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Cost and competitive impacts of addressing aviation's full climate impact by the European Emissions Trading Scheme

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Abstract

The EU Council intends to limit air transport's full climate impact (CO_2 and NO_x, H_2O, SO_x, aerosols, contrails and contrail cirrus). A likely approach is the inclusion of all climate relevant species from aviation in the European Emissions Trading Scheme (EU ETS). We provide a proposal for this practice and analyze the economic impacts. Modelling results indicate that the cost effects of the EU-ETS addressing both CO_2 and non-CO_2 emissions will be much larger than under the current scheme. This is because under the new approach, all climate relevant species are regulated and not just CO_2. The cost effects also depend on the length and altitude of the flight. Both has consequences for the competitive environment of the airlines under the scheme. Especially the full service network carriers will have to bear a competitive disadvantage. Remarkably, some cost effects are contrary to the respective findings for an ETS for the limitation of CO_2 alone.

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Keywords: Air transport, climate relevant emissions, EU Emissions Trading Scheme, cost effects, competitive impacts

1. Introduction

Climate relevant emissions from aviation are carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x), water vapor (H_2O), aerosols, contrails and contrail cirrus. According to the International Panel on Climate Change (IPCC), the actual total climate impact of aviation is estimated to be two to four times higher than the effect of its past CO_2 emissions alone (IPCC, 1999 and 2007). Grewe et al. (2017) and Lee et al. (2009) assessed aviation's full contribution to total radiative forcing to be about 4.9% in the year 2005 where the share of CO_2 was 1.6% and the share of the so-called non-CO_2 species (H_2O, NO_x, SO_x, soot, contrails and contrail cirrus) was 3.3%.

Currently, international as well as national political measures regulate only aviation's CO_2 emissions: Both CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) as agreed in 2016 and the EU Emissions Trading Scheme (EU ETS) for aviation aim at limiting air transport's CO_2 emissions (Scheelhaase et al., 2018). The same applies to the New Zealand, South Korean as well as the Chinese Trading Schemes (IETA, 2016a, 2016b and 2016c).

In 2008, the EU Commission already planned to regulate air transport's NO_x emissions (CE Delft, 2008), but did not (yet) succeed. In October 2017, the European Council requested the EU Commission to speed up its work on addressing the full climate impact of aviation (Council of the European Union, 2017). Possible measures for the limitation or reduction of aviation's full climate impact include integrating the non-CO_2 species into the current EU ETS for aviation as well as operational and technological measures. In this paper, we concentrate on the former. In practice, a combination of all three approaches seems likely.

The EU Council's intention to address aviation's full climate impact from 2020 onwards may have significant impacts both on the environmental footprint of the European aviation sector and on the competitive environment here. Hence, it is crucial to analyze the principal functioning and impacts, which, to our knowledge, have not yet been investigated by any paper in the academic literature.

This paper is organized as follows: First, we provide the main characteristics of aviation's climate relevant emissions. Then, the design of the current EU-Emission Trading scheme and a proposal for integrating the so-called non-CO_2 species from 2020 onwards are presented. Third, we conduct back-of-the-envelope quantifications of the costs associated with the new scheme for selected flights and airlines. Finally, competitive impacts are discussed for a number of use cases.

2. Main characteristics of air transport's climate relevant emissions

Air transport contributes to climate change by emitting carbon dioxide (CO_2), nitrogen oxides (NO_x), sulfur oxides (SO_x), water vapor (H_2O) and aerosols. Also, the formation of line-shaped contrails and contrail cirrus are of importance here (Dahlmann et al., 2016).

