D3.3 – Recommendations

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ClimOP Consortium

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Abbreviations

Abbreviation	Definition
aCCFs	Algorithmic climate change functions
ATM	Air traffic managment
ATR	Average temperature response
CAPEX	Capital expenditure
CLIM	Climate-Optimised Flight Planning
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CSA	Climate sensitive areas
DOC	Direct operating costs
EEA	European Economic Area
ELEC	Electrification of ground equipment of an airport
EU ETS	European Union Emissions Trading System
FREE/WIND	Free Routing and Weather Optimal Flight Planning
INFR	Upgrading airport infrastructure
ISOC	Climate Optimised Intermediate Stop Operations
ISSR	Ice-supersaturated regions
KPI	Key performance indicator
LOSL	Flying Low and Slow
MET	Aeronautical meteorological services
NETW	Strategic Network Planning
OI	Operational Improvement
SAF	Sustainable aviation fuel
SETX	Single engine/electric/hybrid taxiing
TOC	Total operating costs

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1 Introduction

It is estimated that the contribution of global aviation in 2011 was 3.5% of the anthropogenic global warming through CO_2 emissions and non-CO_2 climate effects [1]. In terms of radiative forcing, the contribution of the non-CO_2 effects is estimated to be twice as large as the contribution of CO_2 emissions alone [1]. Tackling the non-CO_2 climate impacts is challenging: they depend on the aircraft operation and the local conditions of the atmosphere. Therefore, it requires a thorough understanding of the atmospheric processes and being able to predict the atmospheric conditions well in advance to take them into account in flight planning or execution properly.

The European research project ClimOP focuses on identifying and assessing the most promising operational improvements to reduce the climate impact of CO_2 and non-CO_2 effects and evaluating the impact of these improvements on various aviation stakeholders. For this purpose, ClimOP investigates promising mitigation strategies. These strategies are defined as the combination of one or more operational improvements with promising regulations and policies to enable the implementation of these improvements.

In Work Package 1, the operational improvements (OIs) went through a multi-step multi-criteria assessment procedure, where 8 OIs were selected divided into three groups:

- Climate-optimised operation of the airline network: Climate Optimised Intermediate Stop Operations (ISOC) and Strategic Network Planning (NETW);
- Climate-optimised trajectories: Flying Low and Slow (LOSL), Free Routing and Weather Optimal Flight Planning (FREE/WIND) and Climate-Optimised Flight Planning (CLIM); and
- Operational and infrastructural measures on the ground: Electrification of the Ground Operation Vehicles (ELEC), Upgrading Airport Infrastructure (INFR), and Green Taxiing (SETX).

In Work Package 2, the climate impact of the selected operational improvements was assessed, including non-CO_2 effects, as well as non-climate KPIs, which include economic, political, operational, and social evaluations [2].

Work Package 3 identified the most relevant regulations and policies to implement and maintain the operational improvements. Regulations and policies that, in their current shape and form, foster the implementation of operational improvements were considered alongside ones that would need adjustment [3]. Indeed, subsequent analysis showed that more than current regulations and policies are needed to facilitate or incentivise the implementation of operational improvements. Therefore, a more quantitative approach to non-climate KPIs and stakeholder impacts was conducted to evaluate the mitigation strategies [4]. Three mitigation strategies were selected and investigated: charging climate sensitive areas; including non-CO_2 in the European Union Emissions Trading System (EU ETS) and ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA); and sustainable taxiing. These were selected based on modelling feasibility, research relevance, policy interest, (high-level) compatibility with the current aviation system, and relevance to various OIs.

Each mitigation strategy is based on a quantitative assessment which includes a climate and cost impact analysis, and a qualitative assessment which includes, among others, regulatory and policy aspects. The ClimOP project is focused on evaluating the mitigation strategies, but ClimOP does not necessarily prescribe or propose them.

Currently, uncertainties in the climate impact calculation of non-CO_2 effects are considerable [1]. The ClimOP mitigation strategies assume that stakeholders have obtained access to sufficiently accurate data on the individual climate effects. As such, the mitigation strategies do not consider decision making under uncertain conditions. The recommendations do, however, address the quality, the resolution and the accuracy of the data and ways to improve some of these aspects.

IATA’s position regarding environmental modulation of charges and taxation is not always aligned with the policy aspects investigated in the ClimOP mitigation strategies. The ClimOP mitigation strategies may therefore investigate aspects which are not endorsed by IATA. Appendix A outlines IATA’s position as representative of the airlines perspective. Appendix A does not include research results from the ClimOP project. As such, it does not reflect the position of the ClimOP consortium.

2 Charging climate sensitive areas

The climate impact of non-CO_2 effects is dependent on time and space. So-called climate sensitive areas (CSA) are regions where the non-CO_2 effects have a particularly high climate impact. Flight trajectories avoiding these areas have the potential to reduce the climate impact of the flight.

2.1 Summary

Charging climate sensitive areas is a pricing mechanism that aims to reduce the climate impact of a flight by incentivising aircraft operators to take routes avoiding climate sensitive areas [5]. This mitigation strategy was evaluated using a case study spanning flights crossing the North Atlantic Ocean. CSA were defined as parts of 4D airspace (3D location and time) for which algorithmic climate change functions (aCCFs) [6, 7] indicated especially strong climate sensitivity, mainly governed by the existence of contrail formation zones. The top-5% of the aCCFs values on the investigated case study day defined the threshold for the CSA to which the charge was applied. For the investigated case study[1], a charge of €1.5 per kilometer flown through the CSA was determined to be just high enough to make the climate-friendly rerouting economically attractive, and offset additional time costs and fuel costs related to rerouting around the CSA. The concept of charging CSA is illustrated in Figure 1.

