How to address aviation's full climate impact best from an economic point of view? – AviClim project overview and update on first results

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Abstract

International aviation is a substantial emitter of CO_2 and additionally contributes to climate change by short-lived non-CO_2 effects, such as emission of NO_X or triggered contrails and contrail cirrus (e.g., Sausen et al., 2005): In 2005, aircraft-induced CO_2 contributed 1.6% to the total anthropogenic radiative forcing (RF). If the non-CO_2 climate effects are also considered, aviation's contribution to total RF is about three times as large, i.e., 4.9% (Lee et al., 2009). Whilst international aviation's CO_2 emissions are regulated in a number of countries by market-based measures, this is not the case for most of aviation's non-CO_2 climate impacts.

The interdisciplinary research project AviClim (Including Aviation in International Protocols for Climate Protection) explores the feasibility for including aviation's CO_2 and non-CO_2 climate impacts (aviation-induced clouds, NO_X emissions, water vapour emissions, sulphur emissions, etc.) in international protocols for climate protection. In addition, the associated economic impacts are studied. From an economic point of view, the implementation of a charge or an emissions trading scheme for selected non-CO_2-gases and substances could be considered among other options. Also, operational measures such as climate optimized flight-paths could be a viable option. The economic and environmental impacts of introducing selected reduction measures will be investigated by employing a DLR-developed simulation model. This paper is an updated ver-

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sion of Scheelhaase et al. (2012). It provides an overview of the AviClim research project and presents an update on the first results.

Keywords: Environment, Aircraft emissions; Air transport policy; Climate change; Environmental economics; Emissions trading.

1. Introduction

This paper presents an updated version of Scheelhaase et al. (2012). As described there, air transport is a substantial emitter of CO_2 and, additionally contributes to climate change by short-lived non-CO_2 effects, such as emission of NO_X or triggering contrails and contrail cirrus (e.g., Sausen et al., 2005): In 2005, aircraft-induced CO_2 contributed 1.6% to the total anthropogenic radiative forcing (RF). If non-CO_2 climate effects are also considered, the contribution of aviation to total anthropogenic RF is about three times as large, i.e., 4.9% (Lee et al., 2009). In addition, international aviation is one of a few sectors expected to grow significantly in the medium and long term. Whilst international aviation's carbon dioxide emissions have been regulated in a number of countries by market-based measures, this is not the case for most of aviation's non-CO_2 climate impacts. Especially the effects of aviation-induced clouds and NO_X emissions on high altitudes are neither fully understood from an atmospheric sciences point of view nor investigated with regard to the possible introduction of regulatory measures at this point.

To complicate matters, the international character of aviation renders national approaches ineffective and requires lengthy political negotiations on the international level. Here, both the International Civil Aviation Organisation (ICAO), as well as any supranational/international political institution of great regional importance such as the European Commission will have to be involved. With regard to expected future annual growth rates of 3 – 7 per cent, depending on the world region (Airbus, 2011), the implementation of global or at least internationally coordinated instruments for the reduction of the non-CO_2 impact of international aviation on climate change seems to be necessary expeditiously.

How can international aviation be included in international protocols for climate protection best from an economic point of view? To investigate this question, the German Aerospace Centre

(DLR) has been tasked by the German Federal Ministry of Research to conduct an interdisciplinary research project in October 2011. AviClim (Including Aviation in International Protocols for Climate Protection) has been scheduled for 36 months and will terminate in September 2014. Important technical and applied oriented objectives of AviClim are:

- To further develop and test metrics for transferring aviation's non-CO_2 climate impacts (aviation-induced clouds, NO_X emissions, water vapour emissions, sulphur emissions, black carbon emissions, etc.) into equivalent CO_2, which eventually can be regulated.
- To analyse the possibilities to limit or reduce these impacts (CO_2 plus non-CO_2) by market-based and/or operational measures. Here both the findings of environmental economics and institutional economics theory as well as the relevant recent developments on the international level (ICAO, UNFCCC, EU) shall be considered.
- To estimate the economic impacts of these measures on both the international aviation sector and the national economies under consideration. This investigation will be conducted on the basis of the results of the empirical modelling. It will be possible to differentiate the findings between regions, sectors, and in some cases even within an economic sector.
- To develop recommendations on how to proceed best strategically both on a national as well as on an international political level in order to reduce the total impact of aviation on climate change.

This paper is organized as follows: Section 2 provides an overview of the current state of the art. In section 3, AviClim's work plan is explained. In section 4, an update on the first results of the research project is provided and discussed and an outreach is given.