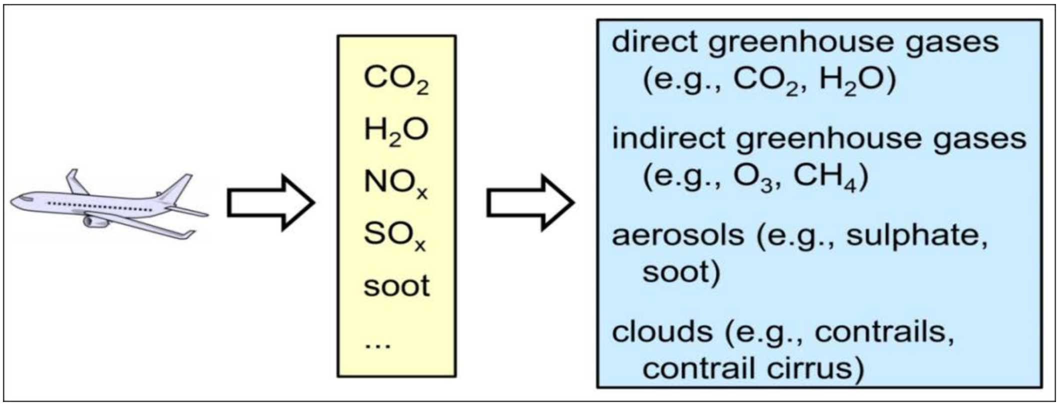

Figure 1: Climate relevant emissions from air transport. Source: DLR.

All of these emissions change the radiation balance of the atmosphere and lead to a radiative forcing (RF) that results in a temperature change (Grewe et al., 2017). The most important non-CO_2 effects are water vapour emission (IPCC, 1999), the formation of line-shaped contrails (Schumann, 1996) and contrail cirrus (Burkhardt and Kärcher, 2011), as well as NO_x emissions which lead to changes in ozone and methane concentrations (e. g. Grooß et al., 1998). These non-CO_2 effects are particularly important for the climate impact of air transport as their impact depends on the location of the emission (flight altitude, geographical location, day time, weather situation etc.) (Dahlmann et al., 2016, Fichter et al., 2005; Mannstein et al., 2005; Fichter, 2009). In addition, the different climate species react on very different time scales. While e.g. contrail cirrus have a large impact shortly after the emission, but a fast decrease in time, CO_2 has a low impact at the beginning, but occurs over a longer time period. Due to the different life-times in the atmosphere, 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 (Scheelhaase et al., 2014a). Against this background, the choice of metric for comparing short-lived effects with each other and with long-lived effects is important. A number of different metrics is discussed in literature (see for instance Dahlmann et al., 2016). In this paper, the metric 'Average Temperature Response 50' will be applied because it seems most appropriate for the question investigated here. The Average Temperature Response 'atr' 50 is the mean change in near surface temperature averaged over 50 years (Scheelhaase et al., 2016). The metric atr 50 more or less balances the effect of short-lived climate agents like ozone and contrail cirrus with the effects of CO_2, as the former show a large effect at the beginning of the time period analyzed but a fast decrease in time, while the latter has a low impact at the beginning, but occurs over a longer time period (Scheelhaase et al., 2014a).

3. Principal design of the EU Emissions Trading Scheme for air transport

In the European Union, an Emissions Trading Scheme (EU ETS) for the reduction of CO_2 emissions from stationary sources has been introduced in 2005. In 2012, international aviation has been integrated into the trading scheme. As mentioned earlier, the EU ETS for aviation limits only air transport's CO_2 emissions. Non-CO_2 impacts of aviation have so far not been included. Legal frameworks are the Directives 2008/101/EC and 2009/29/EC (Council of the European Union, 2009a and 2009b).

In 2012, the scheme covered all flights departing from or arriving at airports in the European Union, Norway and Iceland (so-called European Economic Area 'EEA'). In the EU ETS, European and third-country aircraft operators are responsible for holding and surrendering CO_2 allowances for their flights. For compliance, EU Allowances (EUAs) as well as permits from the Kyoto based 'Clean Development Mechanism' (CERs) and 'Joint Implementation' (ERUs) are accepted. Emission permits from 'Joint Implementation' and 'Clean Development Mechanism' may only be used for up to 1.5 per cent of the number of allowances individually required for surrendering in a given year.

In the timeframe 2013 until 2020, the total quantity of allowances allocated to aircraft operators is limited to 95 per cent of the average historical aviation emissions of the years 2004–2006 (so-called overall "cap") (Meleo et al., 2016; Dae Ko et al., 2017). Allowances allocated to aircraft operators are valid within the aviation sector only, but aircraft operators are free to purchase additional permits from other markets. Flights from third countries having introduced 'equivalent' CO_2 reducing measures may be excluded from the EU ETS. Due to the lack of equivalent measures in countries of relevance, this option has not (yet) played a role.

