "The greatest difference between the two scenarios are related to the sectors transport and industry." The following calculations assume the more realistic scenario "with measures included". It is important to note that the share of international air traffic on total anthropogenic CO_2-emissions in Switzerland would be even higher, if the emission targets were reached!
Swiss greenhouse gases (GHG) emissions were at 53 Mt CO_2-equivalents in 1990. [BUWAL, 2001] The national Communication expects a decrease until 2020 to about 50 Mt of CO_2-equivalents.

To comply with the Kyoto-Protocol, countries only have to include domestic air traffic into the reduction calculations. As a consequence, international air traffic is also excluded from the Swiss Climate Protection Schema, and is not counted as part of the national energy consumption, neither (see 4.1 for further discussion). This leads to the situation that only 4,5% of the air traffic originating from Swiss airports are subject to emission regulations.
Figure 13 shows an overview on the Swiss emission data with and without international air traffic.

Fig 13 : CO_2-and greenhouse gas emissions in Switzerland. *The emissions of international air traffic, which are growing steadily during the next decades, are neither included in the Kyoto Protocoll, nor in the Swiss CO_2-legislation.*



Several approaches are possible to calculate the total Swiss international air traffic. All the approaches differ somewhat in their respective definition : [Kaufmann, 2000]

- Territorial Approach All emissions on Swiss territory are added. The approach includes flights that only cross a country.
- Sales Approach : Calculates the total kerosene sold.
- Citizen Approach : Total demand of Swiss citizens for air traffic. Includes flights of Swiss citizens outside Switzerland as well.
- Flight Schedule Approach : Adds all scheduled flights originating in Switzerland. This approach is used to calculate the scenario in the rest of this paper.

Table 6 compares the different approaches in terms of calculated CO_2-emissions 1999 :

CO_2-emissions 1999 (Mt)	
IPCC-guidelines (only domestic) :	261
Territorial Approach :	1185
Sales Approach :	4703
Citizen Approach :	6264
Flight Schedule Approach :	5989

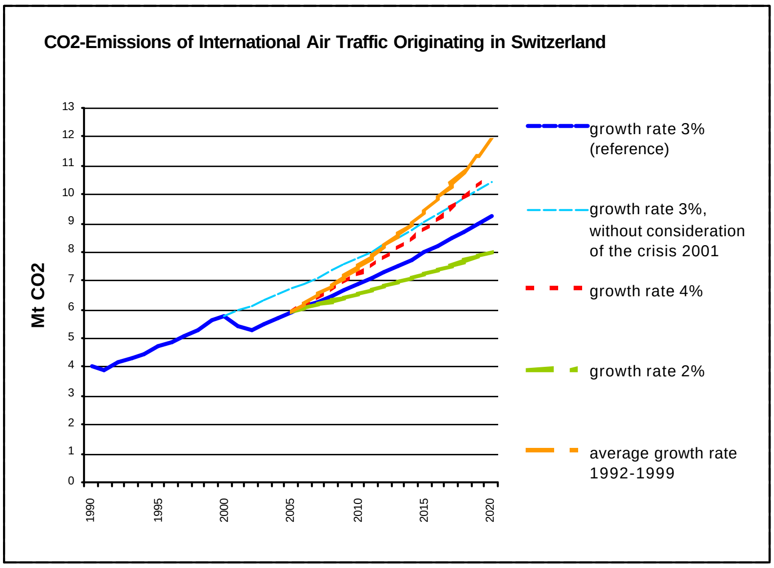
Table 6 : different approaches to measure international air traffic [Kaufmann, 2000]

3.2 CO_2- Emissions Scenario

The CO_2-emissions of Swiss international air traffic have been calculated using the Schedule Approach. To predict possible scenarios for future development, the IPCC short term rate of emission-growth (3%) has been used as the reference scenario [IPCC, 1999]. To show the sensitivity of the scenario, an additional low-growth (2%) and high-growth (4%) are provided. The latter corresponds to the average growth rate 1990-1992. However, if only the period after the crisis of the Gulf War is considered, the average growth rate (1992-1999) is even higher at 4,7%. This scenario is included as well (extra-high-growth scenario).

