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Climate assessment of innovative mitigation strategies towards operational improvements in aviation

D2.1 - Definition of reference scenario including technological and operational boundary conditions and air traffic sample

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CLIMOP Consortium

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Executive summary

This deliverable presents the description of a common reference scenario including the technological and operational boundary conditions as a baseline for conducting the climate impact assessment of different operational improvements. The document provides the context to the overall ClimOP project as well as a detailed description of different types of data available to the consortium partners. Those databases cover the whole spectrum from air traffic data in different levels of granularity, e.g. flight schedule or ADS-B data, through different types of weather and climate data, including climate change functions for an efficient calculation of the climate impact to airport data.

Previous studies focusing on the climate impact of operational measures applied different methodologies and baseline scenarios and lack comparability. In ClimOP, it shall be possible for the first time to conduct a fair “apple-to-apple” comparison of different operational measures by defining a common reference air traffic scenario before conducting the studies with similar assessment workflows. This deliverable elaborates on the preliminary modelling workflows for the various operational improvements and describes how the necessary input data was derived. Based on that an intercomparison of the individual requirements is done resulting in the identification of similarities in the way the OIs should be addressed. For finding a common reference air traffic scenario, the overlap between the required datasets with respect to the geographic and temporal scope as well as flight and aircraft data was maximised. The resulting suggested reference air traffic scenario has a clear geographic focus on the ECAC region, while in the temporal dimension the year 2018 has been identified to be a reasonable period, as it is characterized by a good availability for various data types.

Abbreviations

4D	Four dimensional
ACACIA	Advancing the Science for Aviation and Climate
A-CCF	Algorithmic climate change function
ACI Europe	Airports Council International Europe
ADI	Airport Data Intelligence
ADS-B	Automatic Dependent Surveillance – Broadcast
ALTERNATE	Assessment on alternative aviation fuels development
ANSP	Air Navigation Service Providers
ASK	Available Seat Kilometres
ATAG	Air Transport Action Group
ATCo	Air Traffic Controller
ATM	Air Traffic Management
ATR	Average Temperature Response
BADA	Base of Aircraft Data
BES	Building Energy Simulation
CCF	Climate Change Functions
CDS	Climate Data Dtore
CH_4	methane
CMIP 5	Coupled-Model Intercomparison Project 5
CO_2	carbon dioxide
CSV	comma separated value
DDR	Demand Data Repository
DDR2	Demand Data Repository phase2
DWD	German Meteo Service (Deutscher Wetterdienst)
ECAC	European Civil Aviation Conference
ECMWF	European Centre for Medium-Range Forecast
EEA	European Environment Agency
EMEP	*European Monitoring and Evaluation Programme*
ERA 5	ECMWF Re-Analysis
FRA	Free Route Airspace
GFS	Global Forecast System
GHG	greenhouse gas
GreAT	Greener Air-Traffic Operations
GRIB2	General Regularly-distributed Information in Binary form version 2
GSE	Ground Support Equipment
GUI	Graphical User Interface
GTB	Global Temperature Potential
GWP	Global Warming Potential
H2O	water vapour
HVAC	heating, ventilation and air conditioning
INEA	Innovation and Networks Executive Agency
ISO	Intermediate Stop Operations
KNMI	Koninklijk Nederlands Meteorologisch Instituut
KPI	Key Performance Indicator
METAR	METeorological Aerodrome Report
MI	Sabre AirVision Market Intelligence
NAFC	North Atlantic Flight Corridor

NCEP	National Centers for Environmental Prediction
netCDF	network common data format
NGV	natural gas vehicle
NH	Northern Hemispheric
NM/ nmi	nautical miles
NOTAMs	notices to airmen
NO_x	nitrogen oxides
O_3	ozone
OAG	Official Airline Guide
OD	origin/destination
OI	operational improvement
PM_X	particulate matter (with a diameter of *X* micrometres)
R&D	research and development
SESAR	Single European Sky ATM Research Programme
SMR	short-medium-range
SO_x	sulphur oxides
T	Temperature
TMY	typical meteorological year
UTC	Universal Time Coordinated
VHF	very high frequency
VOC	volatile organic compounds
WP	work package

1. Introduction

1.1 ClimOP project

The aviation industry contributes to human-made emissions mostly by releasing carbon dioxide (CO_2), water vapour (H_2O), nitrogen oxides (NO_x), sulphur oxides (SO_x), soot, and sulphate aerosols. In terms of the influence human activities as a whole have in altering the balance of incoming and outgoing energy in the Earth-atmosphere system, that is, the anthropogenic radiative forcing, the contribution from aviation has been estimated at slightly less than 5% [1]. At present, the Covid-19 crisis has caused an abrupt contraction of the activities in the aviation sector, which is still far from recovery and is not likely to return to 2019 levels before 2024 at the earliest [2]. However, once the current pandemic is overcome, air traffic is expected to resume its growth by 3 – 4% per year. This suggests that the aviation impact on climate will significantly increase over the next decades unless effective counteractions are planned and implemented.

Under the coordination of the Air Transport Action Group (ATAG), the aviation sector has long committed to cut its emissions and implement mitigation strategies to reduce its impact on the environment and climate [3]. This commitment has been recently restated despite the current crisis [4]. At the institutional level, the European Commission is supporting these efforts by promoting the research of innovative methods and technologies aimed at reducing the impact of aviation on climate. ClimOp is one of the four projects selected by the Innovation and Networks Executive Agency (INEA) within the action “Aviation operations impact on climate change” that pursues this purpose. These four projects, namely GreAT (Greener Air-Traffic Operations), ACACIA (Advancing the Science for Aviation and Climate), ALTERNATE (Assessment on alternative aviation fuels development), and ClimOp, focus on complementary aspects, respectively: innovative methods for a more climate-friendly air traffic management; a scientifically sound understanding of the aviation contribution to climate change; new fuels less dependent on fossil sources; and the identification and assessment of the most promising operational improvements to reduce the aviation climate impact and the evaluation of their impact on all the aviation stakeholders.

In the first year of the project, ClimOp made an inventory of the currently known operational improvements (OIs) and the available key performance indicators (KPIs) to quantify the effect of these OIs. Alternative sets of compatible OIs will subsequently be determined, and their impact on climate will be assessed, taking CO_2 and non-CO_2 effects into account. In addition, in collaboration with the stakeholders in the consortium and the Advisory Board, ClimOp will evaluate the impact of these OIs on airports, airlines, air navigation service providers (ANSP), manufacturers, and passengers. As a result, ClimOp will develop a body of harmonised, most-promising mitigation strategies based on the alternative sets of OIs and will provide recommendations for target stakeholders on policy actions and supporting measures to implement the alternative sets of OIs.

1.2 Overview of Work package 2

The overall objective of work package 2 is the iterative quantification of the impact that the operational improvements (OIs), which have been selected in the course of Work Package 1 (WP1), have on climate.

For this purpose, an air traffic simulation environment is required, in which the operational improvements are modelled such that changes in the amount, and the location (including the geographic position and altitude) of the different engine emissions species due to the altered operations become visible with respect to a baseline scenario. Some operational improvements, such as climate-optimised routing, require the inclusion of weather data and climate change functions (CCFs) in order to assess their climate impact since the OI is directly linked to a weather phenomenon, such as contrail formation regions. For other operational improvements, such as Intermediate Stop Operations, where the focus is not on specific weather phenomena, their climate impact is adequately estimated using a climate-chemistry response model AirClim. Hence, in a second step, tools (e.g., climate-chemistry response model) and data (e.g., CCFs) are prepared and linked to the air traffic simulation environment. These tools and data are adapted to capture the specific characteristics of the selected operational improvements in an appropriate way and to capture the climate performance metrics selected in WP1. CO_2 emissions and non-CO_2 effects, such as ozone and methane changes from NO_x-emissions, water vapour changes, contrail-cirrus coverage, and possible impacts from particulates, will be addressed in terms of changes in the concentrations, radiative forcing, and temperature changes.