Some exemptions from the EU ETS apply: Flights performed within the framework of public service obligations (PSO) on routes within outermost regions or on PSO routes with an annual capacity of fewer than 30,000 seats are exempted. Also excluded from the EU ETS are flights performed by commercial air transport operators operating either fewer than 243 flights per four-month period for three consecutive four-month periods (so-called 'de minimis' clause) or flights with total CO_2-emissions of less than 10,000 tons per year. The 'de minimis' clause was introduced with the goal of reducing the administrative costs for operators with a low number of flights to and from Europe. Another exemption refers to flights performed under visual flight rules, amongst some other exemptions.

In 2013, the Council of the EU and the European Parliament agreed to temporarily limit the coverage of the EU ETS to flights within the European Economic Area (EEA) only. This so-called "Stop the Clock" decision was originally limited to the period 2013 to 2016, but as of July 2018, this geographical limitation is still in force and may be extended. The EU's motivation to temporarily limit the scope of the system was to give leeway to an emerging international consensus at the International Civil Aviation Organization (ICAO) level. After decades of negotiations, ICAO Contracting States started developing a global market-based measure for the reduction of international air transport's CO_2 emissions in 2013. Three years later, the global 'Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)' has been agreed by the ICAO Assembly (ICAO, 2016). However, a great number of CORSIA's rules and regulations still have to be developed. Against this background, the EU decided to maintain the geographical limitation of the EU ETS for aviation until more clarity will have been gained on CORSIA's implementation (Commission of the European Union, 2017).

4. Possibilities for including non-CO_2 Species in the EU ETS for air transport

How could air transport's non-CO_2 emissions be included in the EU ETS? In principle this is possible by 'translating' the climate impact of the non-CO_2 species into equivalent CO_2. This way, the different climate relevant species can be compared with each other and the total amount can be added up in kilogram or tons CO_2 equivalent. Under this approach, the existing CO_2-EU ETS could be enlarged by aviation's non-CO_2 species and the full climate impact of this sector could be addressed simultaneously.

For this purpose, the metric atr 50 can be applied. It is important to note that the metric differs according to the actual flight position (flight altitude, longitude and latitude) and the climate relevant species under consideration. This way we take into account that the climate impact of the non-CO_2 species differs by the actual flight position and by climate relevant gas. For calculating the full climate impact of air transport on a flight-by-flight-basis, the following formula can be used. This formula has been developed and successfully applied for the first time in the 'AviClim' research project (for details see Scheelhaase et al., 2014b and 2016).

$$Climate\ relevant\ species\ under\ the\ EU\ ETS = \sum_{peFlight} CO_{2_{(p)}} + NO_{x_{(p)}} * atr_{50_{(p)}}^{(NO_x)} + H_2O_{(p)} * atr_{50_{(p)}}^{(H_2O)} + dist_{(\delta)} * atr_{50_{(p)}}^{(Cont)}$$

Where: $NO_{x(p)}$ is the amount of NO_x emitted on the different flight altitudes, degrees of longitudes and latitudes (identical with flight position p) at different points in time. The climate relevant species H_2O, CO_2 and contrails are differentiated by the flight position p as well, because these species diversify with the local atmospheric conditions and the actual thrust-setting of the engines, as mentioned above. Since the climate impact of CO_2 does not depend on the altitude of emission, it is not necessary to take the flight altitude ($atr_{CO2,p}$) into account for this climate relevant species.

This formula can be applied to all flights and airlines under the EU ETS on a flight-by-flight-basis. It is possible to do this in retrospect (after the flight has been conducted) since the actual flight route taken and the local atmospheric conditions at that time and flight position are known by the airline which conducted the flight as well as by the Air Navigation Service Provider (Eurocontrol, e. g.). The summation of all individual flights' amount of CO_2 equivalent equates to the total amount of climate relevant species (in million tons) under the trading scheme for aviation.

On the basis of the total amount of CO_2 equivalent under the ETS for aviation, the emissions cap can be calculated. In the current EU ETS, the CO_2 cap is currently set at 95% of the average historical emissions (2004-2006). Whether or not the cap for the full climate impact of aviation will be fixed at this level will be a political decision. However, in principle the cap can be calculated and set for any given year for which data on actual flight routes served and local atmospheric conditions for these flights are available by applying the formula above. For all emissions exceeding the cap, permits have to be purchased by the aircraft operators. Since the aviation sector is expected to grow in the future, aviation will be a net buyer on the emission permits market.