2. State of the art

A comprehensive assessment of aviation's climate impact has been provided by the IPCC Special Report "Aviation and the Global Atmosphere" (1999). The findings have been updated by Sausen et al. (2005) and Lee et al. (2009). In 2010, a new international assessment has been prepared within the DLR led EC projects QUANTIFY and ATTICA (Lee et al., 2010):

As mentioned above, the radiative forcing (RF) from aviation-induced clouds is about three times as large as the RF from contrails. The NO_X emissions have several effects resulting in methane destruction, ozone production and ozone destruction at different time scales. In total the RF from NO_X is positive (warming). On a rather short time-scale, ozone is formed (warming effect) with a life-time in the range from weeks to months. As a secondary effect, methane in the atmosphere is destroyed (cooling effect) with a life-time of about a decade. Finally, from the reduced methane a secondary ozone destruction results (cooling), which has the same life-time as methane.

Due to the different life-times, the climate impact of aviation's non-CO_2 effects is not proportional to the CO_2 emissions. Therefore, accounting aviation's non-CO_2 effects by simply applying a factor to the CO_2 emissions is not appropriate as it would provide incorrect incentives. Aviation's non-CO_2 effects depend on flight altitude, geographical location, cruise speed, day time, weather situation etc. (e.g.; Fichter et al., 2005; Mannstein et al., 2005; Fichter, 2009). This allows for climate friendly flight planning, which is currently investigated within the UFO project on behalf of the German Federal Ministry of Research and REACT4C project on behalf of the European Commission.

Currently, the science community discusses how to weigh short-lived non-CO_2 effects (e.g., Fuglestvedt et al., 2010). As of February 2013, no consensus has been reached on the most appropriate metric. But the choice of this metric is not arbitrary, it should be followed from the application it is used for.

From an economic point of view, the implementation of a charge on selected non-CO_2 species could be considered among other options. In 2008, charges on local NO_X emissions combined with a distance factor were proposed by some economists (CE Delft, 2008). Another possible instrument would be emissions trading, which is the trading of emissions allowances for selected non-CO_2 climate species. This would require the transformation of these effects in equivalent CO_2 according to a suitable metric. Compared to traditional command-and-control approaches, both economic instruments are characterised by reaching environmental targets very cost-efficiently. In addition, operational measures such as climate optimized flight trajectories could be a viable option. Both charges and emissions trading are currently or will soon be applied for the limitation of some of aviation's climate relevant emissions in a number of countries:

In Europe, aircraft emission charges on local NO_X and hydrocarbon (HC) emissions are in force for a number of years now. NO_X and HC being emitted during the landing- and take-off-cycle are subject to this charge. NO_X and HC are the main contributors to combustion-related local air pollution and precursors of ground level ozone. A positive more wide spread side-effect of the charge on local NO_X emissions is that it will also reduce greenhouse gas effects to some extent: Because more NO_X friendly engines are used, the amount of the gas emitted will be reduced at cruise level as well as below 3000 feet during the LTO cycle. On the other hand, a trade-off exists between the reduction of NO_X and CO_2 because aircraft engines can technologically be optimized either to minimise fuel burn, and thus CO_2 emissions, or to minimise NO_X emissions (Scheelhaase, 2010). An aircraft emission charge on local NO_X and HC emissions was first introduced in Switzerland in 1997 and in Sweden in 1998. All turbofan engines with more than 26.7 kiloNewton (kN) thrust were ranked according to their specific emissions establishing different emission classes – five classes in Switzerland and seven classes in Sweden. In 2003, a Europe-wide harmonized approach was developed by an European Civil Aviation Conference (ECAC) working group. This group created the ERLIG formula which provides a methodology for classifying and calculating NO_X and HC emissions deriving from aircraft engines (ECAC, 2003). Local emission charges following these guidelines were introduced in Sweden and at London Heathrow Airport in 2004, London Gatwick Airport followed in 2005.

In January 2008, an emission charge based on ERLIG recommendations has been introduced in Germany at Frankfurt and Munich Airports (Fraport, 2007), Cologne Bonn Airport followed in April 2008 and Hamburg Airport acted accordingly in 2010. Dusseldorf International introduced this charge in 2011. In Germany, the introduction of local emission charges is understood as a pilot phase with airports participating on a voluntary basis. After this phase, the environmental and economic impacts of the charge will be investigated and the design of the charge may be subject to modifications. Switzerland modified its system of local emission charges and moved towards the Europe-wide harmonized approach in 2010. While the goal of establishing economic incentives and the principle of revenue neutrality have been practically identical in Sweden, UK and Germany, the methods of calculating differ with regard to the amount of the charge, determining thresholds and the method of achieving revenue neutrality.