1.3 Deliverable 2.1 in the Project's context

The deliverable D2.1 "Definition of reference scenario including technological and operational boundary conditions and air traffic sample" aims at providing a basis for further research activities in ClimOP, especially in WP2, which is devoted to the climate impact assessment of the selected operational improvements. In the course of WP1, the OIs have been shortlisted according to a multi-step, multi-criteria assessment procedure described in detail in deliverables D1.3 [5] and D1.4 [6]. From the original 25 OIs, 11 OIs were selected with priority, covering four different categories of OIs: Climate-optimised operation of the airline network (five OIs), Climate-optimised trajectories (two OIs), Operational and infrastructural measures on the ground (three OIs), Operational measures at regulatory level (one OI). The selected OIs were then further outlined in deliverable D1.4 with respect to their impact on climate and on the involved stakeholders. The expected advantages/disadvantages of those 11 OIs were also discussed in D1.4. Moreover, a preliminary description of the necessary methodology to study those OI's impact on climate and the KPIs/methods to evaluate its impact on stakeholders also in terms of feasibility/implementability were given in D1.4 [6].

This deliverable results from work conducted in task 2.1, which deals with the preparations of the climate impact assessment of the OIs. For this purpose, an initial workshop was carried out involving all partners to collect important aspects, thoughts, and preliminary ideas for workflows to be considered in further. It was decided that for each OI a separate working group is formed comprising of representatives from partners that have a significant interest in the particular OI and can contribute to the modelling and simulation process. The in-depth discussions on the model workflows, the required air traffic scenario, and model input are continued within those individual working groups. As a first exercise, the groups discussed possible ways of modelling the respective OIs and the resulting requirements to the input traffic sample. This work is documented accordingly in section 2.2. Chapter 3 presents an overview of various available types of data and their usage. Based on that and the requirements in section 2.2, chapter 4 provides the conclusions with respect to commonalities between the different OIs and gives first suggestions, which traffic scenario to be used to ensure a common baseline and consequently fair comparisons between the OIs with respect to their climate and stakeholder impact.

The findings from WP2 are essential input for WP3, where climate impact indicators and stakeholder impact indicators are analysed for the implementation of mitigation strategies.

2. Requirements for a common air traffic reference scenario

This chapter summarizes the outcome of the first working group meetings and discussions on the workflows and common air-traffic and ground-management reference scenario. It lays the foundation to understand where similarities in the assessment process can be observed or established and which data is needed to complete the climate impact assessment successfully.

2.1 Why do we need a common reference scenario?

In the past, a number of operational improvements have already been investigated with respect to the climate impact mitigation potential. However, those studies were carried out independently and, hence, applied different methodologies and baseline scenarios. In a review paper by Grewe and Linke (2017) [7] an attempt was made to compare different operational concepts based on published studies with respect to their eco-efficiency expressed in terms of e.g., climate impact reduction, cost-effectiveness, etc. However, due to the lack of one common and consistent reference scenario, this comparison was of qualitative nature . In ClimOP, it will be possible for the first time to conduct a fair apple-to-apple comparison of different operational measures by defining a common reference air traffic scenario before conducting the studies with similar assessment workflows. It is therefore important to carefully collect the requirements to such a baseline scenario from the perspective of each OI individually, analyse their similarities, and derive a common baseline composed of a few different data sets as possible.

2.2 Individual requirements from the selected OIs

In the following, for each operational improvement, the requirements for an input scenario, including air traffic and/or weather data, are described based on the results of the first working group discussions.

2.2.1 Flying low and slow

The concept of Flying low and slow has been studied for some time already, and previous research has looked at it from different perspectives. In ClimOP, the objective is to address identified research gaps with respect to this Operational Improvement and quantify its climate impact reduction potential taking implementation aspects into account. The set-up of the modelling chain and the selection of an appropriate reference air traffic scenario should, therefore, consider multiple aspects, including potential stakeholder impact analyses, such as passengers or Air Traffic Control (see also [6]).

The working group established to address this OI in more detail has elaborated in the course of several meetings that there are some aspects that have not yet been sufficiently investigated in earlier projects, including but not limited to:

- Studying various weather patterns to understand to what extend preferred altitude and speed changes will vary throughout the year according to the weather;
- A more detailed analysis of the implications of Flying low and slow on flight time and the corresponding effects on e.g. (1) aircraft utilisation and changes in flight schedules, (2) fleet composition and assignment, (3) passenger travel time and acceptance;
- An investigation of the effect of cruise altitude shifts to airspace congestion and air traffic controller workload;
- A consideration of future climate data within the study to understand how climate change could affect the potential of this OI;

- A closer look at cost aspects, including Direct Operating Costs and potentially effects on passenger ticket price.

Discussions on the details of the study are still ongoing in the course of WP2 and a more specific description of the work will be provided in deliverable D2.2. However, given that in WP2 the focus is laid on the climate impact assessment, the study could be conducted as follows:

For a defined geographic scope, real flights on selected days with representative weather situations will serve as a baseline. As geographic scope besides the North-Atlantic airspace, Europe (e.g. Western Europe or Pan-European traffic) was discussed. Globally, there have been studies that systematically shifted cruise emission to simulate a change in cruise altitudes. A global representation of the air traffic with sufficient accuracy is very difficult to obtain. Here, flight schedule data without information on individual flights could be used. In case of a purely European scope, real flight data from EUROCONTROL would be available. Here, the R&D archive is a suitable database containing point profile data of individual flights (e.g. allft+ or SO6, see data section). Days with characteristic weather will be selected using a methodology that has already been successfully applied in earlier projects (e.g. eight characteristic weather situations have been identified in the project REACT4C and could be similarly applied in ClimOP). A base year with good data availability is 2018. Meteorological data for those days will be obtained from ECMWF. Also, future climate data should be considered. Corresponding data may be obtained from other sources. A reasonable set of flights from the flight database will be processed; for the ATM impact assessment, it is necessary that this data is as comprehensive as possible. For each flight, the observed real flight situation will be evaluated by reproducing it with a trajectory generator and serves as the baseline. Also, for comparison reasons, the fuel-optimal flight profile will be computed before the cruise flight level will be systematically reduced step-by-step. Separately, in order to decouple the effects, the cruise speed will be reduced as well, while making sure that also the economic altitude/speed combination is covered. All trajectories will be evaluated with respect to their climate impact (no optimisation is carried out).

For this purpose, various options are being discussed: One possibility is the use of algorithmic climate change functions (see data section), which is probably limited to the current climate. This has the advantage of being easily applicable for longer time periods. Also, the climate response model AirClim could be utilised. For this, based on the representative weather situations selected for this study, climatological mean flight patterns could be derived and evaluated with AirClim on climatological base. A third alternative would be applying the nested AirTraf model, which could allow for a closed-loop evaluation considering climate feedback from the climate-chemistry model. In this case, an upgrade of AirTraf from BADA family 3 to model family 4 should be carried out to ensure sufficient model accuracy. Table 1 summarizes the study specifications in the context of a common air traffic scenario.