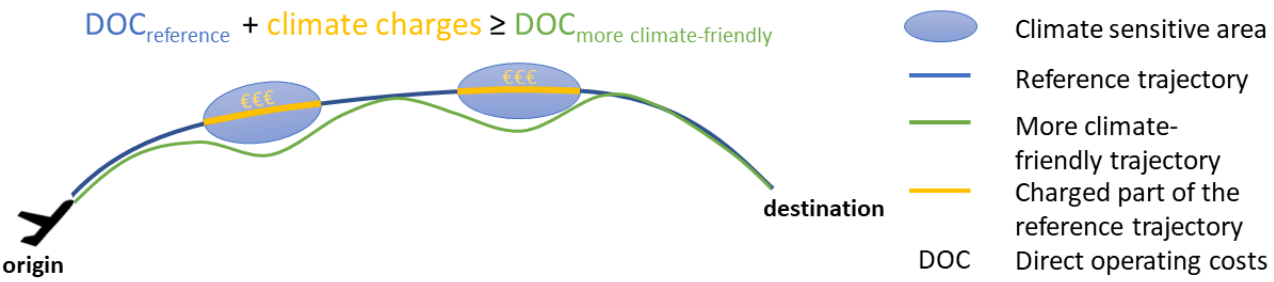

Figure 1: Sketch of the concept of charging climate sensitive areas

From the results of the case study, it was concluded that this mitigation strategy has the potential to incentivise more climate-friendly routes if the original trajectory would cross a CSA. No charge was applied for routes that did not cross such an area, such that the original trajectory could be maintained without changes in cost. The analysis of the application of such a CSA charge on a larger dataset of flights between Europe and North America showed an overall increase in airline direct operating costs (DOC). This cost increase is either caused by the charge or by the additional fuel consumption and flight time increase related to rerouting around a CSA. For 90% of flights on the investigated day, the DOC increase was limited to 1.7% at most, with higher increases (up to 7.3%) observed for the other 10% of flights – of which trajectories crossed larger portions of CSA. The median value was 0.2%.

The implementation of charging CSA could happen in three different ways. They are intended to mark a first approach and more investigation of the feasibility is needed:

1. Inclusion into air navigation fees and subsequent charge modulation.
2. Airlines could voluntarily engage third parties to provide definition, prediction, and monitoring of climate sensitive areas. Alternatively (if approach 1 would be found to be unfeasible), consideration could be given to the introduction of an additional and advanced meteorological

[1] For a flight on the summer day 16 June 2018 more climate-friendly alternative trajectories have been identified and the costs for flying through the climate sensitive area (where the top-5% of the aCCFs values on that day defined the threshold for the CSA) have been varied in the range €0 to €5 per kilometre flown through CSA.

service, paid for using a separate en-route charge, possibly combined with further charge modulation.
3. Taxation, possibly ring-fencing these revenues to reduce aviation climate impact further.

Aviation stakeholders, including airlines and industry associations have expressed concerns and reservations about the implementation of climate charges. The main reasons are related to the the economic impact on airlines.

The mitigation strategy charging climate sensitive areas can be divided into three operational phases and the responsible stakeholders are identified:
1. Planning: calculation and definition of climate sensitive areas by MET providers and/or meteorological institutes.
2. Execution: communication of climate sensitive areas and monitoring by the EUROCONTROL Network Manager for EUROCONTROL member countries and comparable institutions of other countries.
3. Accounting: charging of airspace users by the EUROCONTROL Central Route Charges Office for EUROCONTROL member countries and comparable institutions of other countries.

2.2 Recommendations

This section gives recommendations based on the results and limitations of the work in the ClimOP project and addresses relevant stakeholders as target groups of the recommendations.

1. Develop aCCFs further and validate the aCCFs for an extended geographical scope

To: research community

Although the algorithmic climate change functions (aCCFs) that have been used for the climate impact assessment are state-of-the-art, they should be further developed. Right now, the aCCFs are developed and validated in the region above the North Atlantic Ocean and for selected summer and winter weather situations [6, 7]. For an implementation of charging CSA in other regions, the aCCFs first need to be extended and validated for an extended geographical scope. There should be a process where the aCCFs are evaluated and compared to other methods of estimating the climate impact of aviation. When applied for policymaking, the use of an extended geographical scope is recommended in order to discourage flight trajectories being planned around the scope region to avoid possible charges or other policy impacts (similar to carbon leakage).

2. Increase the resolution of the weather data with respect to altitude levels

To: MET provider

The publicly available meteorological data used in the case study is ERA5 data from ECMWF (European Centre for Medium-Range Weather Forecasts). The meteorological data is given for six different altitudes in the range of typical cruise altitudes. For more detailed studies and a future implementation of charging climate sensitive areas, the resolution of the publicly available weather data with respect to the altitude levels needs to be increased to have reliable data on the flight levels. This could allow for more refined rerouting, potentially alleviating some of the airspace capacity challenge that comes with rerouting, but could also increase computational cost and time.