At the European Union (EU) level, the European Commission has been analysing, since 2008, whether charges on NO_X emissions at European airports can be a viable approach to reduce international aviation's non-CO_2 climate impact. Measures under consideration of the European Commission include a local NO_X charge modified by a distance factor, an en-route charge on NO_X emissions, an increased NO_X stringency for LTO emissions standard and a multiplier on CO_2 emissions (CE Delft, 2008). This approach is part of the general EU strategy to examine the full range of external costs for all modes of transport, to analyse the impact of the internalisation of external costs and to prepare a stepwise internalisation program for the EU (Council of the European Union, 1999).

Lately, a number of emissions trading schemes tackling climate change both on a national as well as on a supranational level affecting aviation have been introduced. However, these trading schemes are designed rather differently (Scheelhaase, 2011 and Scheelhaase, 2013):

In order to reduce international aviation's CO_2 emissions, air transport has been fully integrated into the EU emissions trading scheme (EU ETS) in 2012. This trading scheme covers all flights departing from or arriving at airports in the European Union, Norway and Iceland. By this way, both European and non-European airlines are participating in the EU emissions trading scheme. In this scheme, aircraft operators are obliged to hold and surrender allowances for CO_2 emissions. Concerning the EC Directives for the inclusion of air transport into the EU ETS, strongly diverting views of non-EU countries were expressed at the ICAO Assemblies in 2007 and 2010. Unlike the EU Member States, most other ICAO contracting states believe that an inclusion of non-EU carriers is only possible on the basis of mutual agreements which do not exist to date. In many countries opposed to the EU ETS, countermeasures and restrictions on European airlines have been prepared, such as special taxes and traffic rights limitations.

In November 2012, the EU Commission proposed to 'defer the requirement for airlines to surrender emission allowances for flights into and out of Europe until after the ICAO General Assembly' in autumn 2013. The EU Commission justified this proposal with 'the very positive discussions that took place' lately 'in the ICAO Council on a global market-based approach to regulating greenhouse gas emissions from aviation' (Commission of the European Union, 2012).

New Zealand has introduced an emissions trading system for the limitation of greenhouse gas emissions in 2008 (New Zealand Government, 2012). Until 2015, several sectors will have been gradually phased in the trading scheme. The forestry sector started in 2008. The liquid fossil fuels sector as well as the stationary energy and industrial processes sectors have become mandatory participants by 2010. The waste sector as well as the importers of 'synthetic' greenhouse gases such as HFCs, PFCs and SF_6 followed. In 2015, agriculture will be included, finally. Transport including domestic aviation has been covered indirectly by a so-called upstream approach: The liquid fossil fuels sector is expected to pass through the costs of compliance to the aircraft operators in the form of increased kerosene prices. Fuel used for international aviation (and marine transport) are exempt from the scheme, consistent with the Kyoto Protocol.

In Australia, a mandatory national emissions trading scheme has been introduced in 2012. This scheme is covering the stationary energy sources, parts of the transport sector, industrial processes, non-legacy waste, and fugitive emissions (Australian Government, 2011). Domestic aviation, domestic shipping, rail transport, and fuel used for non-transport applications are included. The scheme does not apply to fuels used for private transport, light vehicle business transport and off-road fuel use by agriculture, forestry and the fishing industry. The trading scheme started with a fixed carbon price of AUSD 23 per tonne which will be raised by 2.5 per cent in real terms in the years 2013 and 2014. In 2015, the carbon price will transition to a fully flexible market price (Australian Government, 2011).

A step-wise linking of the Australian emissions trading scheme with the European emissions trading scheme has been agreed in 2012. Until 2018, both trading schemes shall be fully linked (Australian Government/Commission of the European Union, 2012). By then, it will be possible to use carbon credits from the Australian scheme or allowances from the European Union emissions trading system for compliance under either system.