The attacks on September 11th, the collapse of Swissair in October and a plane crash have turned 2001 into a traumatic year for Swiss aviation. For October 2001 BAZL reported a 18% decline in airplane movements at Swiss international airports and even a 32% decline in transported passengers. [BAZL, 2001] As those regions that have suffered severe decline in air traffic will generally also experience strong recovery, the recent Passenger Forecast provided by IATA is applied for the Swiss scenario, too. (see 2.1.2).

Fig 14 : CO_2-emission scenarios for Swiss international air traffic. *Until 2005, IATA growth forecasts are adopted, which include the consequences of 2001 crisis. After 2005, different growth scenarios are calculated.*

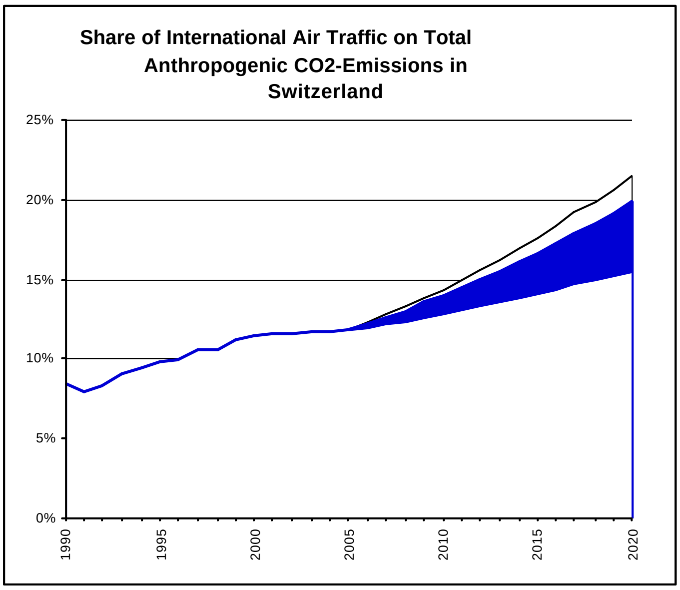


3.3 Share of CO_2-Emission from Aviation

3.3.1 Carbon Dioxides

The National Communication of Switzerland has set up scenario for future CO_2-emissions in Switzerland [UNFCCC, 2001], see 3.1.

Fig 15 : Share of Swiss international air traffic on total anthropogenic CO_2-emissions *(dark blue : range between low and high growth ; bright blue : extra-high growth). By 2020, between 15 and 22% of anthropogenic CO_2-emissions in Switzerland may be caused by international air traffic.*

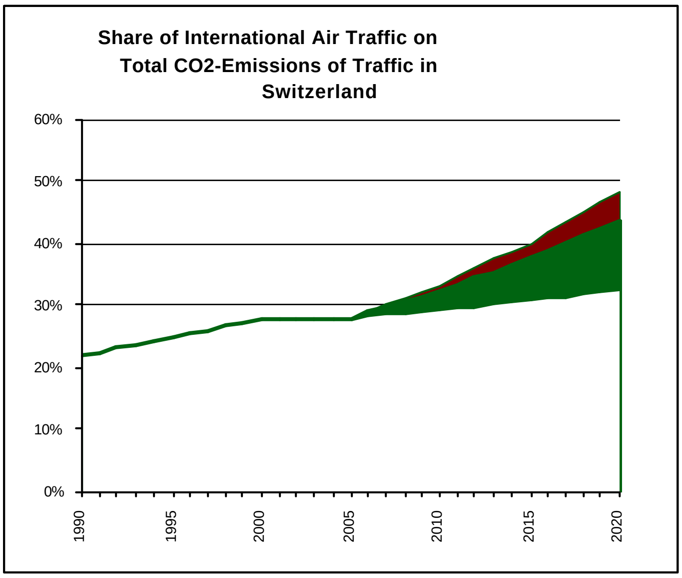


According to the scenario « with measures included » emissions are expected to decline minimally to a level of 43,5 Mt/year between 2000 and 2020. This figure does not take Swiss CO_2-sinks into account. If sinks were included, the share of air traffic would be even higher. If the scenario «planned measures », which assumes significant reductions due to a CO_2 tax, the share of air traffic would be higher, too. Figure 15 shows the share of air traffic on the total anthropogenic CO_2-emissions. The range represents the low- and the high-growth scenario. The upper end of the bright blue range represents the extra-high-growth scenario.