3. Improve the prediction and model validation of ice-supersaturated regions (ISSR)

To: meteorological institutes, research community

Contrails have a large contribution to the climate impact of a flight and they form if the Schmidt-Appleman criterion is satisfied. The formed contrails are persistent if the aircraft flies through ice-supersaturated regions (ISSR) [8]. Avoiding the flight through ISSR would thus avoid persistent contrails. Due to high gradients in the relative humidity field at cruise levels and a lack of reliable humidity data at cruise levels, the prediction of ISSR still needs to be improved. Moreover, the validation of the models with measurements is essential. Existing models can estimate where ISSR are present, however, high uncertainties remain. Reducing these uncertainties is crucial to reduce the likelihood of unnecessary (if a contrail region is mispredicted, i.e., if a contrail was predicted but did not occur) or failed reroutings (if contrails also occur on the adjusted route, even though they were not predicted to), which have an increased impact on global warming. The infrastructure to distribute the data needs to be updated.

a. Installing improved onboard humidity sensors for validation purposes

To: Aircraft manufacturers, airlines, research community, (meteorological institutes)

Installing humidity sensors onboard aircraft would provide the means to obtain relative humidity measurements at cruise levels. The ISSR prediction models could use this data for validation and improvement. Also, the required infrastructure for the data transfer should be installed.

Aircraft manufacturers should investigate the additional effort (including certification and costs) that building humidity sensors into aircraft during the production would bring. Alternatively, instead of waiting for new aircrafts equipped with humidity sensors, retrofits offer a possibility to equip existing aircraft with humidity measurement sensors; however, they are costly. Airlines that decide to buy aircraft with humidity sensors or retrofit aircraft would contribute to the ISSR prediction advancement like it is done by the IAGOS-fleet [9]. The additional weight of the onboard humidity sensors and the associated costs (incuding the extra fuel consumption as a result of the extra weight) are important parameters that must be assessed. Any additional expenses could be publicly funded.

b. Investigate using satellite data for validation purposes and tactical reroutings

To: research community

More research on the applicability (influenced by, among others, resolution and data availability) and usage of satellite data as a promising pathway for the future is needed. Firstly, measurements of the humidity via satellites could be used to improve the ISSR prediction models. Secondly, satellite images can be used to analyse the formation of contrails and their spreading. With this information, tactical reroutings for contrail avoidance could be determined shortly before the start or in-flight.

4. Assess the impact of using absolute and/or relative threshold definitions

To: research community, policymakers, ,air navigation service providers, airlines, network manager

A climate sensitive area is defined within this project as a region where a merged aCCFs value exceeds a certain threshold value. The threshold value needs to be determined in advance with the goal of reducing non-CO_2 effects at the expense of small route deviations. Relative thresholds per day would limit the percentage of charged airspace on that day whereas absolute thresholds would ensure comparability between the climate impacts on different days or different seasons. The effectiveness and feasibility of relative thresholds, absolute thresholds, and combinations thereof need further study.

5. Assess the feasibility of implementation of charging climate sensitive areas

To: policymakers, regulatory organisations, air navigation service providers, airlines, network manager

The three identified policy approaches for charging climate sensitive areas should be further assessed from a regulatory and policymaking perspective. In this process, validation by operational stakeholders should be sought.

6. Perform a pilot project over the North Atlantic Ocean

To: air navigation service providers, network manager, airlines, policymakers, regulatory organisations

Pilot projects would give more insights into the operational feasibility and the associated challenges of charging climate sensitive areas. The EUROCONTROL MUAC contrail avoidance trial in 2021 [10] showed that persistent contrails could be avoided. A pilot project over the North Atlantic Ocean in collaboration between the US, Canada, Iceland, the UK, and the bordering EU states would give valuable insights into the large-scale feasibility of charging climate sensitive areas.

7. Assess the airspace capacity constraints that would result from implementing climate sensitive area charging

To: air navigation service providers, network manager

Rerouting aircraft around CSA could lead to a locally more congested airspace. Further studies should be conducted that evaluate the potential of avoiding CSA, considering the airspace's capacity and its effects on the air traffic flow.

8. Assess the effects of implementing climate sensitive area charging on airlines at network level

To: airlines, air navigation service providers, network manager

Due to the increased flight times of rerouted flights around climate sensitive areas, airlines could be affected in their network. This effect should be studied in more detail with models that consider the whole airline network.

3 Including non-CO_2 in CORSIA and EU ETS

Including non-CO2 effects in EU ETS and CORSIA is a mechanism of pricing non-CO2 effects, which could influence how airlines choose to fly and promote climate-friendly operational improvements. This measure has, however, a considerable impact on airline costs and demand and concepts of operations, which requires attention.

3.1 Summary

Alternative flights with reduced climate impact from the trajectory-related operational improvements, usually show drawbacks in other non-climate KPIs. For instance, to reduce the climate impact, aircraft may deviate from climate sensitive areas, leading to longer trajectories. As a consequence, the flight time and the fuel-consumption increase and, consequently, the direct operational costs (DOC) become higher. Without regulations and policies in place, a profit-based optimisation would neglect non-CO_2 effects during operations. If a cost is attributed to non-CO_2 effects, then aircraft operators might become more inclined to take them into account in their flight trajectory optimisations, assuming a profit-based approach.