China is planning to introduce a nationwide carbon trading system by 2015, according to the 12th Five Year Plan of 2011 (Government of China, 2011). Here, the main emitters of CO_2 shall be included. Amongst other sectors, domestic aviation shall be participating. Following this strategy, China intends to reduce its growing demand for fossil fuels and to limit the impacts of climate change since a number of Chinese provinces are highly vulnerable to these effects. Currently, China is experimenting with seven regional carbon trading pilot systems. This way, various existing trading models are tested with the goal of finding suitable solutions for a Chinese national carbon trading system (Stockholm Environment Institute/FORES, 2012). In September 2012, it was agreed that the EU will provide expertise in setting up China's emissions trading systems (European Voice, 2012).

In May 2012, South Korea's National Assembly has passed legislation to introduce a national emissions trading scheme to tackle carbon emissions by the year 2015 (National Assembly of Korea, 2012). This way, South Korea's greenhouse gas emissions shall be reduced by 30 per cent until 2020. The cap and trade system will cover about 60 per cent of the national greenhouse gas emissions. Installations emitting more than 25,000 t CO_2-equivalent p. a. and entities emitting over 125,000 t CO_2-equivalent p. a. shall be participating on a mandatory basis. In addition, it will be possibly to opt-in on a voluntary basis (Yong-Gun, 2012). Linking arrangements with the European, Australian and New Zealand trading schemes are envisaged by the Korean Government (Europolitics, 2012).

All in all, the global framework for the limitation of aviation's climate relevant emissions is heterogeneous. This will have impacts on competition within the aviation sector. Against this background several ICAO high-level groups are working on global market-based measures for the limitation of aviation's CO_2 emissions. In addition, the ICAO Council has been tasked to establish a process to develop a framework for market-based measures in international aviation. These goals were agreed upon in the 37^{th} ICAO Assembly in October 2010.

In 2012, a new ICAO Council High-Level-Group was formed with the goal to focus on environmental policy challenges. The main objective of the group is to provide recommendations on the feasibility of a global market-based measure scheme appropriate to international aviation, as well as its development of a policy framework (International Civil Aviation Organisation, 2012). Hereby guidance to the general application of any proposed market-based measure to international air transport activity shall be provided. This task should be completed until the ICAO Assembly in October 2013.

Until now, the non CO_2 impacts of aviation on climate change have only been addressed scarcely both on ICAO and on a national level. Due to urgent environmental needs, the political regulation of the full climate impact of aviation is strongly recommended in the foreseeable future.

3. AviClim work plan

AviClim explores the feasibility for including aviation's full climate impact in international protocols for climate protection. The project is conducted within six interacting Work Packages (WPs) as outlined below. Three DLR institutes are involved with AviClim: Institute of Air Transport and Airport Research (DLR-FW), Institute of Propulsion Technology (DLR-AT) and Institute of Atmospheric Physics (DLR-IPA). AviClim is coordinated by DLR-FW.

3.1 WP 1: Metrics

Several RF (e.g., Global Warming Potential (GWP)) and temperature (e.g., Global Temperature Potential (GTP) or time integrated temperature change) based metrics will be adapted for the different aviation-induced contributions to climate change by DLR-IPA. The metrics will be applied to different emission scenarios (standard IPCC consistent scenarios from QUANTIFY; scenarios with reduced specific aviation emissions, e.g., such as suggested by ACARE; scenarios developed by WP 3 within AviClim) to calculate equivalent CO_2 emissions for the non-CO_2 effects involved: effects from NO_X emissions, effects from water vapour emission. Most of the calculations will be done by applying the AirClim model, developed by DLR-IPA (Grewe and Stenke, 2008). The output of this WP will enter WPs 3 and 4.

3.2 WP 2: Emissions Modelling

Within this WP, DLR-AT will carry out calculations of the absolute amount of CO_2 and NO_X emissions of aviation in the past (2000-2010) and in the foreseeable future (2011-2030). DLR-developed simulation and forecast models will be employed here. The application of such models is essential since no detailed and publicly available statistics on global aviation emissions exist to date.

A DLR-developed air traffic module will be applied in order to analyse aviation's historical emissions. This way, aviation's fuel burn and emissions of CO_2 and NO_X can be calculated. In order to forecast aviation's fuel burn, CO_2 and NO_X emissions for the years 2011-2030, an air traffic forecast module will be employed. In principle, the following tasks will be performed by the model as described in full by Schaefer, 2012:

- Regional traffic growth rates will be applied to the base year flight movements database obtained from the Official Airline Guide (OAG, 2011).
- A fleet forecast model will assign new aircraft types to flights from the flight schedules to account for the delivery of new aircraft and the retirement of older models. Future emission standards for NO_X and their influence on engine emissions are considered.
- Fuel burn and emissions of each flight will be calculated by the use of aircraft and engine emission profiles created by DLR's VarMission software.
- Non-aircraft related effects with influence on fuel burn and emissions, i.e. improved Air Traffic Management (ATM) procedures or load factor changes, will be considered during fuel burn and emissions calculations.

