Limiting aviation’s full climate impact by market-based measures:

Results of the research project AviClim

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ABSTRACT:

Aviation contributes to climate change by both long-lived CO_2 and short-lived non-CO_2 effects, such as NO_x or contrail cirrus. According to Lee et al. (2009), aircraft-induced CO_2 contributed 1.6% to the total anthropogenic radiative forcing in the year 2005. If both CO_2 and non-CO_2 effects are considered, aviation contributed 4.9% to the total radiative forcing in 2005. The interdisciplinary research project AviClim has explored the feasibility for including aviation’s full climate impact in international protocols for climate protection and has investigated the economic impacts. The present paper provides results of this research project. In AviClim four reduction scenarios have been designed which differ concerning the level of international support for climate protecting measures. These scenarios have been combined alternatively with an emissions trading for all climate relevant species, a climate tax and a NO_x emission charge combined with operational measures. Also, two different metrics for quantifying aviation’s full climate impact have been assumed alternatively: Average Temperature Response ‘atr 20’ and ‘atr 50’. All in all, a global emissions trading scheme for both CO_2 and non-CO_2 emissions would be the best solution.

1 Introduction

Aviation contributes to climate change by several components: CO_2 with an atmospheric lifetime up to thousands of years and H_2O with a lifetime between hours and months contribute to a positive RF. The NO_x emissions have several effects: Ozone (O_3) is formed (warming effect) with a life-time from weeks to months. As a secondary effect, methane (CH_4) is destroyed (cooling effect) with a life-time of about a decade. Finally, from the reduced methane a secondary reduction of the ozone concentration results (cooling effect), which has the same life-time as methane. Contrail induced cloudiness (CiC, individual contrails and the associated contrail cirrus) result in a positive RF, which is of a similar magnitude than the RF from CO_2 on global and annual average (e.g., Lee et al., 2009, Burkhardt and Kärcher, 2011).

While the climate impact of CO_2 emissions is independent from the emission location and time, aviation's non-CO_2 effects depend on flight altitude, geographical location and partly day time, weather situation, etc. (e.g., Fichter et al., 2005; Mannstein et al., 2005; Fichter, 2009, Frömming et al., 2012). Due to the different life-times and due to the spatially dependent impacts, the climate change induced by the aviation non-CO_2 effects is not directly proportional neither to the CO_2 emissions nor to the amount of non-CO_2 emissions. Therefore simply applying a factor to the CO_2 emissions to account for aviation's non-CO_2 effects, as suggested by, e.g., the European Parliament, is not appropriate as it would provide incorrect incentives (e.g. Forster et al., 2006).

Overall, the global framework for limiting the climate relevant emissions of aviation is diverse. Whilst international aviation carbon dioxide emissions have been regulated in several countries in the recent years, this is not the case for most of the non-CO_2 climate effects. Until now, the non-CO_2 species have only been addressed scarcely both on ICAO and on a national level. Nevertheless it is important to include the non-CO_2 effects as the total climate impact of aviation (in terms of RF) was 4.9 % (in 2005) while the aircraft-induced CO_2 contribution to total anthropogenic radiative forcing was only 1.6% (Lee et al., 2009). Due to urgent environmental needs, the political regulation of the full climate impact of aviation is strongly recommended in the foreseeable future.

Therefore the research project AviClim (Including Aviation in International Protocols for Climate Protection), funded by the German Bundesministerium für Bildung und Forschung (BMBF), focussed on the question: How can international aviation be best included in international protocols for climate protection from an economic point of view? For details see Scheelhaase et al. (2015).

2 Method

In the present study four geopolitical scenarios have been defined, which differ concerning the level of international support for climate protecting measures in aviation: "Greater EU" with EU, Norway, Iceland and Liechtenstein, "Great Aviation Countries" with the main players in international and national aviation, "Annex-I Countries" with "Annex-I Countries" plus the BRIC countries (Brazil, Russia, India and China) and "World" with global support. Within AviClim it has been generally assumed that all flights to, from and within the countries belonging to the respective geopolitical scenario will be regulated.