The EU ETS and CORSIA (ICAO) are economic measures that assign a market-based price to CO_2 emissions, stimulating in-sector reductions or out-of-sector compensation of CO_2 emissions. Following the EASA report [11], European policymakers and legislators have proposed several ways to address the non-CO_2 effects in updates to the EU ETS, which is revised as part of the Fit for 55 set of proposals launched by the Commission in July 2021 [12, 13]. Whereas the Commission proposal did not include non-CO_2, the European Parliament adopted several amendments related to aviation non-CO_2. Specifically, it proposed to [14]:
– set up a monitoring, reporting and verification scheme (MRV scheme);
– submit a legislative proposal containing mitigation measures for non-CO_2 effects, by expanding the scope of the EU ETS to cover such effects, no later than 31 December 2026;
– until the adoption of such a proposal, account for the non-CO_2 effects as a multiple of the CO_2 emissions.

A provisional deal between the European Parliament and the Council of December 2022 dropped the use of a multiplier, but it did include the MRV scheme and outlook of including non-CO_2 in the ETS [15]. Specifically, the agreement between Parliament and Council "provides that the Commission will implement an MRV system for non-CO_2 effects in aviation from 2025. By 2027, the Commission will submit a report based on the MRV and, by 2028, after an impact assessment, the Commission will make a proposal to address non-CO_2 effects." [15].

Although Europe seems to be leading the way in addressing non-CO_2 effects of aviation, ICAO in its latest Environmental Report [16, p. 141] listed "identifying operational opportunities to reduce non-CO_2 emissions" as one of the priorities for the CAEP/13 cycle.

Including aviation non-CO_2 effects in CORSIA or EU ETS could reduce the climate impact by incentivising the selection of climate-optimal trajectories, which, due to the non-CO_2 pricing, could potentially become cost-optimal (Figure 2). In order to include non-CO_2 effects in these pricing mechanisms, non-CO_2 climate impacts need to be expressed as CO_2-equivalent emissions, for which various metrics and approaches exist. This analysis aims to assess the impact of including non-CO_2 effects in EU ETS and CORSIA on airline decision-making, costs and demand.

	Neglecting non-CO_2 costs	Pricing non-CO_2
Cost-optimal solution	Fuel-optimal	Climate-optimal

Figure 2. Simplified representation of the working principle of this mitigation strategy. In practice, several other aspects must be considered, e.g. flight time and indirect operating costs.

The analysis is performed for the period of 2022-2050, with focus on the horizon years of 2030, 2040, and 2050. Including non-CO_2 effects in EU ETS and CORSIA are assumed to occur at the beginning of 2030. Furthermore, it is assumed that the scope of EU ETS will remain for intra-EEA flights only and that extra-EEA flights will be covered by CORSIA. The trajectory optimizations and the climate impact calculations were based on kerosene-powered flights. The influence of SAF on fuel costs and the possibility of airlines declaring the share of SAF used to reduce their CO_2 offset requirement in CORSIA or the required amount of allowances to be surrendered in EU ETS have also been included. The costs per CO_2 and $CO_{2,eq}$ emitted are calculated, considering the following:

- Estimated unit prices for offsetting CO_2 emissions in CORSIA or trading CO_2 emissions in EU ETS (to 65 €/t$CO_{2,eq}$ and 315 €/t$CO_{2,eq}$ in CORSIA and EU ETS, respectively, by 2050);
- Free allowances in EU ETS;
- Emission reductions due to SAF in EU ETS and CORSIA;
- Anticipated future developments in the schemes (e.g., considering the phase-out of free allowances in EU ETS by 2026 and assuming CORSIA's ambition level to be increased to achieving net zero emissions by 2050);
- Evolution in time of EU ETS and CORSIA's cap;
- Evolution in time of sectoral growth factors (CORSIA).

The reduction of $CO_{2,eq}$ (non-CO_2 effects) offset requirements due to SAF, however, has not been taken into account. Although there is evidence of reduced non-CO_2 effects (mainly contrails) when using SAF [17], the quantification of this effect is not sufficiently established. Furthermore, the impact of hydrogen aircraft on costs, CO_2 and non-CO_2 effects has not been included in this analysis.

The efficacy of including non-CO_2 in CORSIA and EU ETS was studied in ClimOP using 16 case study flights from the trajectory-related OIs CLIM, LOSL and ISOC. The climate impact of aircraft emissions is measured using the average temperature response (ATR) as climate metric, assuming a future emission scenario (F-ATR), over a time horizon of 20 or 100 years (F-ATR20, F-ATR100). The efficacy of this mitigation strategy increases with time. In 2030, the number of cases in which the climate impact is reduced and the operating costs are lower than the reference[2] amount to 3 and 4, respectively, based on F-ATR20 and F-ATR100. In 2050, relatively lower climate impact and costs are obtained in 13 of the 16 case studies (for both climate metrics).

Subsequently, the impact on airline cost and demand of including non-CO_2 in CORSIA and EU ETS was evaluated using a significantly larger data set from the NETW OI, spanning flights of three European airlines (about 1100 flight destinations). The evaluation results (based on F-ATR20, climate based) show airline total operating costs (TOC) could increase substantially if airlines do not manage to reduce their non-CO_2 climate impact. By 2030, a cost increase of 7-16% is estimated, increasing to 23-50% by 2050. Passing these costs on to consumers would reduce demand by about 5-12% in 2030 and 12-24% in 2050. Especially in 2030, the impacts on intra-EEA flights are larger due to differences in price and fraction of emissions covered in EU ETS and CORSIA. These differences reduce over time as a consequence of the assumption that CORSIA's cap fall linearly from 2035 down to zero by 2050—aligned with ICAO's long-term aspirational goals. For example,

[2] This is a relative cost comparison, in which non-CO_2 costs are included in both the reference and the alternative flights.

these impacts could be reduced if airlines adjust their networks and trajectories to be more climate-friendly.