By the use of this model, aviation's fuel burn and emissions will be forecasted up to the year 2030.

3.3 WP 3: Political Measures and Scenarios

Alternative political measures for the reduction of aviation's CO_2 and non-CO_2 emissions impacting climate change have been analysed and designed in this WP by DLR-FW. This work has been conducted in a two-step approach: In the first step, viable political measures and their most promising design options have been identified. In this respect, especially global measures have been considered here due to the international character of aviation. At this point, both the findings of environmental economics and institutional economics theory as well as the relevant recent developments on the international level (UNFCCC, ICAO, EU) have been taken into account. Section 4 provides an overview of these results.

In the second step, the best design options for different market-based measures identified in the above described working step have been combined with different scenarios concerning the level of international support for the political measures tackling climate change. These scenarios have been designed in order to take the international dimension of the issue and the challenges associated with the international negotiations on climate change into account. The scenarios selected are presented in section 4 of this paper as well.

The comparison of the environmental and economic impacts of these different market-based measures and scenarios allows for conclusions on the environmental, economic and competitive impacts of the political measures under consideration. This will be investigated in WP 4 as explained below.

3.4 WP 4: Economic and Environmental Impacts

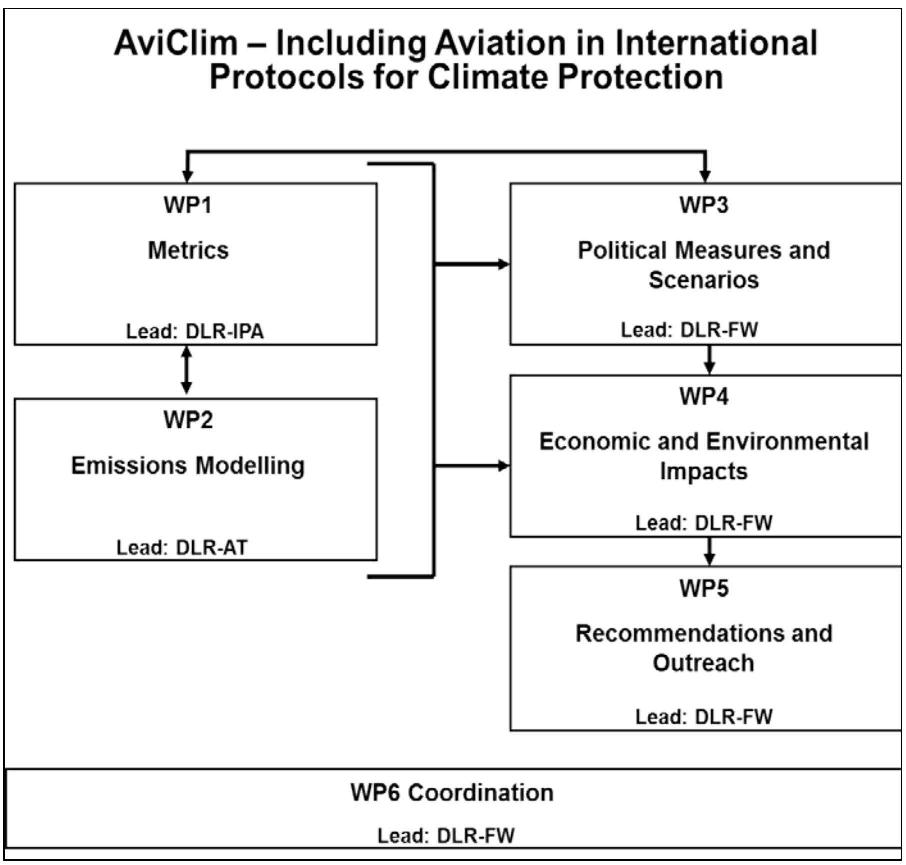
A model-based estimation of the economic and environmental impacts of the political measures under consideration will be conducted within this WP by DLR-FW. The economic impact will be estimated for the aviation sector as such, selected airline groups as well as for selected economies under consideration where the available data allows for it (see below).