The four geopolitical scenarios have been combined with three selected market-based measures to reduce aviation's climate relevant emissions, which have been chosen in respect to economic efficiency, potential environmental benefits and practicability: (1) Emissions trading scheme for all climate relevant emissions, (2) climate tax and (3) NO_x emission charge combined with a CO_2 trading scheme and operational measures, which assume that 50% of flights operated between 30°N and 60°N and on an altitude between 28-38 kft (about 9 and 12 km) will be flying 2 kft (about 630 m) lower to reduce contrail cirrus. The combination of NO_x emission charge, CO_2 trading scheme and operational measure will be called "NO_x charge" afterwards.

The airlines under the respective scheme have increasing costs due to the regulatory measures. These additional costs depend on the future development of prices for CO_2 equivalents, which is difficult to foresee. Therefore we have assumed three different price development paths: For 2010 we assume a price of 10 USD per ton CO_2 for all price development paths and for 2030 80 USD per ton for the 'High Price Path' and 30 USD for the 'Low Price Path. Additionally we assume a 'Mixed Price Path' with low CO_2 equivalent prices for both trading schemes and high prices for the climate tax and the NO_x charge. For both trading schemes a free allocation of 85% of 2010 emissions has been assumed. For any emissions exceeding 2010 emissions, emissions permits have to be purchased by the airlines on the permits market.

Under the assumption that the airlines will try to pass-on the full cost increase to their customers, prices for air services will become more expensive. We assume three cases of price elasticities: (Case 1) The quantitative demand for air services remains unchanged. (Case 2) The quantitative demand reaction is under proportionate to the price increase by the airlines; a price increase of 1% leads to a demand reduction of 0.8%. (Case 3) The quantitative demand reaction is disproportionate to the price increase by the airlines; a price increase of 1% leads to a demand reduction of 2.1%.

FIGURE 1 HERE

For the present study, the Average Temperature Response (ATR), which is the mean temperature change over a time horizon of 20 and 50 years (atr_20 and atr_50) respectively, was used as metric to tranfer non-CO_2 effects into CO_2 equivalents. To find a reasonable compromise between calculation effort and accuracy of the results we decided to use only an altitude dependency of the climate impact. Therefore we calculated the impact of nowadays air traffic for each flight level separately with the response model AirClim (Grewe and Stenke, 2008; Grewe and Dahlmann, 2012; Dahlmann et al., 2015) which calculates the climate impact of different climate agents (CO_2, H_2O, NO_x (O_3+CH_4+O_3^{pm}) and CiC) as functions of the emission location. Then we got the CO_2 equivalents by calculating the climate impact of each species per kg emission or flown distances relative to the impact of one kg CO_2. The CO_2 equivalence factors, which in particular depend on flight altitude, are shown in Figure 1 for atr_20 and atr_50, respectively. An emission of 1 kg NO_x in an altitude of 35 kft, for example, has the same impact on climate over 20 years as about 1000 kg CO_2.

In brief, the modelling of the climate effects of the market-based measures has been analysed by the following steps (Figure 2, for details see Scheelhaase et al., 2015): *VarMission* (Schaefer, 2012; Schaefer et al., 2010) and *4D-Race* (4 Dimensional distRibution of AirCraft Emissions) calculate the absolute amount as well as three-dimensional distributions of the CO_2 and non-CO_2 emissions of aviation in the timeframe 2010-2030 differentiated by the different geopolitical scenarios, which is the forecast emission inventory. The forecast emission inventory was combined with the CO_2 equivalence factors (Figure 1) to calculate the associated amounts of CO_2 equivalents of all climate relevant species for each flight. These amounts of CO_2 equivalents were used to calculate additional cost as well as demand effects, which influence the development of revenues of the airlines addressed by the climate protecting measure. This will lead to a decrease in air traffic and a loss of employment in the aviation sector. This also leads to a reduction in fuel burn as well as other climate relevant emissions, which has been estimated by VarMission on a flight-by-flight-basis. For both trading schemes (trading scheme for all climate relevant emissions and CO_2 trading scheme, respectively), additional CO_2 savings can be derived from the CO_2 purchases from other emitting sectors (e. g. stationary sources). These purchases are necessary to comply with the trading schemes. The change in climate impact due to emission reduction of air traffic and in other sectors due to emission trading was again analysed by *AirClim*.