Although not studied in detail, it is noted that the price differences identified could lead to market distortions or waterbed effects. These are exacerbated if non-CO_2 would only be included in EU ETS and not in CORSIA. Furthermore, uncertainties in the determination and calculation of climate impact should be reduced prior to implementing non-CO_2 in EU ETS or CORSIA.

3.2 Recommendations

In this section, recommendations are given to the relevant stakeholders based on the conclusions and limitations of this work.

1. *Investigate in further detail the feasibility of airlines to cope with the predicted cost increases due to pricing of CO_2 emissions and non-CO_2 effects, combined with the fuel cost increase due to SAF*

To: research community, airlines and policymakers

Airlines are sensitive to cost increases. In 2019, the average net profit margin of airlines was about 3% [18]. Furthermore, most airlines were reported to be close to break-even (about 60 out of 106), while “considerable losses” were reported by a “relatively small number of airlines” [18]. It is, therefore, uncertain whether some airlines will be able to cope with the demand decreases predicted in this evaluation (12-24% by 2050 due to non-CO_2 only). This could lead to a significant change in the air transportation network, e.g. as a result of the consolidation of airlines. Other possible consequences are reduced air connectivity, higher fares (making flying less accessible) and increased air traffic congestion next to climate sensitive areas, where flying around them would likely become cheaper and, therefore, desirable. Air connectivity improves the competitiveness of local and national economies and enhances employment and economic growth [19]. Air traffic congestion is already an issue due to constrained airspace capacity and increasing air traffic demand [20].

2. *Consider market distortions and climate-leakage as a result of the differences between EU ETS and CORSIA*

To: policymakers

The observed differences between costs impacts of flights covered by the different schemes (i.e., EU ETS and CORSIA) affect how passengers choose their flights. Cost-sensitive passengers that cannot travel from their origin to their destination directly, but need to transfer between flights, could try to reduce costs by scheduling their transfer in a less expensive region, for example, because a more stringent or more expensive cost scheme is in place. Such a cheaper route could be one with a bigger climate impact than the initial flight, leading to an unintended increase in climate impact, referred to as *climate leakage,* i.e. the equivalent to *carbon leakage* for the climate impact, including non-CO_2 effects.

The magnitude of the climate leakage risk depends on a variety of factors. Regional cost differences, the availability of alternative travel options and consumer behaviour are considered most influential. A study on potential carbon leakage of the joint set of Fit for 55 proposals by the European Commission [21] showed the effect to vary substantially across routes, but averaging 6% across intercontinental routes by 2035—meaning that 6% of the CO_2 savings achieved by the set of measures are effectively made undone by carbon leakage. In case non-CO_2 effects were to be implemented only in EU ETS, but not in CORSIA, climate leakage and market distortion would likely be increased.

3. *Improve the accuracy of the estimated impact on cost and demand*

To: research community

Further research, tackling the limitations of this work, could improve the accuracy of the results. The main points are listed below.

a. Perform a profit-based network optimisation in combination with trajectory optimisation, already including SAF and non-CO_2 costs

In this work, the network optimization and trajectory optimization have been realized prior to the cost and demand analysis, with SAF and non-CO_2 costs only being incorporated at a later stage. If these costs had been incorporated prior to the profit-based optimizations, new optimal solutions of reduced impact were expected to be found. Therefore, the estimates of cost and demand impact realized in this study are conservative ones, as the actual impact is expected to be lower.

b. Include aircraft efficiency improvements for horizon years and recalculate the climate impact for these years

The horizon years analysed in this study only consider new prices of SAF, CO_2 and $CO_{2,eq}$ emissions. Aircraft efficiency improvements will reduce the fuel consumption and CO_2 emissions and therefore the impact on costs and demand. This could not be considered in this work as the climate impact calculations preceded the cost and demand impact analysis and could not be updated for this purpose.

c. Include the effect of SAF on non-CO_2 effects

The use of SAF has the potential of reducing the number of soot particles and, consequently, the number of ice crystals in contrails [17]. This, in turn, might yield a reduced impact from contrails. The precise estimation of the impact on contrails due to SAF requires further research. Therefore, this effect has been neglected in this study.

d. Consider the impact of hydrogen-powered aircraft

The impact on demand and costs of hydrogen aircraft has not been considered. Although the use of hydrogen would eliminate CO_2 emissions during flight and likely change non-CO_2 effects, estimating the impact on non-CO_2 effects and the infrastructure costs of implementing hydrogen is in itself an active topic of research, but was left out of scope of this study.

e. Consider the development of total operating costs with time

The total operating cost estimations only considered the changes in the SAF mix and future SAF costs. The other components of TOC, including the fossil fuel price, have been assumed static. Furthermore, the TOC would also increase in order to implement the OIs, for instance, due to increased workload related to flight planning and additional infrastructure required, when considering non-CO_2 effects. This has not been considered in this evaluation.

f. Consider the development of new operational strategies and business models

The increasing operating costs may force airlines to reformulate part of their operational strategies and the way they conceptualise their network. For instance, the cooperation between airlines when developing their network, the reposition of part of their operations to other markets, different strategies for fleet renewal, or the change of business focus (e.g. into a purely point-to-point operations) may influence the costs and the demand expected in the future. These strategic operational changes have not been considered.

g. Consider differences in SAF mix for flights departing from outside of the EEA

In this study, the SAF mix was based on Destination 2050 [22] and on the ReFuelEU Aviation [23], which are applicable to flights departing from the EEA. The same SAF mix has been assumed for flights departing from outside of the EEA, however, the SAF mix in such cases depends on the regulations and policies of the country of origin and it could deviate substantially from that applied in the EEA.