We will be estimating the costs of reducing the climate relevant emissions/costs of compliance associated with the political measures under consideration for the airlines, for airports and air navigation service providers, as appropriate. Also, the competitive impacts as well as the economic efficiency of the market-based measure under consideration will be analysed. Furthermore, the economic effects for the consumers will be analysed. In addition, the effects on other economic sectors of the economies under investigation will be investigated where the data quality allows for it. For this research question, an Input-Output model will be employed. Input-Output models use a matrix representation of a nation's (or a region's) economy to predict the effect of changes in one industrial sector on others and on the consumers, government, and foreign suppliers on the economy. Finally, the environmental impacts of the market-based measure under consideration will be analysed. For this purpose, the results from employing the air traffic module will be combined with the previously conducted work steps of WP 4. This analysis allows for conclusions on the environmental effectiveness of the market-based measure under consideration, differentiated by the scenario assumed. Complementarily, the potential social benefits of reducing the CO_2 and non-CO_2 emissions of aviation impacting climate change will be investigated and compared with the reduction costs.

3.5 WP 5: Recommendations and Outreach

This WP will provide recommendations on how to proceed best both on a national as well as on an international level to include aviation's CO_2 and non-CO_2 impact on climate change in international protocols for climate protection. The following picture visualizes the work plan and the interactions between the work packages within AviClim.

Figure 2: AviClim Pert Chart



Source: DLR.

4. Update on first results and outlook

As of February 2013, WP 3 has mostly been completed. Based on a thorough literature review and the outcome of recent political discussions, market-based measures such as charges and emissions trading as well as operational measures (optimized flight paths, e. g.) seem to be most promising instruments for the limitation of aviation's full climate impact. This is because market-based measures aim to reduce the climate impacts of civil aviation in a most cost effective manner in contrast to command-and-control approaches such as stringencies and operating restrictions. This goal can be reached by a price signal via taxation, a charge or a trading scheme. If the price signal is set correctly, this approach leads to the internalisation of the negative external effects and thus a more adequate allocation of abatement costs.

Quite a number of different design options for market-based measures for aviation have been discussed both at ICAO CAEP and EU level as well as in literature for some years now. Based on our analyses, best options, in respect to economic efficiency, environmental benefits and practicability include:

- a climate tax,
- a climate charge,
- an emissions trading scheme for aviation's climate relevant emissions,
- operational measures: climate-optimal flight trajectories for the minimization of contrails.

The objective of a climate tax for aviation is to reduce the emission of greenhouse gases by giving the airlines a price signal for emissions reduction. This objective can be achieved in principle by investing in environmentally friendlier aircraft or by a reduction in passengers and/or freight demand. The implementation of a so-called climate tax is very attractive from a political point of view since it generates revenues. However, it is not guaranteed that the ecological targets are being met because it is a complicated matter to find the correct level of taxation. Also, the tax might have to be set at a relatively high price level in order to show any effects. Then emissions reductions would most probably result from a reduction of passenger demand and/or freight due to higher ticket prices/freight rates. Within the context of AviClim, the environmental and economic effects of a climate tax have therefore to be analysed in a very detailed and balanced manner to get to reliable results.

The climate tax shall be imposed on all climate relevant species emitted by aviation. The accountable entities of the climate tax will be the commercial aircraft operators. These companies will have to register at the relevant institutions, which could be the Ministry of Finance in analogy to the German ticket-tax, for instance. The commercial aircraft operators will have to monitor the basic data for the calculation of the climate tax (amount of fuel used, numbers of flights, arrival and departure airports of these flights, distance flown, aircraft employed, etc.). This data will be submitted ex-post on a monthly basis to the relevant institution which will determine the amount of the climate tax for this specific month. The amount of the climate tax will be calculated on the bases of the climate impact of the different species emitted in this month (CO_2, NO_X, H_2O, contrails and cirrus clouds). Therefore, the climate impact of the different species emitted by the commercial aircraft operator will be transferred into equivalent CO_2. In order to calculate equivalent CO_2 emissions for the non-CO_2 effects involved, different metrics will be applied. Since the climate impact of aviation is driven by both long-term effects from CO_2 emissions and shorter-term effects from non-CO_2 emissions (H_2O, particles, NO_X etc.) (Lee et al., 2010), metrics for two alternative timeframes will be analysed: 20 years and 50 years. A relatively short timeframe will put the emphases on the impacts of the rather short-lived species. A timeframe of 50 years, on the other hand, will allow to put the emphases on the impacts of the long-lived species such as CO_2.