Emissions of Traffic :

In Switzerland CO_2-emissions originating from traffic are predicted to grow from 20 to 24 Mt/year between 2000 and 2020. International air traffic's share today is at about 28%. By 2020, international air traffic may be responsible for 33 to 48 % of traffic's CO_2-emissions. It is important to note that this significant increase of air traffic's share occurs even while the emissions of ground traffic are growing, too – ground traffic itself is far from meeting its reduction target! Figure 16 shows the share of international air traffic on total traffic in Switzerland.

Fig 16 : Share of Swiss international air traffic on total CO_2-emissions of traffic. *(dark green : range between low and high growth ; bright green: growth at average rate 1992 - 1999). By 2020, up to 45% of CO_2-emissions of traffic are caused by aircrafts flying internationally.*



3.3.3 Greenhouse Gases (GHG)

To estimate the impact of air traffic on the climate, it is important to know its share on the total anthropogenic GHG emissions. The assumptions to compare the share of air traffic on total CO_2-emissions with the share on total GHG-emissions can be applied analogically for the situation in Switzerland. (see 2.4.2). According to IPCC, the overall radiative forcing by aircraft for all scenarios is a factor 2 to 4 larger than the forcing by CO_2 alone. However, these calculations assume again a factor of 2.25 to provide more conservative estimates [NFP41-M25, 2000].

Under these assumptions, in 2000 Swiss international air traffic's share on total anthropogenic GHG emissions is at about 19%. 2020, this figure is between 26 and 32%. If the extra-high growth scenario materializes (after 2005: growth at average rates of 1992-1999), the share could even be at 34%. Air traffic could then be responsible for nearly a third of the total Swiss anthropogenic GHG emissions. Figure 17 shows the shares of international air traffic on total Swiss anthropogenic greenhouse gas emissions.

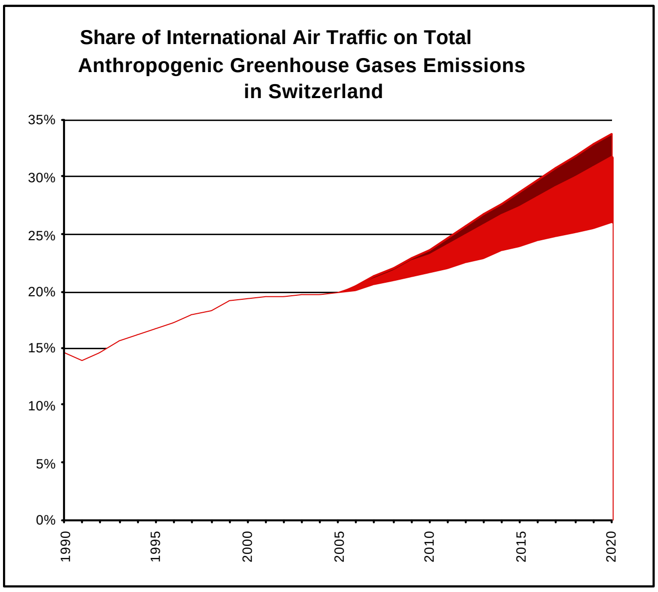


Fig 17 : Share of Swiss international air traffic on total anthropogenic GHG emissions *(dark red: range between low and high growth ; bright red: extra-high growth). By 2020, up to a third of Swiss greenhouse gases emissions may be caused by international air traffic.*

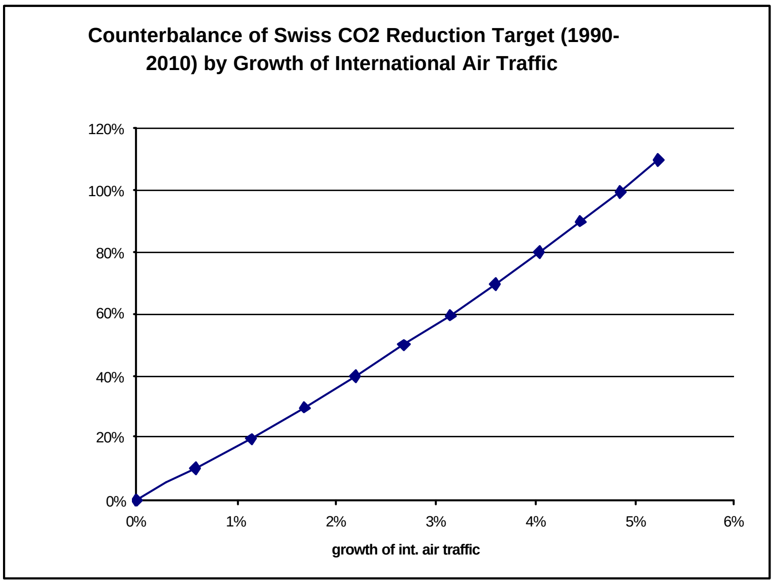
3.4 Implication for the Swiss Climate Protection Efforts