4. Address the uncertainties related to calculation of the climate impact from aviation and incorporate them in the reported impacts and in the decision making

To: airlines, air navigation service providers and research community

Uncertainties related to the calculation of the climate impact from aviation remain relatively high [1]. Efforts on minimizing these uncertainties are required, but dealing with them accordingly is also needed. This means including uncertainty ranges on the final reported values—be that on climate impact or on any derived quantity, such as $CO_{2,eq}$ costs—as well as considering such ranges for making decisions, minimizing the associated risks. These considerations were beyond the scope of this work.

5. Consider other KPIs, e.g. connectivity and air traffic congestion

To: research community and policymakers

This work focussed on the impact of OIs and regulations and policies on costs and demand. Other key performance indicators, such as the air connectivity and air traffic congestion, should be adequately addressed as they affect, for instance, economic growth, safety and ATM workload.

6. Consider the impact on other stakeholders, e.g. air navigation service providers and aircraft manufacturers

To: research community and policymakers

This analysis focussed mainly on the impact on airlines, as they are, together with passengers, the most impacted stakeholder by this mitigation strategy. However, pricing non-CO_2 effects may influence how airlines choose to fly and possibly which aircraft they choose to buy. These changes will indirectly influence air navigation service providers and aircraft manufactureres, and the resulting impact deserves further consideration.

7. Ensure that the CO_2,eq computations are sensitive to any effects of SAF on non-CO_2 effects

To: policymakers

The calculation of $CO_{2,eq}$ due to non-CO_2 effects when using SAF should differ in comparison to kerosene. Once research on the impact of SAF on non-CO_2 effects (recommendation 3.c) matures, these differences should also be incorporated in trading and offsetting schemes (assuming non-CO_2 effects have been included therein).

4 Sustainable taxiing

Sustainable taxiing operations include single-engine taxiing, electric towing (e.g. TaxiBot), or electric taxiing using an onboard system (e.g., WheelTug). Sustainable taxiing operations can bring substantial benefits to the climate and local air quality around airports.

4.1 Summary

Electric towing

By using electric tow trucks the aircraft is towed over a substantial part of the distance between the gate/stand and the runway, so that it does not have to operate its own engines. This saves fuel and therefore emissions, which has a positive impact on climate and local air quality. The analysis performed by the ClimOP consortium shows electric towing has the potential to approximately halve the emissions from taxiing [4]. The electric towing service is provided to airlines by either the airport or by ground handling service providers. Airlines will be charged for using this service. The cost assessment shows that such solutions are most attractive for aircraft in the single-aisle and wide-body categories. This is mostly influenced by the CAPEX of the electric towing vehicle, fuel prices and economies of scale.

The costs impact analysis performed by the ClimOP consortium considers two approaches for calculating the service charges that airlines would have to pay to use the electric towing vehicles. In the first approach the towing charge reflects the actual cost of the service provided. The implementation is cost neutral considering both the capital and operational expenditures of the towing truck, profit margins for the airport or ground handlers have not been included. In the second approach it considers equal distribution of costs between the airport and the airlines.

The ClimOP project performed case studies for Malpensa Airport. Based on a cost neutral implementation of the service charges for electric towing, landing and take-off fees at Malpensa Airport would increase by 22% for the regional category (e.g. Embraer 190), 7% for the single-aisle category (e.g. A320-family) and 8% for the wide-body category (e.g. A350-family) if the trucks are autonomous. This cost increase would, however, be partly or fully offset by savings in fuel cost. For airlines, it is economically beneficial compared to single engine taxiing (assuming central CAPEX estimates for towing vehicle) for the single-aisle category for jet fuel prices above €0.65 per kg and for the wide-body category for jet fuel prices above €1.2 per kg. This service charge is not beneficial for the regional category unless single-engine taxiing is not yet implemented.

Electric taxi using an onboard system

For electric taxi using an onboard system, which increases the aircraft operating empty weight and, thereby, increases fuel consumption and associated emissions during flight, the environmental benefits depend on the application. Environmental and economic benefits are the largest for relatively short flights with relatively long taxi times, operated by smaller aircraft (regional jets), and decrease with increasing aircraft size, increasing flight distance and decreasing taxi time. Across aircraft classes, the onboard taxi system weight was found to be of major influence on the feasibility of such systems.

- The climate impact and cost assessment contain several sources of uncertainty. The uncertainties in the climate impact calculation are related to the Breguet Range equation and NO_x emissions index. The uncertainties related to the cost assessment are linked to the capital and operational expenditure estimates. As such, the results provide a preliminary estimate of the percentage of profitable flights with decreased climate impact.
- For regional jets considering 2019 price levels, the onboard taxi system weight reduction (from 500 kg to 250 kg) is effective with respect to both climate impact and cost impact. The percentage of profitable flights for airlines that have a reduced climate impact increases from

68% to 82%. For 2050 price levels and a system weight of 250 kg, the percentage of profitable flights with a decreased climate impact increases to 99% when including non-CO_2 pricing.