Table 1: Summary of requirements for an air traffic scenario

Geographic scope	Pan-European flights
Temporal scope	A number of days with characteristic weather in 2018
Aggregated schedule vs. individual flight	Individual flights (on the selected days), point profiles
Data sources	EUROCONTROL R&D archive (point profile data), ECMWF ERA5 weather data

2.2.2 Free routing in high-complexity environment/flexible waypoints

On the road to SESAR's business trajectories and 4D profiles, the free route airspace (FRA) is a key landmark in achieving free routing across European airspace. The implementation of the FRA leads to a number of benefits and also poses several challenges to the users. In ClimOP, our objective is to present an appropriate implementation of this concept and analyse its impact on the climate and different stakeholders. The general discussions of the study have been started on the working group, and further discussions will be carried out to specify the details of the work. The details of the study will be described in the next deliverable. The requirements for the implementation of this OI and the general implementation concept could be presented as follows:

The study will focus on several en-route airspaces in the European Civil Aviation Conference (ECAC) area to implement the free routing concept. The airspaces will be chosen according to traffic density and complexity metrics. For a realistic implementation, real flight data will be used to simulate the traffic in the corresponding airspaces. The EUROCONTROL's database will be utilised to obtain the point profiles of individual flights (e.g. ALL_FT+ or SO6, see data section). Several days will be chosen to implement the strategy. But, the choosing strategy is still under discussion. A day could be chosen by considering the NOTAMs (notices to airmen) and traffic on the corresponding airspace or focusing the problem from the perspective of climate. Hybrid cases could also be evaluated. The strategy will be decided in further discussions. Wind/weather data for those days could be obtained from NCEP GFS or ECMWF (see data section). For the implementation, a trajectory generator will be used to simulate the traffic in the corresponding airspace in which aircraft flies according to flight plans obtained from flight records. A base scenario will be produced using the real flight plans, whereas the free routing concept will be implemented by using direct routes between entry and exit points of the airspace. The obtained trajectories in both cases will be assessed in terms of the climate impacts, released emissions, air traffic controller (ATC) workloads, travel durations, and airline costs. The requirements for an air traffic scenario are summarized in Table 2.

Table 2: Summary of requirements for an air traffic scenario

Geographic scope	Several en-route airspaces in the ECAC area
Temporal scope	A number of days without additional NOTAMs in the corresponding airspaces (or/and considering characteristic weather situations)
Aggregated schedule vs. individual flight	Individual flights (on the selected days), point profiles
Data sources	EUROCONTROL R&D archive (point profile data), NCEP GFS wind/weather data (or another wind/weather data source)

2.2.3 Climate-optimised flight planning

Climate-optimised flight planning has the potential to reduce the overall climate impact of aviation, considering both CO_2 and non-CO_2 effects.

Such an operational improvement relies on the implementation of operational measures that aim to avoid those atmospheric regions that are in particular sensitive to non-CO_2 aviation effects, e.g., where persistent contrails form. When working towards sustainable aviation, quantitative estimates of mitigation potentials of such climate-optimized aircraft trajectories are a required. Within this OI a comprehensive modelling approach will be performed aiming to identify such climate-optimized aircraft trajectories. The overall concept relies on a multi-dimensional environmental change function concept, which is capable of providing climate impact information to air traffic management (ATM). Estimates on overall climate impact reduction from comparing a climate-optimized air traffic sample to a fuel-optimal solution rely on the best estimate for climate impact information as developed in earlier studies ([8],[9],[33],[35]). Mitigation potential is influenced by specific weather situation on the day of analysis as well as on the season of the year, containing regions with e.g. high contrail impact, or strong NOx-induced photochemical ozone-production.

Spatially and temporally resolved climate impact information, so-called climate change functions have been developed and evaluated for the North Atlantic Flight Corridor and parts of the Northern Hemispheric extratropics. Hence during ClimOP Phase 1, geographic scope of our OI analysis is defined as the Northern Hemispheric (NH) extratropics, with a particular focus on the North Atlantic Flight Corridor (NAFC) combining US American and European air space. Due to the strong seasonality of the associated climate impacts our analysis will comprise more than one season, hence representing seasonal variation of overall climate impacts and associated mitigation potentials. Hence, during the course of the year, the climate impact reduction per individual alternative trajectory shows a strong variation and, hence, also the mitigation potential for an analyzed city pair, depending on atmospheric characteristics along the flight corridor as well as flight altitude.

Additionally in the OI "climate-optimized flight planning" analysis particular focus will be given to the representation of synoptic scale weather situations, as in earlier studies it has been identified that the individual archetypical weather situation strongly influences location, structure and also strength of individual aviation climate impacts, represented by strongly variations in the climate change functions. Selection of the individual traffic sample needs to be performed following the individual study objective. In order to quantify the overall mitigation potential for the intra-European air traffic, a representative fleet of aircraft will be identified and flight details made available. Additionally, we intend to establish a uniform scenario definition for a reference case focusing on providing a basis for comparision. Such a reference might focus on one single aircraft type, in order to systematically explore driving parameters from the atmosphere-ATM-system within the overall optimization and investigate associated changes in climate impact mitigation potentials. We suggest to use this reference case also for other OIs in order to construct a set of OIs within ClimOP which can then rely on the same set of air traffic and air space by using identical key parameters, and quantify a mitigation potential comparing to an identical base case. Additionally we will explore synergies with other European research projects, involving SESAR Exploratory Projects, e.g. FlyATM4E, ALARM, CREATE. Table 3 provides an overview on the preliminary requirements for an air traffic scenario from this OI.

Table 3: Summary of requirements for an air traffic scenario

Geographic scope	Northern Hemisphere focusing on the North Atlantic Flight Corridor (= US/Europe)
Temporal scope	Multiple seasons, i.e. a number of days with characteristic weather in 2018
Aggregated schedule vs. individual flight	Individual flights (on the selected days), flight track data
Data sources	Climate change functions, EUROCONTROL R&D archive (point profile data) amended by ADS-B data, ECMWF ERA5 weather data

2.2.4 Wind/weather-optimal dynamical flight planning

Wind and weather-optimised flight plans can save airlines millions of gallons of fuel every year without forcing the airlines to compromise their schedules or service, and fuel saving can reduce the released emissions. One of the most fundamental strategies in flight planning is to focus on the problem considering the wind and weather information, which certainly requires a sufficiently high data resolution. There have been several studies (se e.g. [10]-[14]) in this area, but there are also still some open issues. The impacts of the strategy on different stakeholders and climate have not been investigated properly. In ClimOP, the aim is to develop a wind/weather optimal flight planning process that fills the gaps in the current literature and analyse the impacts of this planning strategy on the climate and several stakeholders. The general discussions of the study have been initialised on the working group, and further discussions will be carried out to specify the details of the work. Further details will be given in the next deliverable. The requirements for the implementation of this strategy and the general implementation concept could be presented as follows:

For the implementation of the wind/weather flight planning concept, the main focus will be on several en-route airspaces in the ECAC area. The real flight data will be used to simulate the traffic in the corresponding airspaces. We will benefit from the EUROCONTROL's database to obtain the point profiles of individual flights. Several days with nominal and extreme wind/weather conditions in the corresponding airspace could be chosen to implement the OI. However, the choosing strategy has not been decided yet. Another option could be focusing on the evaluation of the candidate days with regards to climate features. The strategy will be determined in further discussions. Wind/weather data for those days could be obtained from NCEP GFS data. Another data source could also be used. For the implementation of the OI, the planning problem will be transformed into an optimisation problem to generate optimal control strategies with regards to defined objectives. The impact of the wind/weather-optimal planning on the climate and different stakeholders will be assessed by comparing the optimisation results with the base scenario obtained via real flight records. The comparison analysis will be based on the climate impacts, released emissions, ATC workloads, travel durations, and airline costs. The requirements for an air traffic scenario are summarized in Table 4.

Table 4: Summary of requirements for an air traffic scenario

Geographic scope	Several en-route airspaces in the ECAC area
Temporal scope	A number of days with characteristic wind/weather situations
Aggregated schedule vs. individual flight	Individual flights (on the selected days), point profiles
Data sources	EUROCONTROL R&D archive (point profile data), NCEP GFS wind/weather data (or another wind/weather data source)

2.2.5 Strategic planning: merge/separate flights; optimal network operations

Airline network planning is one of the most critical strategic decisions in airline operations and tightly coupled with its business model and available resources. We aim to incorporate the climate impacts of operating the airline's route network and its monetary objectives in network planning. A research workflow is under development to establish a sound research routine and reflect the stakeholders' interests in the model. The workflow addressing this bi-objective approach should also consider the involving requirements from both climate and operation modelling sides.