In addition, it will be important to take into account the location of aviation-induced NO_X emissions when designing a climate tax for air transport. This is because the climate impact of aviation-induced NO_X emissions depends sensitively on where the emissions occur. Both changes on flight altitude and geographical location can cause different climate impacts of aircraft-induced NO_X emissions (Köhler et al., 2013). Since the climate tax will be calculated ex-post, the amount can be calculated on the bases of the actual route flown. This way, the climate impact of NO_X can be taken into account according to today's atmospheric science knowledge. When modelling the climate impact of NO_X in WP4 we will be adopting simplifying assumptions. These assumptions will refer to the distance and the altitude flown on cruise level, inter alia.

The climate tax can be calculated in three consecutive steps: In a first step, the amounts of the different aviation-induced species will be weighted with their specific climate metric. This way, the impact of non-CO_2 species can be transferred into equivalent CO_2. In a second step, these amounts are summed up. The result will be the total amount of equivalent CO_2 (in tons) emitted on the flights conducted in the timeframe under consideration. As a third step, the total amount of equivalent CO_2 will be multiplied by the price charged per ton equivalent CO_2. This approach can be illustrated by the following example for a climate tax on CO_2 and NO_X emissions. Under the assumption that the metrics 'Average Temperature Response (ATR)' with a timeframe of 20 years was applied, this climate tax can be calculated as follows. The other aviation-induced non-CO_2 species can be covered accordingly.

[$tCO_2*ATR_{20} + tNO_{x\ LOW}*ATR_{20} + tNO_{x\ CRUISE\ (i)}$] * price per ton equivalent CO_2 = amount of the climate tax.

Where: $NO_{X\ LOW}$ is the amount of NO_X emissions emitted below cruise levels. $NO_{X\ CRUISE}$ is the amount of NO_X emitted on cruise level. Note that the formula differentiates where the NO_X emissions occur ($_i$). To calculate the amount of the climate tax, at first the amounts of CO_2 and NO_X emitted will be calculated. Here, the NO_X emissions will be distinguished by the altitude and geographical location of emission. As a next step, the amount of each species will be multiplied by the corresponding metrics (here: ATR_{20}) with ATR_{20} for CO_2 taking a value of 1. The result is equivalent CO_2 for each species emitted.

A charge on climate relevant substances could be designed as an en-route charge, a charge on local emissions combined with a distance factor, amongst other options. A LTO-NO_x charge, which is already applied at different European airports, is particularly an instrument which aims to improve local air quality. However, it does not include cruise NO_x emissions. Therefore, within AviClim, a LTO-NO_x charge combined with a distance factor will be analysed in particular as this instrument will regulate both LTO-NO_X and cruise NO_X emissions. The inclusion of cruise NO_X emissions will improve the effectiveness of this instrument for the reduction of global climate change impacts (CE Delft, 2008). However, it has to be taken into account that a trade-off exists between NO_x and CO_2. This implies that applying current technologies, a reduction of NO_x emissions leads to a higher fuel consumption and subsequently to higher costs for airlines and an increase of CO_2 emissions.

When calculating a LTO-NO_X charge combined with a distance factor, as a first step LTO NO_X emissions have to be estimated. The data for this calculations can be taken from the ICAO "Aircraft Engine Exhaust Emissions Data Bank" (ICAO, 2004), the Swedish Aeronautical Institute FOI "Emission data bank for turboprop engines" and the "Emission Value Matrix for Aircraft with Unregulated Engines" developed by the Swiss Federal Office for Civil Aviation and the Swedish Civil Aviation Authority" (Unique AG, 2003). In these data banks, emission data on all engines produced in the past has been provided by ICAO and the engine manufacturers. On the bases of the LTO NO_X emissions, the total NO_X emissions can be calculated by introducing a distance factor which can be estimated by the great circle distance of the flights under consideration and a factor which represents the specific NO_X emissions of the airframe/engine combination employed (CE Delft, 2008). When modelling the economic and environmental effects of the climate charge in WP 4, simplifying assumptions will be introduced at this point.

In analogy to the climate tax discussed above, the amount of the charge can be calculated in three consecutive steps: Firstly, the metrics for NO_X emissions differentiated by the latitude and geographical location will be applied (ATR_{20} respectively ATR_{50}). Secondly, the resulting amounts of equivalent CO_2 will be summed up. Finally, the sum of equivalent CO_2 will be multiplied by the price per unit equivalent CO_2. The amount of the climate charge for a given flight will be resulting.