- For the narrow-body category of aircraft (e.g., Airbus A320 and Boeing 737), decreasing the onboard taxi system weight (from 500 kg to 250 kg) increases the percentage of profitable flights that have a reduced climate impact from 34% to 49%. For 2050 price levels and assuming an onboard taxi system weight of 250 kg, the percentage of profitable flights that have a decreased climate impact increases to 98%.
- Implementing onboard electric taxi systems on wide-body aircraft is not profitable on the short term. Assuming 2019 price levels and a low onboard taxi system weight of 500 kg, the system would only be economically feasible on 4% of the flights. In 2050, the profitability would increase to 77% when including non-CO_2 pricing.
- Especially for wide-body aircraft, a portion of the profitable flights for which the onboard electric taxiing systems can be used, actually increases the climate impact. To prevent airlines from installing the onboard system on these flights, pricing non-CO_2 emissions can create the correct incentive.

Although not investigated in detail by the ClimOP project, it is noted that the main challenges related to the implementation of electric towing trucks are operational. These depend on the airport type and layout, but also include stakeholder cooperation and workload. Concerns about air traffic controller workload especially could be addressed through using a combination of onboard electric taxi systems and electric towing trucks.

4.2 Recommendations

In this section recommendations are given to the relevant stakeholders based on the conclusions and limitations of this work.

1. Bring to the market electric towing trucks for the narrow-body category (e.g. Airbus A320 and Boeing 737 families) and the wide-body category (e.g., Airbus A330 and Boeing 767)

To: towing truck manufacturers

For both aircraft types, the electric towing trucks can yield financial benefits for airlines and airports while reducing fuel consumption and thereby emissions. For some narrow-body aircraft, TaxiBot currently has a certified option on the market. The wide-body towing truck variant is being developed for, amongst others, the Boeing 767 and Airbus A330 aircraft. This variant is, contrary to the narrow-body variant, not yet certified.

2. Bring to the market an onboard electric taxiing system for the regional category (e.g., Embraer 190) with a low onboard taxi system weight (<250 kg)

To: onboard electric taxiing systems manufacturers

Multiple onboard electric taxiing systems are currently under development. Currently solutions are being developed by Wheel-Tug, DLR, EGTS and Safran. Manufacturers should focus on a low onboard taxi system weight below 250 kg to ensure that the percentage of profitable flights for airlines that have a reduced climate impact increases above 80% for an average fleet utilization.

3. Investigate the feasibility of an electric towing system which can also provide electricity to onboard equipment and engine start-up

To: research community and towing truck manufacturers

Emissions savings by using electric towing systems are currently limited due to the need to turn on the APU to power onboard systems and start-up the main engines. To increase emission savings during taxiing and improve the business case for electric towing trucks, it is interesting for towing truck manufacturers to investigate providing additional power such that the APU can remain switched-off. This would make the electric towing truck larger and heavier.

4. Investigate the feasibility of electrifying the APU

To: research community, aircraft and engine manufacturers

Emissions savings by using electric towing systems are currently limited due to the need to turn on the APU to power onboard systems and start-up the main engines. In order to further save emissions during ground operations it would be valuable to investigate electrifying the APU or running the APU on renewable energy sources (such as SAF or hydrogen). If thereby the weight of the onboard APU system increases, the total climate impact has to be assessed based on flight distance and taxi time.

5. Consider the benefits of sustainable taxiing on local air quality when making investment decisions

To: policymakers, airlines, airports and ground handling service providers

Improvements in air quality, and thereby also improvements in the health of employees working at the airport, should be considered by airports, ground handling service providers and airlines in the investment decision to invest in greener taxi solutions. The approach on how to monetise the emissions which affect local air quality should be investigated. In particular, the approach may consider that emissions close to the aircraft gate/stand may affect the health of employees working at the airport differently than emissions closer to the runway.

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Appendix A IATA position to climate related charges

This appendix outlines the position of IATA, one of the partners of the ClimOP project and representative of the airlines perspective as main airspace users, with respect to climate related charges. As these are positions rather than research results from the ClimOP project, they are presented in this separate appendix and not integrated into the main text of this deliverable. This appendix does not reflect the opinion and position of the ClimOP consortium.

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Airlines have been investing in newer and quieter aircraft for decades: each new generation of aircraft is on average 20% more fuel-efficient than the model it replaces. However, despite of the efforts of the industry, the introduction of new concepts of operation like the ones defined in this project could bring an opposite effect with new charges for the aircraft operators / airspace users, undermining the progress achieved to establish a coherent and effective policy framework to address aviation's impact on climate change.

IATA position with regards to charging for climate sensitive areas (CSA)

The 3 proposed options have the same final effect; in one way or another, the airspace user eventually pays and / or increases the DOCs for environmental taxation:

- **Option 1: Inclusion into air navigation fees** or modulation of charges: an airline crossing a CSA, business as usual, will have to pay more ANS charges.
- **Option 2: additional advanced MET service**, more expensive MET service (which is also paid by airlines through ANS charges[3]) will also be paid by the airline through ANS charges. This option is basically the same as option 1.
- **Option 3: Taxation** is self-explanatory.

Technically / technologically / operationally, not just Option 2, but the three of them, are difficult to implement. All of them involve the definition of the CSAs, complex new ground and airborne systems and SOPS, new ATM functions, determination of authority, rulemaking, and a large etcetera.

From the conceptual point of view, EU Reg. 2017/373, as well as ICAO Manuals 9161 and 9082 include the option of modulation of ANS charges. The report[4] that the Commission requested to an external consulting firm on charges modulation shows that this matter is full of complexities. A further deep study like the one mentioned, but from the environmental perspective, would be needed to see the full picture and to consider all the implicit facts within this deliverable.