Based on the working group discussions, we compiled some aspects of modelling and domain considerations, which are not addressed in the literature. The following three sequential steps are needed to carry out in modelling and analysis of this OI:

1. Climate: generating Pareto frontiers to assess the climate impact of various trajectories for each Origin/Destination (OD) pair under multiple costs, flight times, and aircraft types.
2. Airline: The AOMAS model will be executed for four types of representative airlines while passing on a certain number (model parameter) of alternative trajectories (which have been chosen based on the Pareto frontier from the previous block) for each OD pair. The

result of KPIs for each airline type will be extrapolated to meet the initial air traffic scenario scale.

3. Airport: average frequencies for all airports are then delivered to airport qeue network model in order to calculate airport-related KPIs.

We have five inputs linked to the blocks in the workflow. Firstly, we need a pre-selected number of airports, the air traffic scenario associated with those airports and technology assumptions for the climate model block. Technology assumptions are including types of aircraft, engines etc. Secondly, passenger demand data for all pairs of selected airports is needed to run the strategic airline network planning model. According to the AOMAS model, there is no limitation on the location of selected airports or flight schedule. The only required data is the average yield and load factor for all OD pairs, which is provided by the climate step and passenger demand that provided externally. DLR colleagues have access to the demand data from the Sabre AirVision Market Intelligence database, including information on passengers' true origin and destination airports. They will check whether it is possible to provide data needed for this block. Finally, airport capacity data is required to calculate the airport congestion.

The climate model step aims to calculate alternative trajectories with different costs, flight times and climate impact (Average Temperature Response (ATR)). The calculation process and the models are assumed to be the same as the optimised intermediate stopover (ISO) OI. As non-CO_2 climate effects are strongly related to the meteorological conditions of emissions, further discussion is needed on the possibility of incorporating average non-CO_2 climate impacts in the AOMAS model.

In the airline planning step, we assumed that initially given air traffic comprises four categories of flights. Each category is associated with the operation of one of the following types of airlines.

- Major H&S (Legacy)
- Secondary H&S
- LCC
- Regional

As these airline types have principal differences in their business models and networks structure, we will assign a customised AOMAS model to each. The results from AOMAS are representing one airline's operation decisions, including network structure, fleet utilisation and total profit of operation. In order to meet the initial air traffic input, we extrapolate the combined results of four AOMAS models.

Finally, ITU will collaborate to assess the airport-related KPIs using their airport queueing model in the airport block. In this block, airport capacity data is also needed, which should be provided externally. Currently, ITU has declared capacities and runway service time distributions for the airports in Europe. A possible extension could be integrating the airports in the United States by estimating their capacities using open-source flight records in this region. An important topic that needs more discussion is making the inputs and outputs of airline and airport steps compatible. According to the current setup, AOMAS provides average weekly flight frequencies, and the airport network queuing model requires flight schedule as the input. This topic will be discussed in the following working group meetings.

In summary, to make the OIs more comparable, we assumed that the climate block in this OI has the same structure and assumption as the climate impact module in ISO. On top of that, two more requirements need to be fulfilled. No matter which geographic or temporal scope is considered as the baseline for the climate block, associated passenger demand and airport capacity data should be available for the airline and airport blocks. The requirements for an air traffic scenario are summarized in Table 5.

Table 5: Summary of requirements for an air traffic scenario

Geographic scope	Selected airport network (Europe)
Temporal scope	Longer period of time, climatological mean values
Aggregated schedule vs. individual flight	Aggregated schedule (flight plan)
Data sources	Sabre Market Intelligence schedule data, passenger demand data, flight fares, flight operational costs, airport capacity data

2.2.6 Climate-optimised intermediate stop-over

The goal of this OI is to replace nonstop long-haul flights with heavy aircraft and a full tank by two or even more sub-missions with reduced tank content to save weight that are interrupted by intermediate stops at a nearby airport for refuelling. Instead of applying ISO for optimal fuel efficiency despite additional takeoff and landing operations, in ClimOP project ISO will be applied to reduce the climate impact and particular non-CO_2 effects, although total fuel burn itself will be increased by an additional landing and takeoff cycle.

An appropriate traffic scenario to model and assess the climate impact of OI climate optimised intermediate stop operations (ISO) could be a global flight schedule containing the aircraft type, origin and destination airport and departure and arrival time. Those data can be found e.g. in the Sabre Market Intelligence database. Flight track data of the actual routes are not necessary for an assessment of the OI. The temporal range of the traffic scenario should cover a few days where typical weather patterns occured. Alternatively, climatologically averaged atmospheric conditions could be assumed. In both cases meteorological reanalysis data from ECMWF could be used.

First of all, flights with a great circle distance below 2500 nautical miles (nmi) can be ignored, because application of intermediate stop operation is only useful for long-haul flights. Beyond that, the requirements of the traffic scenario are quite similar to the OI flying low and slow. In contrast to previous studies about ISO, both modelling of the cruise altitudes and the choice of the potential intermediate stop airport should be rather optimised to a minimum climate impact than to fuel efficiency. Lighter aircraft would fly on higher altitudes when flying fuel optimised, but a higher altitude also increases the risk of forming contrails and thus additional climate forcing. Hence it is necessary to combine the effects of ISO with the effects of climate optimised routing.

For the assessment of the OI three scenarios should be modelled. The reference scenario would be the traffic scenario operating only nonstop flights assuming the respective reference aircraft as applied currently.

In a second scenario, the missions would be separated into one or more sub-missions interrupted by intermediate stops on the best located intermediate stop airport in terms of minimal climate impact. The ISO missions would still be modelled with the reference aircraft that are designed as long-haul aircraft.

In a third scenario, the missions would be modelled with intermediate stop operations, but the initial aircraft will be replaced by aircraft types that are designed for shorter ranges. Applying short-medium-range (SMR) aircraft instead requires an adjustment of seating in the cabin with extended legroom as the passengers will spend even more time during the mission onboard compared to a nonstop flight due to the intermediate stops. To replace one long-haul aircraft with 400-500 seats, 4 or 5 SMR aircraft with the same cabin comfort might be necessary to obtain the same aggregated seat capacity and satisfy the passenger demand. This fact might reverse the initial benefits of climate optimised ISO due to a multiple number of flights and has to be considered in the assessment when modelling the traffic scenario with redesigned SMR aircraft.

With a network model the potential of causing congestion at the airports and the adjacent airspace sectors due to the additional stops could be investigated. For such a quantification, further information about the departure and arrival time in the flight schedule would be required. To regard monetary aspects, an assessment of the arising costs due to detours and additional landing fees could also be part of the workflow. Finally, a survey about the passenger acceptance of the enhanced travel time due to ISO application would be an option. A summary of the requirements for the traffic scenario can be found in the following Table 6.

Table 6: Summary of requirements for an air traffic scenario

Geographic scope	Global flights > 2500NM
Temporal scope	Longer period of time, climatological mean values
Aggregated schedule vs. individual flight	Aggregated schedule (flight plan)
Data sources	Sabre Market Intelligence schedule

2.2.7 Single engine taxiing / E-taxi and hybrid taxi

The first question to answer for any measure to limit emission during ground operations is what the potential saving is for a given flight at a given airport. For this, three sets of data are needed, as shown in Figure 2. First, the taxi time for each operation. This can be, in order of preference, either measured data per operation, specified per gate-runway combination or as a statistic normal distribution, as provided by Eurocontrol [15]. Secondly, the start-up and cool down times per aircraft and engine type must be given, as these determine the amount the engine on time can be reduced with. Finally, the fuel and emissions per aircraft and engine type, including the Auxiliary power unit, must be specified per minute of operation.