In contrast to the above mentioned instruments, an emission trading system limits the climate relevant emissions to a predefined amount. This implies that a given emission reduction goal can be met by this instrument. Furthermore, the trading scheme allows for emissions reductions in the most cost efficient manner. Different design options are, for instance, open emissions trading schemes which include aviation and other emitting sectors versus closed emissions trading schemes where trading can only occur within the aviation sector. An open system would be advantageous since costs of emission reduction within the aviation sector are very high compared to other sectors (Witt et al., 2005). Thus, airlines would be able to contribute to the emission reduction by purchasing emissions permits from other sectors which are able to reduce emissions at lower cost. In addition, other sectors receive financial resources which can be directly invested in further emission reduction measures. Within AviClim, the effects of the implementation of two different emission trading schemes will be further analysed in this context. These trading schemes will cover different climate effects:

(1) CO_2 + LTO NO_X, + Cruise NO_X
(2) CO_2 + LTO NO_X, + Cruise NO_X + H_2O + aviation-induced cirrus clouds, particles, etc.

While the first option concentrates on the climate effects of CO_2 and NO_X, the latter option also covers further climate relevant aviation-induced species. Both options require a metrics differentiated by the emissions species addressed. The main advantage of the latter option would be the inclusion of the majority of the climate relevant substances in one reduction scheme. For the calculation of the amounts of equivalent CO_2 and the price of the required emission permits per flight, the method explained above in the sections ‘climate tax’ respectively ‘climate charge’ can be applied.

With regard to operational measures, climate-optimal flight trajectories like the reduction of cruise altitude are intensively discussed as a potential beneficial option (Dahlmann, 2012, Koch et al., 2011; Gierens, 2008; Williams et al., 2002; Williams et al., 2003). The advantage of this approach is that the formation of contrails and contrail cirrus can be minimized. However, the adjustment of aircraft altitude also results in other adverse side-effects. Due to a suboptimal flight altitude, aircraft might not be operated in a cost efficient way. Fuel burn would increase and hence more CO_2 would be emitted into the atmosphere. Furthermore, journey time might increase which implies potentially higher costs for airlines (e.g. staffing, scheduling) and less travel comfort for passengers particularly on short haul flights (Williams and Noland, 2005). Therefore, it is of importance to take operational, economic and environmental aspects into account of the analyses. The EC project REACT4C conducts a feasibility study with regard to flight altitudes and flight routes that lead to reduced fuel consumption and emissions, and lessen the environmental impact. Therefore, the results of this project will provide important inputs for AviClim.

The selected market-based and operational measures will be combined with different scenarios of international support for the environmental instrument under consideration: Based on the political discussions on UNFCCC- and ICAO-level in the last decade, four scenarios seem to be worthwhile considering:

- The first scenario assumes that the political measure under consideration will be implemented by the Member States of the European Union (EU27) plus Norway, Iceland and Liechtenstein, but not by the rest of the world.
- A second scenario which assumes that the US, Canada, South Korea, Japan, Singapore, Russia, Australia, India, China, Brazil and the United Arab Emirates will introduce this political measure in addition to the European States (EU27, Norway, Iceland, Liechtenstein and Switzerland). This way, the major players and emitters in international aviation will be addressed.
- A third scenario assumes that all Annex-I Countries of the Kyoto Protocol plus Brazil, Russia, India and China but none of the other developing countries will implement the climate protecting measure under consideration.
- Finally, a scenario assumes that the climate protecting measure under consideration will be implemented worldwide.

As a reference development, a business-us-usual scenario will be developed. In this scenario, the absence of climate protecting measures in aviation other than described in section 2 of this paper, is assumed. Table 1 visualizes how selected measures and scenarios will be combined and analysed in WP 4.

Table 1: General approach in AviClim WP 4

Reduction Instruments/ Measures	**Scenario 1: EU27 + Norway, Iceland, Liechtenstein**	**Scenario 2: USA, Canada, South Korea, Japan, Singapore, Russia, Australia, India, China, Brazil, UAE plus EU 27, Norway, Iceland, Liechtenstein, Switzerland**	**Scenario 3: Annex-I countries plus Brazil, Russia, India, China**	**Scenario 4: World**
Climate tax				
Climate charge	Environmental	effects?		
Emissions trading				
Operational measures	Economic	effects?		
…..				

Source: DLR.

First quantitative results will be presented at the WCTR 2013 conference in Rio. AviClim final results can be expected in autumn 2014. Results will be discussed with important stakeholders in aviation business, aviation politics and research.

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