The Swiss Climate Protection Scheme (CO_2-bill) states that in 2010 the CO_2-emissions must be 10% less compared to 1990 emissions. Traffic is supposed to reduce its emissions by 8% based on 1990 levels. In the CO_2-bill international air traffic is explicitely exluded from contributing to the emission reduction target. See 4.3 for a further discussion of the Swiss CO_2-bill. Art. 2 section 2 of the CO_2-bill states the following:

> **The CO_2-bill in Switzerland, [„*CO_2-Gesetz*“],**
> **Section 2 Aim to reduce emissions.**
> The total emissions originating from the energetic use of fossil fuels are to be reduced 15 per cent and the emissions originating from fossil fuels used for transportation only are to be reduced by 8 per cent (without fuels for international flights).

This exclusion has critical effects on Swiss climate protection efforts. The achieved CO_2 reductions will – at least partly – be counterbalanced by the emissions of growing air traffic.

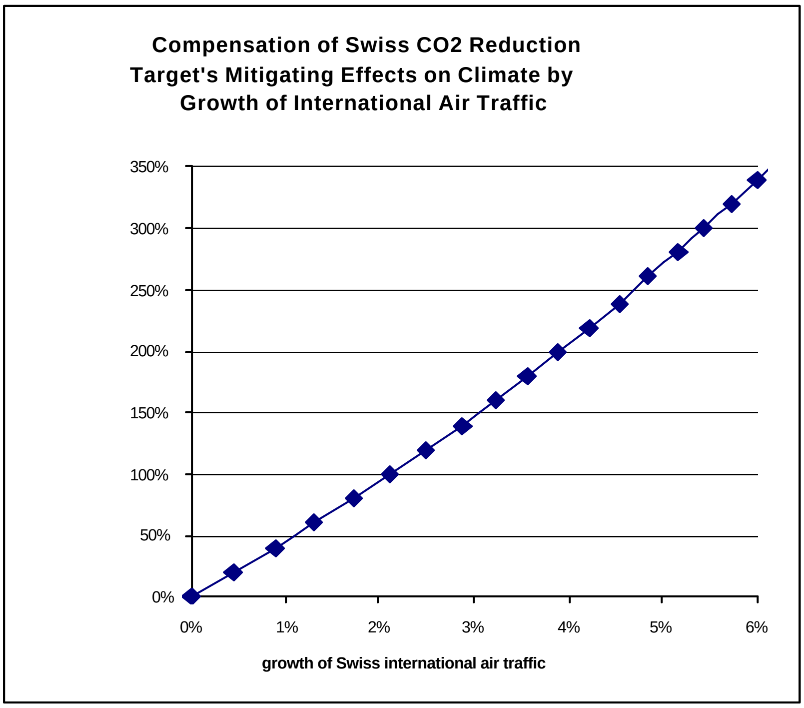
Fig 18 : Achievements of CO_2 reductions in Switzerland will be counterbalanced by growth of international air traffic. *If international air traffic grows further with the average rates of 1992 – 1997, CO_2 reduction achievements by the Swiss* CO_2-bill *could be fully offset.*



If air traffic grows at 2,7% (which is less than the reference-scenario), it will compensate 50% of the scheduled achievements by 2010. If air traffic grows according to the extra-high scenario (4,7%, average of growth rates 1992 - 1997), its emissions will counterbalance 100% of the achieved reductions! Figure 18 indicates the growth rate at which international air traffic counterbalances a certain percentage of the reduction target.

The situation looks even more critical if the total impact of Swiss international air traffic on the climate is considered, instead of only the effect of its CO_2 emissions.