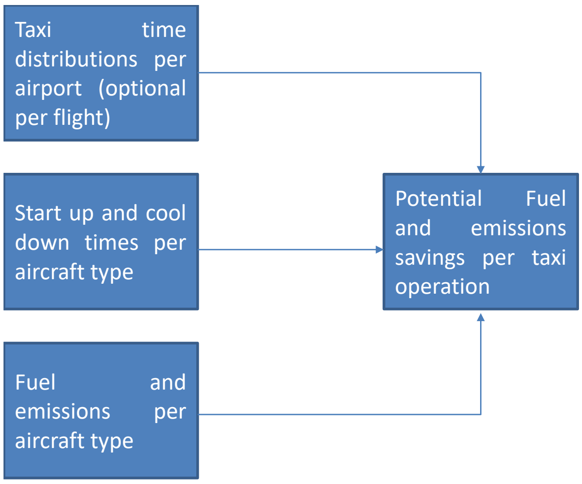

Figure 1 - Determinination of the potential savings per operation

For determining the potential savings of applying towing vehicles at an airport, a flight schedule for that airport is required. For a given number of towing vehicles per type, the assignment for towing vehicles to flights generating the highest savings can now be determined, as shown in Figure 3, also allowing a comparison with using single-engine vs. all engine taxying. Varying the number and type of vehicles allows a determination of the marginal savings per additional vehicle. As the implementation of autonomous e-Taxi, illustrated in Figure 4, is on a per aircraft basis, this requires a flight schedule per airline and aircraft type. An extra complication is that fitting an aircraft with an e-Taxi device increases its weight and limits its maximum payload, which causes a fuel burn an emissions penalty per flight, depending on flight distance. Combining the fuel burn penalty with the savings per airport, results in a change in fuel burn and emissions per route. The routes with the highest savings are generally short-range routes between airports with long taxi times.

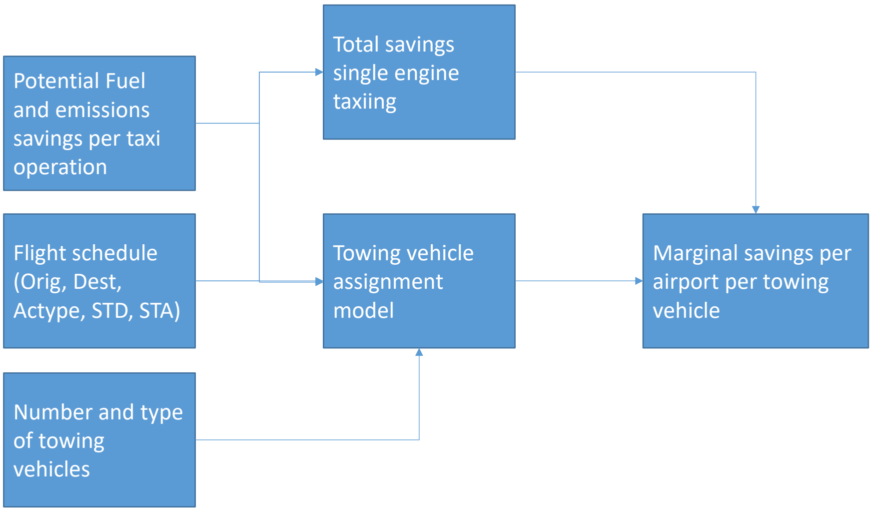

Figure 2 - Determinination of the potential savings per airport for towing

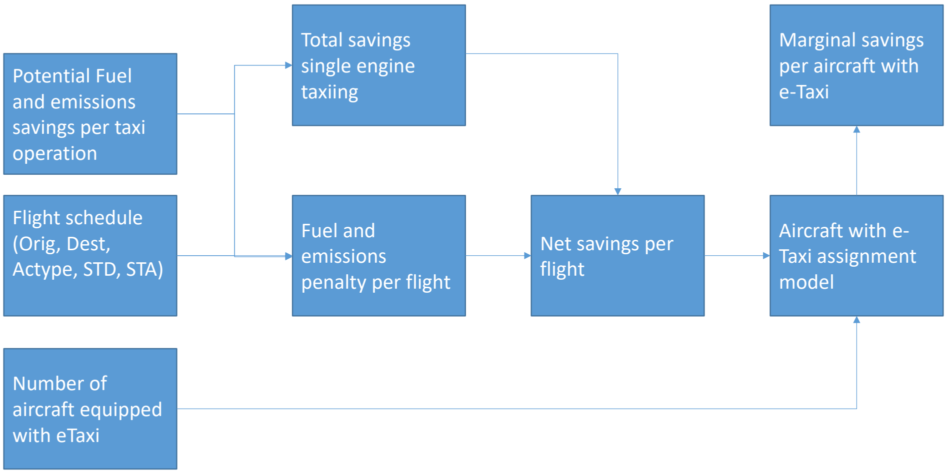

Figure 3 - Determinination of the potential savings per aircraft for e-taxi

An optimisation model is used to determine if an aircraft of a certain type is equipped with an e-taxi device, which routes it can be best be assigned to throughout the day. Changing the number of aircraft equipped with an e-Taxi system, allows the determination of the marginal savings per vehicle.

Table 7: Summary of requirements for a ground operation and management scenario

Geographic scope	Europe, selected airports (e.g. Milan Malpensa)
Temporal scope	A longer period of time, climatological mean values
Aggregated schedule vs. individual flight	Airport operations incl. Individual flights
Data sources	Airport flight operations data

2.2.8 Electrification of ground vehicles and operations

ACI Europe and its member airports have committed to reach net zero carbon emissions for operations by 2050 [6], [7], [16], [17]. As part of this commitment, ACI Europe developed a

“Sustainability Strategy for Airports” [16] to provide guidance to the sustainability efforts of European airport operators. A fundamental step in this strategy is the transition towards a complete electrification of the ground support equipment (GSE). In the context of this deliverable, GSE refers to the broad category of vehicles and equipment under the direct control of the airport management, including those used for maintenance, logistics, passenger buses, baggage tractors, belt and container loaders, de-icers and emergency vehicles, vehicles for airport personnel, and providing various services to the aircraft (air conditioning units, ground power units, etc). In the strategy of ACI Europe, the electrification of GSE should ideally be combined with the on-site generation of electric energy from renewable sources and the use of excess electricity for producing hydrogen and synthetic fuels.

The environmental impact of airports is most often quantified in terms of their contribution to deteriorating the local air quality and noise levels (e.g. [16], [18]). The indications of the “Sustainability Strategy for Airports” to cut the greenhouse gas (GHG) emissions will expectedly have a positive impact on climate, reducing the airports’ contribution to climate change. However, the extent of this impact and its proportion compared to that of aviation as a whole has yet to be computed in detail.

ClimOP aims to fill this gap by developing a model to calculate the net variation of total GHG emissions due to the complete electrification of the airport ground equipment and operations. Subsequently, the effect on the climate of this variation will be quantitatively estimated in the same reference frame as other aviation emissions to enable comparisons. The process to achieve this purpose is summarised as follows.