In the EU ETS aircraft operators can either reduce their climate relevant emissions or buy permits for their operations. By climate friendly flight planning it is possible to avoid substantial amounts of climate relevant gases. According to Grewe et al. (2014), a large potential exists to reduce air transport's contribution to climate change by re-routing. Also, small changes in flight trajectories already significantly reduce their climate impact. These climate friendly operational measures can be planned and conducted by employing a DLR-developed flight planning tool which optimizes flight routes with respect to their climate impact and costs (Grewe et al., 2014). Technological measures, for instance the investment in more fuel efficient engines, can also lower air transport's climate impact. But it should not be forgotten that a trade-off exists between the reduction of NO_x and CO_2. This is because today's aircraft engines can technologically be optimized either to minimize the use of fuel, and thus CO_2 emissions, or to minimize NO_x emissions.

For modelling also the share of free allocation has to be been assumed. In this paper, a free allocation rate of 85 % like in the current EU ETS has been assumed. The remaining 15 per cent of permits can be auctioned by the airlines. Applying these rules, the amount of climate relevant species under the emission trading scheme and the amount of emissions exceeding the cap can be calculated. For the latter, emission permits have to be purchased by the airlines. The amount of permits allocated free of charge to the individual airlines can be determined by a so-called benchmark – identical to the current EU ETS.

The method of calculating the benchmark for aviation has been described in literature, for instance see Scheelhaase et al. (2010) for details. In short, the total amount of CO_2 equivalent of the base year is weighed with the share of emission permits allocated for free (current EU ETS: 85%). The result will then be calculated as a ratio of the total revenue ton kilometres (RTK) of the base year. This benchmark in turn will be multiplied by the absolute number of RTK submitted by the airline for the base year to calculate the individual amount of permits allocated free of charge. This way, very environmental efficient airlines will get a higher amount of emission permits for free while relatively inefficient aircraft operators will receive a smaller number of permits per RTK. Thus, early movers in terms of climate friendliness will be rewarded for their past steps. The benchmark applied can be regarded as a measurement for the environmental efficiency of the flights under the reduction scheme.

5. Costs and competitive impacts of an EU ETS regulating air transport's full climate impact

Which costs will be associated with an EU ETS for regulating aviation's full climate impact from an airline point of view? In principle, this cost impact can be calculated by subtracting the number of permits allocated free of charge to the airline under consideration from the absolute amount of CO_2 equivalent emitted. The delta is the number of permits which has to be purchased by the airline on the emission permits market. This delta can be multiplied by the price for CO_2 equivalent. The costs for complying with the emission trading scheme on an airline level result. However, an estimation of the costs on individual companies' level would be associated with too many uncertainties. This is because airline's management strategies and market developments play a predominant role in this respect, which are difficult to foresee for external parties. The summation of the costs of all airlines under the trading scheme equates to the total costs of the airline sector for complying with the scheme's regulations.

By applying an averaged ratio 'free allocation/permits purchased' to single flights of airlines under the trading scheme, the costs for complying with the EU ETS for all climate relevant species can roughly be estimated on the level of individual flights. However, it should be noted that these estimations are based on a number of simplifying assumptions. For instance, the amount of CO_2 equivalent under the EU ETS cap has to be assumed which in practice will highly depend on political decisions. Therefore some uncertainty is associated with the results for individual flights.

Data basis for the estimation of the flight specific costs is a forecast emission inventory developed by DLR. In the AviClim research project, this inventory has been combined with CO_2 equivalence factors (on the bases of atr 50) to calculate the associated amounts of CO_2 equivalents. For details see Scheelhaase et al. (2014b) and Scheelhaase et al. (2016).

For this purpose, the climate impact of different climate agents (CO_2, H_2O, NO_x (O_3+CH_4+ O_3^{pm}) in different flight altitudes has been analyzed by the climate response model AirClim (Dahlmann, 2012). The climate impact of different climate agents is used to estimate the amount of CO_2 equivalents using the metric atr 50. As mentioned above, the Average Temperature Response 'atr' is the mean change in near surface temperature averaged over 50 years. The CO_2 equivalents which in particular depend on flight altitudes have been calculated on a flight-by-flight basis (Scheelhaase et al., 2016).