FIGURE 2 HERE

3 Results

Here we only present results for the scenario "World" with the assumption of "Low Price Path" and atr_50 as climate metric. More results can be found at Scheelhaase et al., 2015. The cost impacts of the market-based measures are presented in Figure 3a as total. Total costs will be the highest for a climate tax (solid line). Both, an emissions trading scheme (dashed line) and a NO_x charge (dotted line) will lead to much lower overall costs. This can be explained by the specific assumptions that for the trading schemes a free allocation of 85% of 2010 emissions has been assumed.

Under the assumption that the airlines pass on all additional costs, prices for air services will increase. Modelling results show that under the assumption of a price elasticity of demand of -0.8 (case 2), revenues will decrease by 3 to 7 % in the period 2010-2030 (Figure 3b). Again, effects of the climate tax are the largest while the impacts of the emissions trading scheme and the effects of the NO_x charge are far lower.

The reduction in air traffic leads to a reduction of climate impact from aviation since less fuel will be burned and also the non-CO_2 climate effects such as contrails are reduced. For the two market-based measures including emissions trading, additional environmental benefits are derived from the necessary purchase of CO_2 allowances from other sectors to comply with the regulation scheme.

The temporal development of climate impact in terms of temperature change is presented in Figure 4. For the emissions after 2030 we assume constant emissions as the future development is difficult to foresee. Without the possibility to buy permits from other sectors, only small impacts on the temperature change can be realized (3 % to 8 %). If purchases of permits are taken into consideration, the temperature change in the year 2100 will be reduced by up to 65 %. Due to the fact that for emissions trading the amount of purchases from other sectors is larger than the CO_2 emission from aviation, the temperature change decreases after 2040 despite constant aviation emission after 2030.

FIGURE 3 HERE

FIGURE 4 HERE

The increasing temperature change after 2030 for all other scenarios is due to the thermal inertia of the atmosphere and the very long lifetime of CO2, which leads to an accumulation in the atmosphere. Overall, AviClim results show that environmental benefits are the greatest for the emissions trading scheme for all climate relevant emissions from aviation.

4 Final remarks

Her we only have presented the results for atr_50. The AviClim project indicates that the choice of the metric has a great influence on both the economic and the environmental effects of the market-based measure analysed. For simplification reasons modal switching has not been considered in the present study. This will be subject to further research. Therefore, environmental benefits calculated are at the upper end and may be smaller in reality.