Air Navigation Service Providers as true monopolies (at least in the en-route area) should be obliged to provide the service in the greenest manner, where and when required by their customers. Given the protected market of ANSPs, flexibility should be requested from them to cope with airspace users preferred routes in terms of operational performance, which do not have the same protection benefits. Adapting competitive demand to monopolistic restrictions justified by environmental protection is the wrong measure.

To implement such proposed mitigations, in a complex environment like the EU, with high disparity of realities, neither stakeholders, nor Member States and Commission, would converge to a single solution. There should be alternative ways to achieve environmental targets than putting the burden on airlines and creating complicated charging systems. Increased flight times and distances is very much contrary to all environmental targets within the Single European Sky. IATA has its own positions about environmental modulation of charges and taxation:

Aviation Charges & Climate Change IATA Position

IATA's position paper on 'Aviation Charges & Climate Change'[5] provides clear statements related to the inconvenience of increasing or modulating ANS charges due to the climate change. For reasons outlined in the position paper, *"IATA urges*

[3] The MET services are Air Navigation Services (ANS), as the ATC (ATS) or the CNS. And so that, the MET services, being ANS services, are completely paid by airlines in a full cost-recovery mode under the ANS charging scheme, in which the ANSPs, including the MET providers, recover the 100% of the costs of the MET service delivery in a risk-free monopolistic environment.
[4] https://transport.ec.europa.eu/news-events/news/study-policy-options-modulation-charges-single-european-sky-2016-09-22_en
[5] https://www.iata.org/contentassets/fa95ede4dee24322939d396382f2f82d/iata-positionpaper-climatechangecharges-nov2020.pdf

authorities, airports and ANSPs to refrain from applying or modulating charging schemes to address aircraft CO2 emissions".

Taxes & the environment

IATA's position paper on 'Taxes & the environment'[6] provides a clear position related to the increasing trend, particularly within Europe, to tax airlines for the environmental impact, which is a practice proven to be an ineffective policy choice as it negatively impacts passengers, other airline customers, jobs, and the economy, without incentivizing newer and greener technology. Mainly, it notes that *"the financial impact of a tax on airlines will limit their ability to invest in newer, cleaner and quieter aircraft and technology, delaying fleet renewal and the associated environmental benefits. Passengers will be more heavily taxed or opt for longer journeys - resulting in more emissions - through airports where no such taxes are levied"*.

IATA's Updated position on SES2+

IATA does not support the European Commission's SES2+ proposal to modulate charges[7], mainly as it "would be against the principles agreed in ICAO Assembly Resolutions A40-18 and A40-19".

IATA's opinion about retrofits

Although there is not a formal IATA policy about retrofitting aircraft to adapt airframes to technological evolution, IATA points out some remarks derived from specific ClimOP project recommendation of "*instead of waiting for new aircrafts equipped with humidity sensors, retrofits offer a possibility to equip existing aircraft with humidity measurement sensors;"*

Retrofit is usually 3-4 times more expensive than line-fit and generates the operational impact involved in grounding an active aircraft. When considering options for the adoption of a new technology onboard an aircraft, there should be a solid concept of operation, framed in a proper operational scenario, with characterized use cases, properly tested, validated, and defining without any ambiguity roles, responsibilities, times and means that would bring the intended operational benefits to the airlines. We understand that the project is not yet in that maturity level, so talking about deployment options as retrofit is not applicable at this point in time.

Generally, retrofit are not usually the means preferred by airspace users for onboard technological evolution. Only in certain cases where there are solid, thorough, and positive CBAs, endorsed by airlines, then, retrofit could work. Even, the latest cases of CNS regulations in Europe do not promote retrofits, but forward-fit[8] certain technology that has been tested after passing all the maturity gates of its development lifecycle, in the framework of EU R/D.

IATA position with regards to inclusion of non-CO2 in EU ETS and CORSIA

The uncertainty from impact of non-CO_2 effects is still relatively large compared to that for CO_2. In the past couple of years, there have been several initiatives involving airlines to improve the measurement capabilities of parameters such as relative humidity of air during flight and, therefore, the prediction of climate sensitive areas – particularly of Ice Super Saturated Regions (ISSR). These initiatives show promise in reducing the climate impact of non-CO_2 from contrail avoidance, yet they remain immature to be commercially deployed in the immediate future.

The ClimOP work acknowledges the inappropriateness of using multipliers to capture the complexity of non-CO_2 climate effects and therefore as ineffective abatement mechanisms. Regardless the approach applied, the most accurate methods for calculating CO_2eq currently depend on real-time measurements and the relay of data to which airlines have no capabilities.

With respect to the calculation method applied in the ClimOP study, the results presented do indicate the significant economic impact on airlines. While a future analysis using a network optimized for reducing climate impact could mitigate the order of magnitude of the economic effect on airlines, the ClimOP study does not provide an understanding of the role, responsibilities, and the impact of other stakeholders (ATCs, ATMs, ANSPs) in the coordination and implementation of operational measures needed to effectively mitigate the non-CO_2 impacts of aviation.

[6] https://www.iata.org/en/iata-repository/pressroom/fact-sheets/fact-sheet--taxes-environment/
[7] https://www.iata.org/contentassets/02dcd8ec59da4f798c13aebb738ffa76/iata-ses-position.pdf
[8] For example, see ATM Functionality 6, inclusion of onboard ADS-C EPP capabilities in CP1 Regulation (EU Reg. 2021/116), in which the retrofit is not mandated, but the line-fit instead.