As a next step, the amount of CO_2 equivalent for selected short haul, medium haul and long haul flights has been interrogated. Table 1 presents these results in tons CO_2 equivalent per flight for the year 2020. Here, we differentiated between CO_2 and non-CO_2 species. Underlying assumptions are an autonomous efficiency increase of 1.4 per cent p. a. on average in the future and a ‘Standard Atmosphere’ for the flights under consideration.

Table 1. Climate relevant emissions of selected flights in the year 2020

Departure	Destination	Aircraft	Seats	Distance (miles)	CO_2 + Non-CO_2 (tons)	CO_2 (tons)
AMS	CDG	B737	132	248	9.8	6.5
CGN	TXL	B738	189	289	12.0	7.3
BCN	DUS	A319	144	726	46.5	11.5
DUB	FMM	B738	189	814	62.6	17.0
MUC	PMI	A320	144	756	54.3	14.5
DUS	DXB	A332	278	3114	427.3	105.3
MUC	MIA	A333	221	5008	590.5	177.9
CDG	LAX	B772	280	5670	1088.8	243.7
PRG	JFK	A332	225	4082	543.7	128.6

Source: DLR modelling results, based on Scheelhaase et al. (2014a).

As expected, taking into account the full climate impact of aviation always results in larger amounts of climate relevant species than considering CO_2 alone. However, the ratio (CO_2 + Non-CO_2)/CO_2 is not a constant, it rather depends on the individual flight and on the flight length. While this ratio for a short-haul flight like Amsterdam (AMS) – Paris (CDG) or Cologne/Bonn (CGN) – Berlin (TXL) amounts to 1.5 and 1.6, respectively, for a long-haul flight such as Munich (MUC) – Miami (MIA) or Paris (CDG) – Los Angeles (LAX) it is 3.3 and 4.4, respectively. Here it shows that the time flown on cruise level is an important factor for the climate effect of each flight. This is mainly because NO_x emitted on high altitudes (i. e. cruise levels) has an increased climate effectiveness (Lee et al. (2010) and Lee et al. (2009)). Consequently, short- and medium-haul flights cause relatively smaller amounts of non-CO_2 emissions than long-haul operations.

As a next step, an averaged percentage ‘free allocation/permits purchased’ of 62 % to 52 % has been applied on all flights. This averaged percentage has been calculated by the author on the basis of assumptions for the free allocation rate explained above and on the grounds of the AviClim project. It depends on the environmental efficiency of the airline under consideration in the past and on the airline’s business model. Low cost carriers (LCC) like Ryanair (IATA code ‘FR’), for instance, will receive a higher percentage of permits free of charge compared to a full service network carrier (FSNC) such as Lufthansa (IATA code ‘LH’). This can be explained by the relatively high load factors and therefore better environmental performance of the low cost carrier.

The outcomes are the amounts of CO_2 equivalent for which emission permits have to be purchased for the selected flights. Multiplying this outcome by an assumed CO_2 equivalent price, costs for complying with the EU ETS for the flights under consideration result. In this paper, a CO_2 equivalent price of 8 € per ton has been assumed. Table 2 presents the results of these calculations.

Not surprisingly, costs for complying with an EU ETS for CO_2 only regime are much smaller than the cost impact triggered by an ETS for regulating the full climate impact of aviation. Again, the flight length is a crucial factor for the cost impact. In absolute numbers the highest cost impact can be expected for long-haul flights while short-haul connections will only have to bear a relatively small financial burden. For instance, costs for the flight Prague (PRG) – New York (JFK) will amount up to 2’071 € (CO_2 + Non-CO_2 regime) and 490 € (CO_2 regime) (per flight segment), whereas a short- or medium-haul connection, respectively, such as Barcelona (BCN) – Dusseldorf (DUS) or Dublin (DUB) – Memmingen (FMM) will lead to a cost increase by 141 € (CO_2 + Non-CO_2 regime) and 34 € (CO_2 regime) and 190 € (CO_2 + Non-CO_2 regime) and 51 € (CO_2 regime), respectively.