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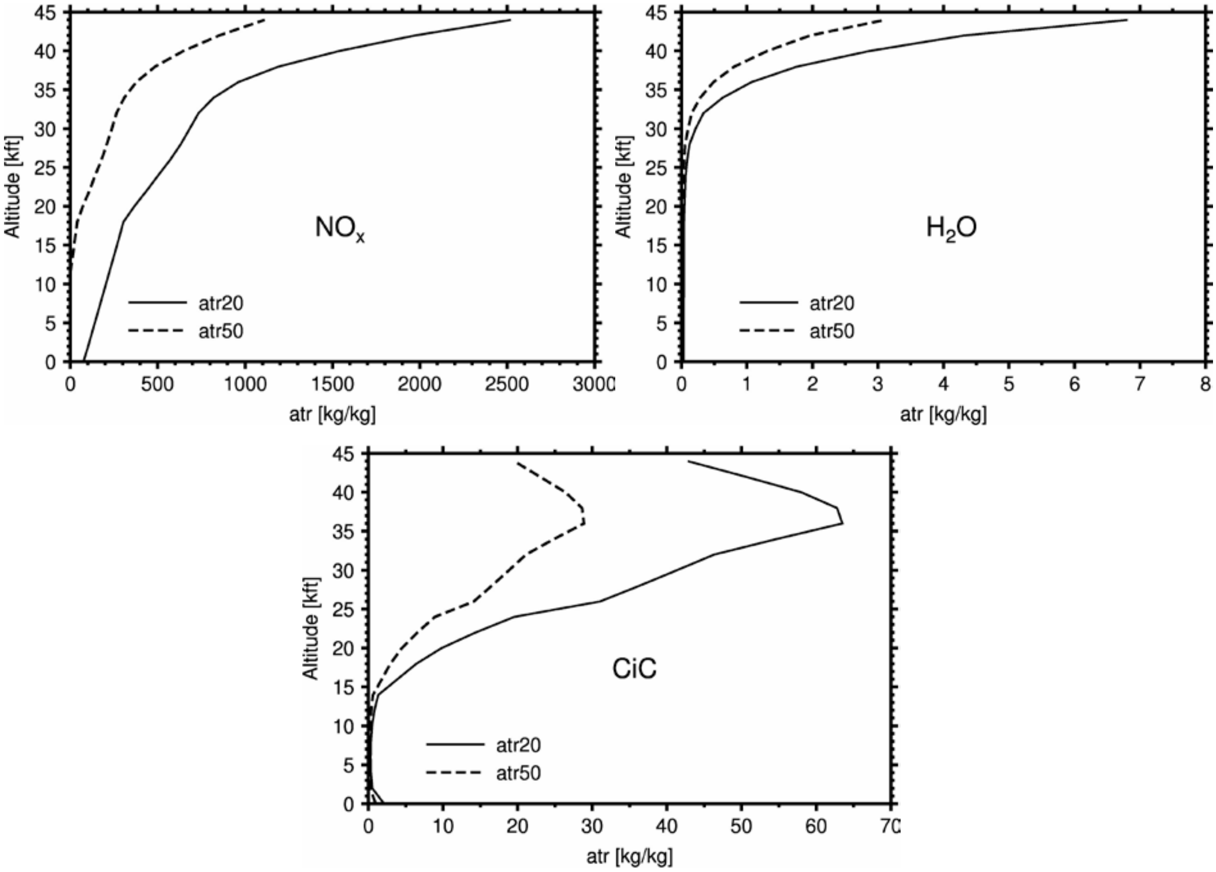

Figure 1: CO_2 equivalence factors (in kg(CO_2^{equi}) per kg emission or flown km) in dependency of flight altitude for NO_x, H_2O and CiC using atr_20 and atr_50 as metric, respectively.

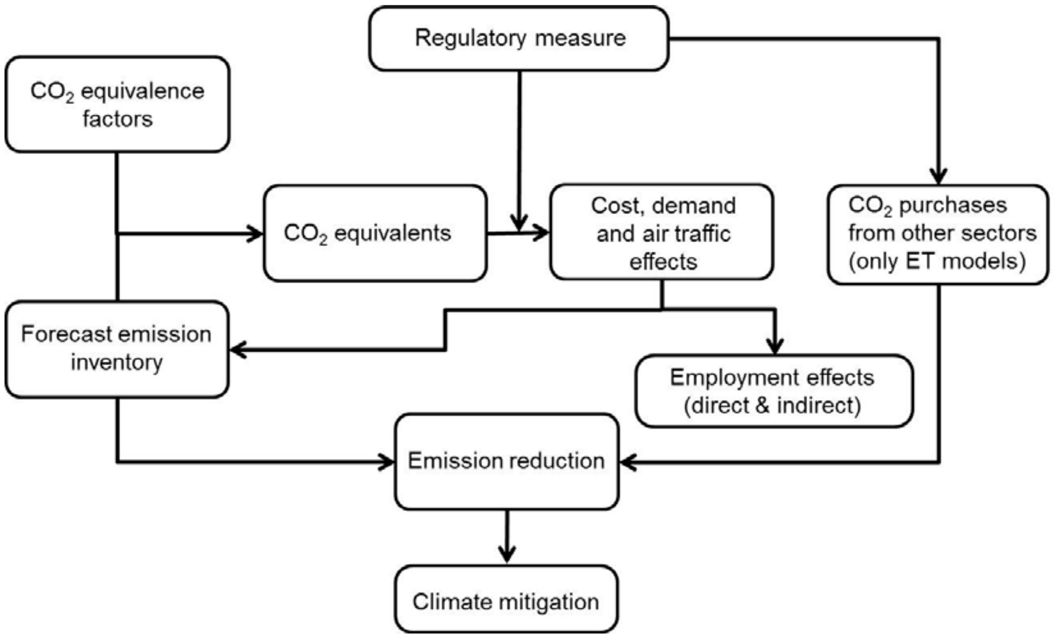

Figure 2: Schematic of the AviClim modelling approach.