1. SEA Milan will provide detailed data of usage, fuel consumption and emissions of its current fleet of ground vehicles. The fleet composition will be divided into categories based on their size and average fuel consumption, for example: automotive, buses, trucks, winter or airport-specific vehicles.
2. For each of these categories, the average emissions (e.g. per year or per 100 km) of multiple pollutants will be calculated, including for example CO_2, NO_X, particulate matters (PMs), volatile organic compounds (VOC). The foundation of this analysis is the mileage and fuel consumption data recorded by SEA Milan. The conversion from fuel consumption to the amount of emissions will be based on the guidelines of the “EMEP/EEA air pollutant emission inventory guidebook” [19].
3. The amount of energy will be calculated that would be necessary if all vehicles of the current fleet are replaced with an electric vehicle of the same class. For this purpose, a simple approach proposed in some studies (e.g. [20]) is to assume a direct proportionality between energy consumption and distance travelled. More sophisticated models that estimate the energy consumption of electric vehicles based on real travel data are also available (e.g. [21] - [24]). Multiple approaches will be tested with the aim of developing a general model to compute the supply of electric energy necessary for the optimal functioning of all airport ground operations. Such a model will be designed to be applicable to airports of variable sizes and fleet compositions and will be validated with the results of a detailed internal study commissioned by SEA Milan to guide its transition to complete electrification. Because with the current technologies not all ground vehicles can be readily replaced by a fully-electric analogue, a more realistic fleet mix will potentially be considered which also includes hybrid and NGV engines.
4. The GHG emissions resulting from the energy production necessary to guarantee the supply of the electric fleet will be computed. The initial assumption will be that the energy is provided by the electricity network, and thus an average European mix of electricity production [25]. Other assumptions will be considered, which include different

proportions of local energy generation at the airport by renewable sources, for example, 30% and the limit scenario of 100%.

5. The impact of the airport emissions on the climate will be quantified by customising for the purpose of the TransClim model, which was originally developed by DLR and TU Delft to assess the climate impact of road traffic [16]. With this approach, it will be possible to directly compare the overall effect of airport emissions with those of other aviation operations.The impact the airport emissions have on climate will be quantified by customising for the purpose the TransClim model, which was originally developed by DLR and TU Delft to assess the climate impact of road traffic [26]. With this approach, it will be possible to directly compare the overall effect of airport emissions with those of other aviation operations.

The model developed in steps 1–5 will be tailored to the characteristics of the Linate and Malpensa airports managed by SEA Milan. The final step will be to make this model applicable to different airports. Different approaches will be tested to correlate quantities such as the fuel consumption, energy demand, and GHG emissions to parameters that capture how active an airport is, for example the number of flights to and from the airport, the number of passengers travelling through the airport, or the total number of staff involved in airport operations.

Table 8: Summary of requirements for ground operation and management scenario

Geographic scope	Europe, Milan Malpensa, Linate
Temporal scope	Typical year of operations
Aggregated schedule vs. individual flight	Standard airport operations
Data sources	Airport operational and fuel consumption data, Eurostat

2.2.9 Upgrade of the airport infrastructure according to energy efficient criteria

Airport buildings consume a significant amount of energy to maintain comfortable occupancy conditions, which require space heating and domestic hot water preparation, ventilation and air conditioning/cooling, power supply for lighting and other systems. Improvements in the infrastructure are expected to contribute to the reduction of the energy consumption of airports, which, in turn, highly depends on climate conditions. Indeed, temperature, humidity, irradiation, and wind direction and speed are key factors of energy consumption in terminal buildings. In the climate change era, these conditions might change in the future. Since upgrading the airport infrastructure is a long-term investment, it becomes mandatory to account for potential changes in the climate condition when evaluating the potential of this OI in reducing aviation impact.

ClimOp embraces the philosophy of ACI Europe that incorporates adaptation measures into its sustainability strategy [6-7], [16], [17]. Therefore, the scientific questions that ClimOp aims to answer are the following:

1. What is the potential impact of improving the energy efficiency of airport infrastructure?
2. How will climate change impact the energy consumption of airports?

The OI assessment will investigate what is the potential for reducing energy consumption through infrastructure upgrading. Parallel to that, it will clarify how the energy demand will change in the upcoming decades and will identify the regions where the climate conditions will change so that the present infrastructure will soon become obsolete. To this end, the ClimOp consortium will focus on the atmospheric conditions that impact the energy need of airports the most: temperature, humidity, irradiation, and wind direction and speed.

To answer the posed scientific questions, ClimOp will exploit **EnergyPlus**. EnergyPlus is an open-source software developed by the US Department of Energy, and it is the most widely used package for *building energy simulation* (BES). An EnergyPlus simulation is mainly based on input from text files, which increases the effort to define all necessary input data compared to engines with graphical user interfaces (GUI). For this reason, the OpenStudio software has been developed, initially as a simple GUI for EnergyPlus, which operates as a SketchUp plugin, the latter being a graphical computer interface developed by Google for 3D modelling. However, OpenStudio has now evolved to become an object-oriented framework for building energy modelling, providing a way to leverage existing building simulation tools holistically.

A large amount of input data is needed to run a building energy simulation. Generally, the following basic information is required:

- *Location and weather file*. Energy simulation tools need hourly data on ambient conditions (i.e. temperature, humidity, wind velocity, solar radiation, etc.) at the building location.
- *Building geometry*. Building elevation and floor plans are required to create the geometric model of a building. Architectural drawings may have many details that might not be directly useful for energy simulation. It is important to simplify the drawings based on thermal zoning into a single line drawing by removing unnecessary details.
- *Envelope components*. It is necessary to have construction details, such as the thickness and thermophysical properties of materials used in each layer of the building envelope. Besides the opaque components, it is very important to know the properties of the window glass, frames and shading devices.
- *Building services*. Information on various services such as heating, ventilation and air conditioning (HVAC) and lighting is required. This includes equipment capacities, energy efficiency, location and controls.
- *Use of the building*. The hourly values of the following are required: occupancy, lighting, equipment, thermostat setpoint, HVAC operation.

One of the partners of ClimOp consortium, SEA, has provided benchmark data for the energy consumption of different areas of the Malpensa Airport. The data also include a temporal dimension since they are provided as time-series. Therefore, this study will focus first on the specific case study of the Malpensa airport. The Malpensa case study will serve as a starting point to extend and generalize the drawn conclusions to other airports in Europe, with the scope of reaching a comprehensive overview of the impact of this OI at continental scale.

The most commonly used methodology to produce current climate files is called *Typical Meteorological Year* (TMY). These files are assembled by compiling the individual months, which best correspond to the long-term monthly means of different climate variables. The most commonly used method to produce future climate files for BES is called “morphing”, which preserves real weather sequences and is specific to an observed location. The algorithms use three simple operations to modify present-day weather data: (1) a shift is applied when an absolute change to a variable is required, (2) a stretch or scaling factor when the change is projected in a percentage, and (3) a combination of both shifting and scaling may be used to adjust present-day data to reflect future projections. For future climate conditions, the climate projections available through Coupled-Model Intercomparison Project 5 (CMIP5) will be considered.

The assessment of the OI will focus on the following KPIs:

- K51: Annual electricity consumption per unit of volume
- K52: Annual thermal energy consumption per volume unit
- K53: Annual electricity consumption per traffic unit
- K54: Annual thermal energy consumption per traffic unit

- K59: Social acceptance

Table 9: Summary of requirements for ground operation and management scenario

Geographic scope	Europe, Milan Malpensa
Temporal scope	Typical meteorological year, future conditions
Aggregated schedule vs. individual flight	Standard airport operations
Data sources	Airport data (incl. building geometry and equipment), CMIP5 climate data

3. Data availability

The common air traffic scenario will obviously contain various data. Therefore data availability is of key importance for the selection of an appropriate scenario and constitutes boundary conditions that have to be considered. The following section will give an overview on the various types of data that are available to the ClimOP consortium.

3.1 General considerations

For the evaluation of the climate impact of an Operational Improvement (OI), the corresponding changes in flight or ground operations have to be modelled and simulations will be conducted considering all relevant operational influences. One important aspect, which may influence significantly the potential a certain OI can have, is weather. Some operational improvements, such as climate-optimised routing, require the inclusion of weather data and climate change functions (see also section 3.3.2.1) in order to assess their climate impact, since the OI is directly linked to a weather phenomenon, such as contrail formation regions. For other operational improvements, such as Intermediate Stop Operations, where the focus is not on specific weather phenomena, their climate impact is adequately estimated by using a climatological mean respresentation of the weather situation over a long period of time and apply the climate-chemistry response model AirClim. For the selection of an air traffic reference scenario it therefore needs to be taken into account that whenever specific days are to be analysed the interrelation between air traffic and weather data is adequately captured and the corresponding weather data is selected as part of the scenario. The following sections will consequently present different types of data relevant for the baseline scenario, such as e.g. air traffic and weather data.