In reality, these costs for the airlines under the emission trading scheme can be lowered, if, for instance, operational measures will be applied by the airlines. Also, the cost effects depend to a large scale on the actual price for CO_2 equivalent on the emissions trading market. For comparison: as of February 2018, the price for EU Allowances was about 8 € per ton CO_2 equivalent (EEX, 2018). But there is reason to believe that CO_2 equivalent prices will rise in the future, as the emissions cap for the EU ETS for stationary sources will be constantly decreased in the upcoming years.

Table 3 presents the costs for complying with the EU ETS per passenger and table 4 shows these costs per mile and per passenger mile. Belly freight and a possible pass-over of the costs of the EU ETS on belly cargo have not been considered here. Against this background, results in tables 3 and 4 illustrate rather the upper end of the cost increase.

Table 2. Cost for complying with the EU ETS per flight segment in the year 2020

Departure	Destination	Airline	Rate of free allocation	Price per permit (€/t CO_2equivalent)	Cost for emission permits per flight segment in €	
					CO_2 + Non-CO_2 regime	CO_2 regime
AMS	CDG	KL	0.56	8	34.50	22.60
CGN	TXL	4U	0.62	8	36.45	22.29
BCN	DUS	4U	0.62	8	141.74	34.88
DUB	FMM	FR	0.62	8	190.82	51.89
MUC	PMI	LH	0.56	8	190.30	50.64
DUS	DXB	EK	0.52	8	1628.31	401.24
MUC	MIA	LH	0.56	8	2068.43	623.08
CDG	LAX	AF	0.56	8	3813.84	853.63
PRG	JFK	DL	0.52	8	2071.96	490.27

Source: DLR modelling results, based on Scheelhaase et al. (2014a).

Table 3. Cost for complying with the EU ETS per passenger in the year 2020

Departure	Destination	Airline	Seats	Load factor	Cost per passenger per flight segment in €	
					CO_2 + Non-CO_2 regime	CO_2 regime
AMS	CDG	KL	132	0.81	0.32	0.21
CGN	TXL	4U	189	0.76	0.25	0.15
BCN	DUS	4U	144	0.76	1.29	0.32
DUB	FMM	FR	189	0.97	1.04	0.28
MUC	PMI	LH	144	0.79	1.66	0.44
DUS	DXB	EK	278	0.75	7.80	1.92
MUC	MIA	LH	221	0.79	11.79	3.55
CDG	LAX	AF	280	0.86	15.80	3.54
PRG	JFK	DL	225	0.86	10.76	2.55

Source: DLR modelling results, based on Scheelhaase et al. (2014a). Belly freight has not been taken into account for the selected flights. Load factor data was taken from the airlines’ websites.

Table 4. Cost for complying with the EU ETS per mile and per passenger mile in the year 2020

Departure	Destination	Distance	Cost per mile (€)		Cost per passenger and mile (€)	
		(miles)	CO_2 + Non-CO_2 regime	CO_2 regime	CO_2 + Non-CO_2 regime	CO_2 regime
AMS	CDG	248	0.13	0.09	0.0013	0.0008
CGN	TXL	289	0.12	0.07	0.0009	0.0005
BCN	DUS	726	0.19	0.04	0.0018	0.0004
DUB	FMM	814	0.23	0.06	0.0013	0.0003
MUC	PMI	756	0.25	0.06	0.0022	0.0006
DUS	DXB	3114	0.52	0.13	0.0025	0.0006
MUC	MIA	5008	0.41	0.12	0.0024	0.0007
CDG	LAX	5670	0.67	0.15	0.0028	0.0006
PRG	JFK	4082	0.50	0.12	0.0026	0.0006

Source: DLR modelling results, based on Scheelhaase et al. (2014a). Belly freight has not been taken into account for the selected flights.

As tables 3 and 4 illustrate, costs for complying with the EU ETS for short-haul operations can be considered negligible. According to our calculations, ticket prices are expected to increase by between 0.15 and 1.66 € per flight segment and passenger. For medium-haul and especially long-haul operations, this changes. For the long-haul flights selected, ticket price increases in a range of 2.55 to 3.55 € (CO_2 regime) and 10.76 to 15.80 € (Non-CO_2 + CO_2 regime) have been estimated. This may appear small at first sight, but for airline customers using meta booking engines like kayak.com or skyscanner.com this could be an important factor for choosing a certain flight or not. From an airline's point of view, it is very important to appear among the first 5 to 10 search results of the meta booking engine to get the awareness of this costumer group.