Fig 19: Potential Mitigation effects of CO_2 reductions compared with growth of international air traffic. *As a risk assessment we could assume that the efforts of reducing CO_2 (according to the reduction target 2010 of the Swiss CO_2 bill) have no other positive side-effects, but that the total radiative forcing potential of air traffic might be about three times higher as the forcing potential of its CO2 emissions. Under this assumption an air traffic growth rate of only about 2% might compensate the impact of the measures planed in the framework of the Swiss CO_2 bill.*



As discussed in 2.4, the total radiative forcing potential of air traffic might be about three times higher than the forcing potential of its CO_2 emissions only. If we consider this potential total impact of air traffic on the climate form a risk assessment point of view and assume no or little additional impact on other green house gases of the planed CO_2 measures by the Swiss CO_2 bill, the result is highly challenging. Under this assumption an air traffic growth rate of only 2% might already compensate the impact of the measures planed in the framework of the Swiss CO_2 bill, as shown in Figure 19. The risk assessment also shows that positive effects on the climate of the measures of the Swiss CO_2 bill could potentially be highly over-compensated by growth of international air traffic. (Note that the calculations assume no changes in other greenhouse gases emissions during the considered period.) [IPCC, 1999]

4 Options to Reduce Climate Impact

Airplanes gain constantly in efficiency. As shown in chapter 2.2, the potential to reduce fuel consumption exists even for the next 50 years. IPCC estimates a yearly reduction of fuel consumption per passenger-km of 1,3 up to 1,9%. This would mean that in 2050 airplanes are 48 to 58% more fuel efficient than in 2000 [IPCC, 1999].

However, this gain in efficiency alone is not sufficient to wholly compensate the additional GHG-emissions that are expected due to the steady growth in demand for air traffic. As described in chapter 2, for 2050 IPCC calculates a six-fold increase in demand compared to 1990, which corresponds to an annual increase of about 3%. Furthermore, IPCC recognizes a possible NOx problem: "Engine efficiency improvements reduce the specific fuel consumption and most types of emissions; however, without advances in combuster technology, NOx emissions may also increase." [IPCC, 1999]

A range of approaches to mitigate the impact of air traffic on the climate is proposed by several actors. This chapter presents an overview of the different options.

4.1 Overview of options

Apart from measures to increase fuel efficiency of airplanes and air traffic management, several options are discussed to decrease the impact of air traffic on the climate. These options can be grouped into three goals, which are: Measures to shift demand for highspeed to other means of transport, measures to decrease the demand for highspeed, measures to compensate the emissions elsewhere.

Figure 20 presents an overview of the measures in discussion [IPCC, 1999], [Germanwatch, 2000].