3.2 Air traffic data

Data on air traffic or flight movements can certainly be obtained and processed differently. The types of data mainly differ with respect to the level of detail and, hence, in the amount of information available per flight and the resolution. The air traffic data available to the ClimOP consortium can be subdivided into schedule data and flight track data.

3.2.1 Schedule data

Global flight schedule data contains a comprehensive collection of worldwide scheduled commercial passenger and cargo flights. It can be considered to be an integrated timetable of all airlines. Widely used data products are provided e.g. by the Offical Airline Guide (OAG) or Innovata. DLR has access to the Sabre AirVision Market Intelligence (MI), formerly known as Airport Data Intelligence (ADI), which includes besides schedule data also demand data. Sabre's schedule data is primarily based on the Innovata data and can be used to look up all scheduled flights that took place during any given period of time (e.g. a particular day, a week, a month, a quarter or a year). Figure 4 shows an example schedule query in the browser-based user interface. The parameters that can be obtained are listed in Table 10. All queries can be exported to CSV files.

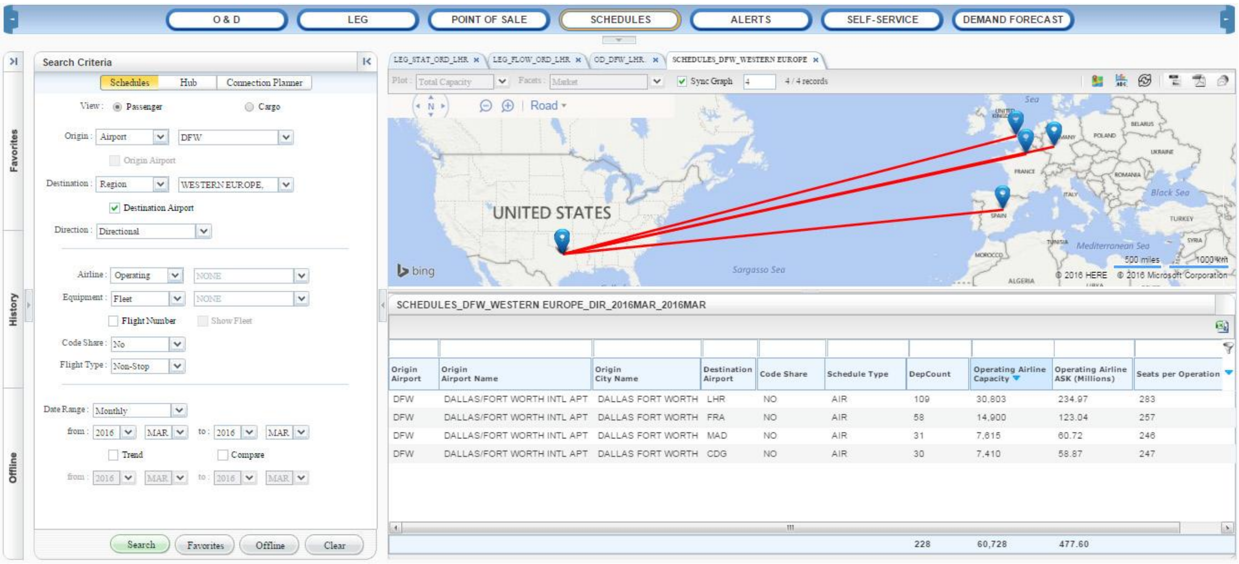

Figure 4 – Browser-based user interface of Sabre AirVision Market Intelligence

An advantage of the global flight schedule data is that it provides a quite complete overview of scheduled flights. For each flight connection, the corresponding airline, aircraft type, and flight number can be obtained. However, there is no information on the individual aircraft (registration number), which was used for the flight, because this can be subject to short-term changes based on airline decisions and may vary for a given flight number. There are other databases, such as e.g. Cirium Flight Fleets Analyzer, that provide detailed insight into airline fleets with respective registration numbers, which can for e.g. be used to gather any missing information on the aircraft.

Table 10: Overview on parameters available in Sabre AirVision Market Intelligence database

Parameter	Variable name	Comment	Example
Origin Airport	Orgn	IATA 3-letter-code	AUH (Abu Dhabi)
Destination Airport	Dest	IATA-3-letter-code	LHR (London Heathrow)
Operating Airline	OperatingAirline	IATA airline designator	EY
Operating Airline Name			Etihad Airways
Code Share	CodeShare	Yes/No	No
Fleet	Fleet	IATA aircraft designator	388 (Airbus A380-800)
Fleet Name	FleetName		Airbus A380
Manufacturer		Aircraft manufacturer	Airbus
Flight No	FltNum	Flight number as of airline timetable	19 (-> EY 19)
Effective Date	EffDate	Data valid from	20150815
Discontinued Date	DiscDate	Data valid until	20150831
Departure Time	DepTime	Planned departure time (local!)	08:20
Arrival Time	ArvTime	Planned arrival time (local!)	13:05
Flight Duration	FlightDuration	Flight time (planned), in minutes	465 (-> 7h 45m)
Departure Terminal	DepTerminal	Departure terminal	3
Arrival Terminal	ArvTerminal	Arrival terminal	4
Restricted Code			
Frequency			
Mon/Tue/Wed/Thu/ Fri/Sat/Sun	Mon/Tue/Wed/Thu/ Fri/Sat/Sun	Days of week, when flight takes place	M, T, W, T, F, S, S
Schedule Type	ScheduleType		AIR
Departures Count	Depcount	Number of departures per period	1
Operating Airline Capacity		Number of seats per period	498
Operating Airline ASK		ASKs per period, in million	2.74
Seats per Operation		Number of seats per flight	498
Distance	Distance(kms)	Great circle distance, in km	5494

It also should be noted, that due to the fact that no single flights are listed, but flight groups, no information about the actual flight track or route is provided. Based on the origin and destination airports meaningful assumptions have to be taken in order to model the flight sufficiently, e.g. by a great circle segment. Also departure and arrival time information is provided per flight. Here it needs to be noted, that all times provided are local times and they have to be converted to Universal Time Coordinated (UTC) to have a global reference independent from the location.

3.2.2 Flight track data

In contrast to schedule data, flight track data provide more detailed information per individual flight. This data normally allows for imitating the actual flight event including its vertical profile and lateral route by appropriate trajectory generators or simulators. Examples include ADS-B data, radar data or point profile data such as provided by e.g. EUROCONTROL.

3.2.2.1 ADS-B data

Automatic Dependent Surveillance – Broadcast (ADS-B) is a transmitting system that broadcasts unencrypted 4D aircraft trajectory data into its environment in a temporal interval of at least 10 seconds. Essential on-board hardware equipment for ADS-B application are several navigation systems (satellite and inertial), ADS-B modules and a Mode-S transmitter in the very high frequency (VHF) range. Separated channels for input and output streams are available, besides the broadcasting of the own aircraft position to air traffic management (ATM) operators, data of surrounding aircraft can be received and the adjacent air traffic can also be displayed in the cockpit [27].

The following aircraft status data are collected and broadcasted by the ADS-B system [28]:

- longitude-latitude position from Global Positioning Signal (GPS)
- baro- and geoaltitude
- ground speed
- climb/descend rate
- heading
- time stamp

Those data enable localizing every aircraft, that is ADS-B equipped, in airspace anytime and are important for navigation processes and ATM as they increase the aviation safety.

A network of globally distributed ADS-B receivers on the ground pick up those signals. The coverage of ADS-B receiver on the ground is inhomogeneous and widely spreaded gaps can be identified over Central Africa, Western China and large areas over the Pacific Ocean [29].