The results calculated for the specific cost per mile and cost per passenger mile illustrate the importance of the time flown on high altitude for the economic effect by the EU ETS for regulating the full climate impact of aviation: While the cost per passenger mile for a CO_2 only regime decrease by the flight distance operated, the costs per passenger mile rise in a Non-CO_2+CO_2 regime in relation to the distance. For instance, under the Non-CO_2+CO_2 regime the short-haul flight segment CGN – TXL will become more costly by only 0.0009 € per passenger mile and the long-haul connection CDG – LAX by 0.0028 € per passenger mile. In other words: the latter flight will have to bear more than three times the specific cost increase compared to the short-haul flight.

This leads to the following consequences for the competitive environment of the aircraft operators under the trading scheme. Firstly, only optimizing fuel efficiency will not be rewarded under an EU ETS for reducing aviation's full climate impact. Instead it becomes more important to keep the trade-off between fuel efficiency and NO_x emissions in mind. This finding is contrary to the respective results for an EU ETS limiting CO_2 alone. Secondly, airlines concentrating their business on long-haul operations such as Emirates will be facing a competitive disadvantage compared to aircraft operators mainly offering short- and medium-haul flights. This finding is also contrary to the respective findings for political measures limiting aviation's CO_2 emissions only. Thirdly, full service network carrier (FSNC) will have to bear a competitive disadvantage compared to airlines offering just short- and medium-haul connections. If the EU ETS for regulating aviation's full climate impact will only be introduced for European airlines, especially the local FSNC (Lufthansa, Air France, Iberia, e. g.) will have to face a competitive disadvantage against their FSNC-competitors from outside Europe (Delta Airlines, Turkish Airlines, e. g.). This is because particularly long-haul operations will become more costly under this kind of EU ETS which are the most profitable operations for FSNC from today's point of view.

6. Conclusion

The EU Council intends to regulate aviation's full climate impact (CO_2, H_2O, NO_x, contrails etc.). A likely approach is the inclusion of all climate relevant species from aviation in the EU Emissions Trading Scheme. We developed a practicable method for this approach and analyzed the cost effects on the level of individual flights.

According to our modelling results, the cost effects of the EU-ETS addressing both CO_2 and non-CO_2 emissions will be much larger than under the current scheme as the non-CO_2 species contribute to a large amount to the total climate impact of aviation. The cost effects also depend on the length and altitude of the flight. Especially the flight time operated on cruise level is an important factor for the climate effect of each flight. This is mainly because NO_x emitted on high altitudes (i. e. cruise levels) has an increased climate effectiveness (Lee et al. (2010) and Lee et al. (2009)). Consequently, short- and medium-haul flights cause relatively smaller amounts of non-CO_2 emissions than long-haul operations.

The EU Council's intention to address aviation's full climate impact from 2020 onwards may have significant impacts both on the environmental footprint of the European aviation sector and on the competitive environment here: Firstly, only optimizing fuel efficiency will not be rewarded under an EU ETS for reducing aviation's full climate impact. Instead it becomes more important to keep the trade-off between fuel efficiency and NO_x emissions in mind. This finding is contrary to the respective results for an EU ETS limiting CO_2 alone. Secondly, airlines concentrating their business on long-haul operations such as Emirates will be facing a competitive disadvantage compared to aircraft operators mainly offering short- and medium-haul flights. This finding is also contrary to the respective findings for political measures limiting aviation's CO_2 emissions only. Thirdly, full service network carrier (FSNC) will have to bear a competitive disadvantage compared to airlines offering just short- and medium-haul connections. If the EU ETS for regulating aviation's full climate impact will only be introduced for European airlines, especially the local FSNC (Lufthansa, Air France, Iberia, e. g.) will have to face a competitive disadvantage against their FSNC-competitors from outside Europe (Delta Airlines, Turkish Airlines, e. g.). This is because particularly long-haul operations will become more costly under this kind of EU ETS which are the most profitable operations for FSNC from today's point of view.

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