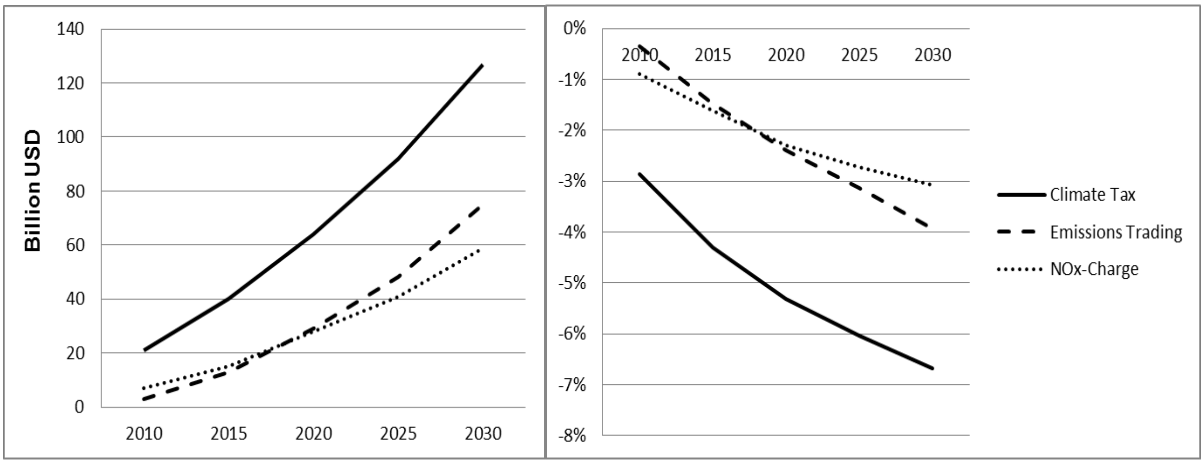

Figure 3 Costs of different market-based measures (left) and changes of demand relative to Business-as-usual for a price elasticity of demand of -0.8 (case 2, right) analysed in Scenario "World", assuming the 'Low Price Path' and the metric atr_50.

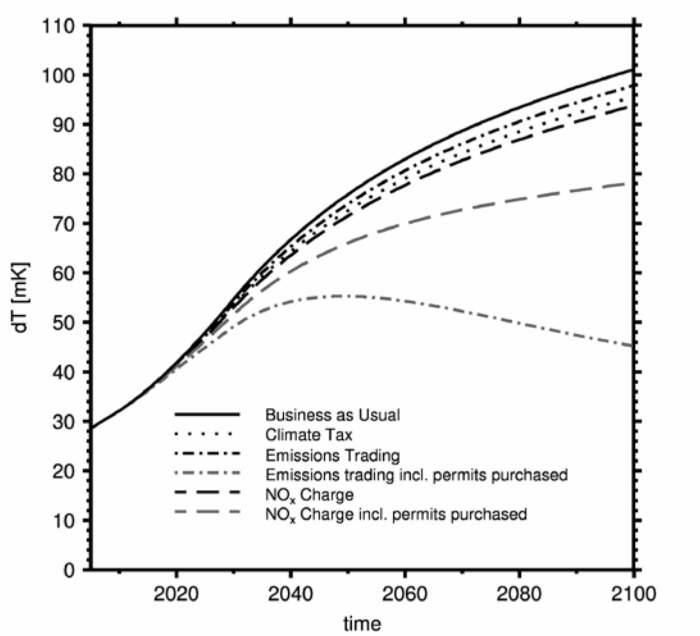

Figure 4: Temporal development of temperature change for the scenario "World" with the 'Low Price Path' and the metric atr_50.