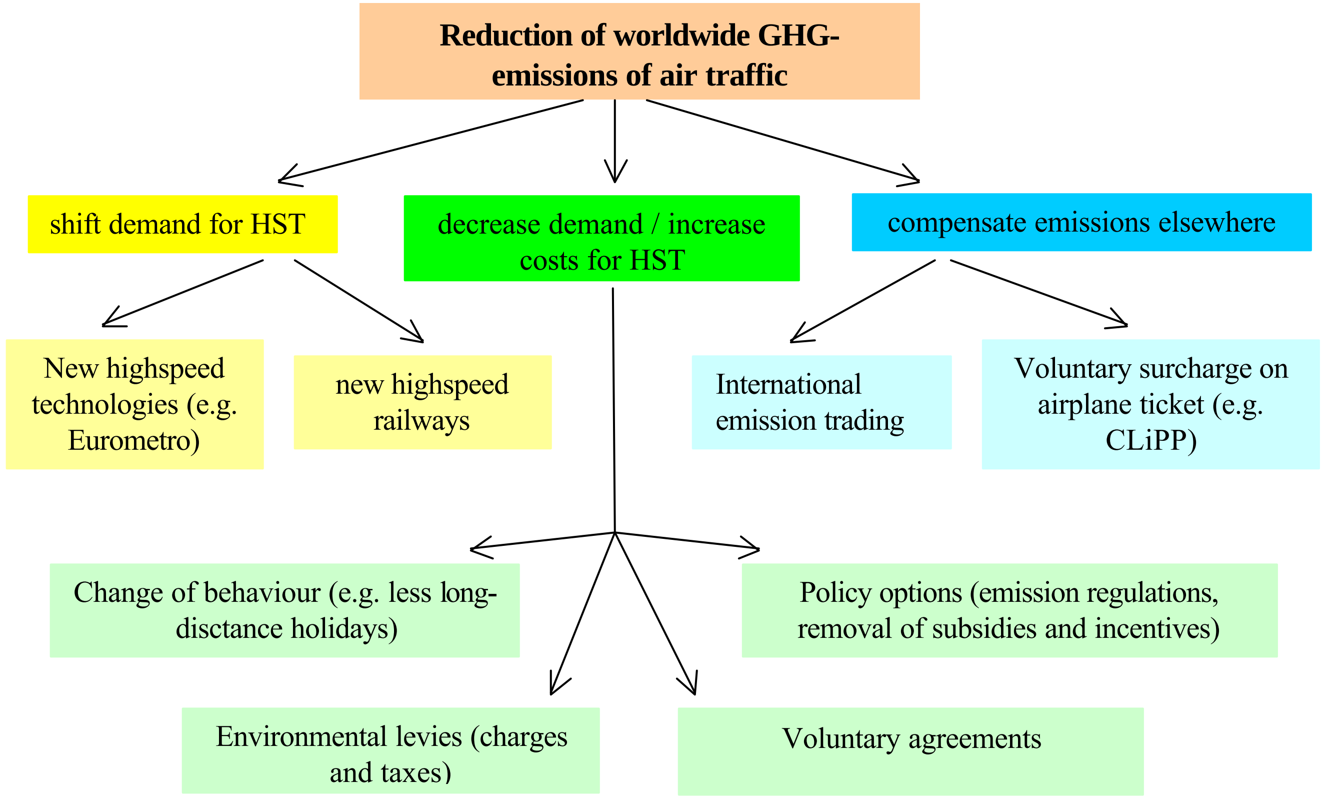


Fig 20: Options for action in order to reduce the impact of air traffic on the climate

4.2 Measures to Decrease Demand or Increase Cost of Air Traffic

The measures that decrease demand or increase costs of air traffic are the only options that tackle the problem at its roots. It does not come as a surprise that these measures are also the most difficult to implement. International air traffic is regulated with a complex network of bilateral agreements between nations. Most of these agreements explicitly exempt kerosene from any taxes or duties. Due to the difficult allocation of the emissions, but also out of economic interests air traffic is also excluded from the Kyoto Protocol. Instead, the International Civil Aviation Organization (ICAO) was assigned the responsibility to coordinate any future measures to tackle the climate impact of air traffic. Attempts to introduce a tax on kerosene are further discussed in 4.3

Change of Behavior

The most efficient and direct solution to reduce the negative impact of aviation would simply mean to fly less. However, practical experience as well as research clearly indicates that this approach is the least realistic. The demand models developed at MIT that are based on the concept of "travel-time" and "travel money budget" show the huge theoretical potential of further growth in highspeed traffic [Schaefer and Victor, 2000]. These models are presented in section 2.1.4.

Possible Unwanted Side Effects of Demand Reduction - Oriented Measures

As is the case with all planned measures, the efforts to decrease demand of air traffic could cause unwanted side effects that should be anticipated.

Developing countries could be more vulnerable:
For many developing countries, international tourism means one of the most important channels of income and of foreign currency savings. Often, a considerable number of jobs are directly or indirectly linked to the tourism industry. A decrease in demand for long-distance flights could cause negative economic and social consequences for the population of these countries, if the reduced number of flights is not compensated by a longer average duration of the time spent in the country.
Rising air ticket costs could cause a further disadvantage for developing countries, as the purchasing parity of their people is lower, which means that the financial consequences of a tax would be higher for these countries. GERMANWATCH therefore recommends that flights to and from developing countries should be treated differently.

Shift of demand to railway could open slots for long-distance flights:
At first sight, the shift of short-distance flights to other means of highspeed travel is a very suitable measure. Paradoxically, a shift to railways could in the short term even be contra-productive. The bottleneck that limits growth of air traffic in Europe is currently the availability of slots for landing and take-off at the airports. As short-trip flights are less profitable, the airline is keen to replace free slots with long-distance flights. Therewith, the emission situation could even worsen. [GERMANWATCH, 1999]

4.3 Environmental Levies to Increase Cost of Air Traffic

One of the most frequently discussed measures that lead to fairer conditions between air traffic and other means of transport is the introduction of a tax on kerosene. If the tax would be used to cover air traffic's damage to the climate, air traffic would also be subject to the polluter-pays principle.
A study conducted for the EU Commission assessed the impacts and consequences of a fuel tax. [EU, 2000]. It calculates the effects in 2005, under introduction of the tax in 1998. The study assumed a tax of 245 Euro / 1000l of kerosene imposed on flights within the EU. With the tax applied to all routes from EU, the demand for fuel would decrease by 2,4%. If the tax was applied only on routes within the EU, the reduction in demand for fuel would only be at 0,5%. The study shows that a unilateral introduction of such a tax by only one country is ineffective. Wherever possible, airlines would avoid

taxation by filling up with oil in "duty free" countries. The study shows that as a result of this tax avoidance, the positive effects on the environment would be reduced by 30 to 70%.

Legal Constraints Impede the Introduction of a Fuel Tax

One of the important obstacles to the introduction of a fuel tax is the complicated network of agreements that regulate the taxation of kerosene. The Chicago Agreement, which came into existence in 1944 together with the International Civil Aviation Organization (ICAO), states the only internationally binding rules. Paragraph 24 deals with customs duty:

> CONVENTION ON INTERNATIONAL CIVIL AVIATION, SIGNED AT CHICAGO, ON 7 DECEMBER 1944 (CHICAGO CONVENTION)
> Article 24 - Customs duty
> (a) Aircraft on a flight to, from, or across the territory of another contracting State shall be admitted temporarily free of duty, subject to the customs regulations of the State. Fuel, (…) on board an aircraft of a contracting State, on arrival in the territory of another contracting State and retained on board on leaving the territory of that State shall be exempt from customs duty, inspection fees or similar national or local duties and charges. (…)

According to the convention, only fuel that is already aboard is freed from duties. The convention would permit a taxation of fuel filled up in a host country. However, in addition to the convention, a network of bilateral agreements between nations further regulates air traffic. Many of these agreements prohibit a taxation of kerosene. As an example, a section of the Air Transport Agreement between the USA and Switzerland is presented here. An international tax on kerosene would first require the adaptation of the relevant agreements.

> AIR TRANSPORT AGREEMENT between THE GOVERNMENT OF SWITZERLAND and THE GOVERNMENT OF THE UNITED STATES OF AMERICA
> Article 9: Custom Duties and Charges
> (2.) There shall also be exempt, on the basis of reciprocity, from the taxes, levies, duties, fees and charges (...)
> (c.) fuel, lubricants and consumable technical supplies introduced into or supplied in the territory of a Party for use in an aircraft of an airline of the other Party engaged in international air transportation, even when these supplies are to be used on a part of the journey performed over the territory of the Party in which they are taken on board.

National Legislations Exclude Taxation of International Air Traffic

The mentioned international agreements have of course consequences on national legislations. The member states of the European Union, for example, are obliged to exempt international air traffic of excise duties:

> Council Directive 92/81/EEC of 19 October 1992 on the harmonization of the structures of excise duties on mineral oils
> Article 8
> 1. In addition to the general provisions set out in Directive 92/12/EEC on exempt uses of excisable products, and without prejudice to other Community provisions, Member States shall exempt the following from the harmonized excise duty under conditions which they shall lay down for the purpose of ensuring the correct and straightforward application of such exemptions and of preventing any evasion, avoidance or abuse:
> (b) mineral oils supplied for use as fuels for the purpose of air navigations other than private pleasure flying.

However, in the same article the directive requires to review the exemptions of fuel taxations from an ecological point of view:

> 7. No later than 31 December 1997 the Council shall review the exemptions provided for in paragraphs 1 (b) (...), on the basis of a report by the Commission and taking account of the external costs entailed in such means of transport and the implications for the environment and shall decide unanimously, on a proposal from the Commission, whether to abolish or modify those exemptions.

The result of this review is the study mentioned at the beginning of this chapter [EU, 2000]. Obviously, the EU is very unlikely to introduce a tax unilaterally in the near future.

International Air Traffic is excluded from Emission Reduction Targets
International air traffic enjoys also a special position within the Kyoto-Protocol of the UNFCCC. While the industrialized countries (the parties included in Annex 1 of the protocol) made binding commitments to reduce their GHG emissions in all sectors to a certain level, international air (and ship) traffic remains excluded from the reduction targets. Concerning air traffic, the Kyoto-Protocol only recommends that ICAO should coordinate further activities:

> Kyoto Protocol, Paragraph 2 Section 2:
> The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively.

One reason for the exclusion of international air traffic is the fact that its emissions are difficult to allocate. The emissions could be assigned to countries using different procedures. It is for example disputable, which country would have to come up for GHG emitted on oceans. The Kyoto-Protocol assigns all emissions strictly to the territory, where they were caused. A further reason for the exclusion is the mentioned complex network of air transport agreements, which make the introduction of air traffic into the Protocol difficult, as it would challenge the chances of implementation of the Kyoto Protocol drastically. Finally, a factor that must not be underestimated is the high economic interest that countries do have in a growing air traffic industry.

As discussed in chapter 3, the Swiss CO_2-legislation excludes international air traffic, too. It is not a surprise that during the negotiations, the role of air traffic in international agreements and conventions played a crucial role as well. According to Mr. Stadler from the Swiss Agency for the Environment, Forests and Landscape (BUWAL), international air traffic was originally included in the draft version of the CO_2-legislation. The draft version required a –5% reduction for total emissions of traffic. It then became obvious that there was no chance to include aircraft GHG emissions in the Kyoto-Protocol. As a consequence, the parliament decided to exclude international air traffic from the legislation, but to put –8% as the reduction target for traffic instead of –5%. In addition, the Swiss government is obliged to put forward international efforts to reduce emissions of air traffic. If international air traffic had not been excluded, the other sectors of transport would have had to compensate drastic amounts of greenhouse gases to make up for the growth in air traffic and its emissions.

4.4 Shifting Demand to Other Means of HST

If air traffic is seen as a part of “high speed traffic” (HST), shifting the demand to other means of transport leads to a high-potential, long-term option: modern high speed train systems. Modern Maglev technology opens the potential to connect cities or commercial centres in Europe with travel times less or closed to total travel times of airplanes up to distances of 1000 km.

Several papers presented show different aspects of the Swissmetro-technology, an underground Maglev system in tunnels under partial vacuum. It has a particularly high potential to reduce the energy demand of highspeed travel by a factor of 5 or even more. Since it can be driven by electric power, as most train systems, the greenhouse gas emission and its impact on the climate can be reduced even much farther, if the electricity used will be produced from renewable resources.
The emissions trading option (see 4.5) might even become a major financing source of the proposed Eurometro system. A combination of economic and technical measures could thereby open a major path towards a new more sustainable high-speed system in Europe. In this future system modern Maglev-"planes" would "fly" underground, only a few centimetres above a rail, but thereby saving the energy needed to clime up to 10'000 meters to meet similar conditions as reached with modern technology in a Eurometro-tunnel system.
Considering the potential critical impact of aviation on other efforts to protect the climate, a new technical system with a high efficiency-potential as provided by Maglev- and Swissmetro-Technology, urgently needs to be further evaluated. It could become a major option towards more sustainable means of high-speed transport in Europe or other continents.

4.5 Compensating Emissions Elsewhere

The measure that probably has the highest chance to be implemented in the near future is the introduction of "emission-trading" for air traffic. This mechanism is in line with the options that the Kyoto Protocol offers. With the trading system, greenhouse gas emissions from air travel are compensated in areas with lower reduction costs. The prices for air tickets would generally rise to pay for measures to offset the aircraft emissions.
In Switzerland, CLiPP (Climate Protection Partnership) is a voluntary compensation scheme. CLiPP is presently developed by a group of consulting companies, environmental NGO's and public institutions in cooperation with students and faculty members of Swiss and international universities. Its main idea is to provide an option for immediate action, as all other measures are very likely to take several years until their final implementation. A CLiPP ticket is a voluntary surcharge on the normal fare. The money is collected in a fund, and thereafter re-invested in sustainable compensation projects in developing and industrialized countries. More information can be obtained under the project's homepage: http://www.clipp.org.

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