Air navigation service providers (ANSPs) use the data for navigation and ATM. Real-time flight tracking services like flightradar24 or opensky-network collect, process and convert the data to time series of the observed aircraft tracks and publish real-time air traffic data online on their web services.

Those services are helpful to get crucial information about the actual routing in global air traffic and its daily and seasonal variation, the flight level distribution and the traffic density itself. In advance a quality check of the raw data is necessary because interferences between various ADS-B participants that might use the same frequencies for transmission and the common errors of avionic sensors and wireless data transmission could lead to errors and outliers in the data. An extract of those ADS-B datasets can provide a real traffic scenario and is applicable for the assessment of OIs as information in various complexity can be used. Some OIs need the origin and destination airport pair and the aircraft type for an assessment, while others may need detailed information about the specific routing and the vertical cruise level statistics.

To avoid large amounts of data, only short time series in the magnitude of a few hours should be extracted at once. The raw data, that are available in text format and can be converted to csv-files for download, show all received signals of various aircrafts in a temporal order. So several aircraft trajectories are mixed in the data and filtering by aircraft ID during a preprocessing is necessary to obtain entire trajectories.

3.2.2.2 Radar data

Radar data is regularly stored and can be monitored via the internet. For transparency reasons different ANSPs allow access to this data through special web applications. The German ANSP DFS, for instance, uses the NLR-developed Stanly Track software (https://stanlytrack3.dfs.de/st3/STANLY_Track3.html). The tool is based on the Flight Track and Aircraft Noise Monitoring System (FANOMOS). This flight track recording system makes it possible to display and evaluate the flight tracks of individual aircrafts arriving at or departing from an airport. It is based on radar data and can be used to assess aircraft noise complaints and possible violations of rules. Unfortunately, there are no ways to download or export the data in a structured way, which makes it difficult to use it for scientific purposes in large air traffic scenarios.

3.2.2.3 Point profile data

EUROCONTROL deploys a series of European-wide air traffic management (ATM) programs and projects, involving a range of ATM players. Demand Data Repository (DDR) is one of these projects that aims to provide European airspace planners and airspace users with data that will depict a straight picture of past and future European air traffic demand for the purpose of meeting the planning and monitoring needs. The repository provides a refined analysis of past demand in order to enable post-operations analysis and identify best practices for future operations. DDR2 (DDR – phase2) contains historical traffic, future traffic and filtered traffic data. DDR2 includes two types of datasets, namely ALL_FT+ and SO6, associated with 4D trajectory by flight segments. While SO6 m1 file format provides 4D flight trajectories last filled flight plan (FTFM), SO6 m3 file gives same properties that are updated prior to flying (CTFM). ALL_FT+ data consists of SO6 point profile records and contains additional information regarding the historical air traffic in the ECAC area. A typical ALL_FT+ file for a single day includes the details of all flights in European airspace on that day. This dataset encodes various types of information for individual flights occurring in European Airspace including intercontinental flights that overfly the European Airspace. The dataset contains basic flight information such as departure and arrival airports, callsign, tail number, aircraft type, aircraft operator, scheduled departure time, scheduled arrival time, etc. Besides, in the ALL_FT+ dataset, one can find information about the exact point that the aircraft change its plans in a flight regarding the planned information (FTFM), regulated one (RTFM) and the one prior to flying (CTFM). All flight models have point profiles and airspace profiles, and these profiles are compound attributes. In this project, we will benefit from the point profile field in this dataset while creating case studies and modelling the OIs. The full description of a point profile element is presented in Table 11 below. A flight contains several instances of this element to indicate its trajectory.

Table 11: Overview on parameters available in point profile data from EUROCONTROL

#	Parameter	Field	Type	Comment	Example
1	Time	TimeOver	Date-HHMMSS	Time at the related point	20170102144700
2	Name of the point	Point	char	Name-codes for the current point (Airport, FIX, VOR, …)	EGCC
3	Name of the route	Route	char	Name-codes for the route (SID, STAR, Airway, DCT)	SANBA1R
4	Flight Level	FlightLevel	num	Flight level, e.g. FL230	3

5	Distance from the first point	PointDistance	num	The distance over the trajectory measured from the first bound (usually ADEP) to the point. (measured in kilometers)	0
6	Type of the point	PointType	char	values A, D, G, N, S, V or W	A
7	Geographic position of the point	GeoPointID	ggmmsso	The latitude and longitude of the current point (g: degrees; m: minutes; s: seconds; o: orientation (N/S – E/W))	532114N0021630W
8	Relative distance	RelDist	num	Measured in kilometers	Empty
9	Visibility	IsVisible	char	Y or N	Y

3.3 Weather and atmospheric data

In the following sections an overview on different types of weather and climate-related data is provided.

3.3.1 Meteorology

In order to assess the climate impact of aviation correctly and identify climate sensitive zones in the atmosphere, globally available meteorological datasets, that cover all vertical levels where air traffic operates, are necessary. National weather services of each country operate a network of ground measurements of pressure, temperature, humidity, wind speed and direction, radiation and precipitation. A lot of those meteorological stations are based at airports as reliable weather data are vital information for safe landing and takeoff maneuvers. In the oceans a few buoys are placed not to neglect the ocean area. Information from atmospheric layers beyond the near surface and vertical profiles of the atmosphere and its stratification is obtained by a few radio soundings that are mounted mostly every six hours. Also a lot of aircraft are equipped with meteorological sensors and record the atmospheric state along their trajectories, particularly during climb and descent. The density of the aforementioned measurement methods are inhomogeneous and vary both over land and sea and the latter depends on air traffic volume. A global coverage could be reached with remote sensing measurements like satellites that enable a global view on cloud coverage, water vapour content and temperature. Satellite data have to be calibrated and validated with the aforementioned ground measurements and vertical profiles to avoid bias as they receive a wave length spectrum of emitted thermal radiation.

3.3.1.1 Reanalysis data

All the datasets will be checked, interpolated and temporally assimilated with complex numerical methods to get the initial state and input data for the weather forecast model. Instead of forward integrating to obtain a numerical weather forecast, the models could be also applied to get a global reanalysis of the atmospheric state for a certain time on a discrete numerical grid, that is physically consistent with the conservation laws of mass, momentum and energy.

3.3.1.2 ECMWF Reanalysis

ERA5 global 4D reanalysis data have been developing since 2016 and are the advanced successor of previous ERA interim reanalysis datasets both derived from the European Centre for Medium-Range Forecast (ECMWF). ERA5 reanalysis data have been currently released for the years from 1979 to maximum three months behind the present day. The ERA5 reanalysis simulation bases on 0,75 million observations per day and 24 million daily values in 2018. The increasing number of input data results from novel remote sensing technologies from satellites. The reanalysis data are not available continuously but on a discrete numerical grid. The horizontal resolution is 0.28125 x 0.28125 up to 31km. The temporal model timestep is 12 minutes and the datasets are published as aggregated values with different resolutions from monthly averages up to one hour. In ERA5, the atmosphere is vertically resolved by 137 non-equidistant model levels from 1013.25hPa on ground to 0.01 hPa that represents approximately an altitude of 80km. Also applicable is a ERA5 dataset, that consists of 37 pressure levels from 1000 to 1hPa with vertical interpolated values. The gridded data are stored in the binary GRIB2 format but can also be downloaded from the ECMWF climate data store (CDS) in the converted netCDF format.

The following atmospheric parameters have been simulated and are available as discrete values for each grid cell and on each level in ERA5 reanalysis dataset. For example U- and V- wind components, vorticity and divergence that describe the dynamic in the atmosphere, thermodynamic variables like temperature, water content in liquid and ice phase, relative and specific humidity and also chemical variables e. g. the ozone mixing ratio. The resilience of the high-resolved main run of the reanalysis data can be assessed by a 10-member ensemble with reduced horizontal resolution, that shows the statistics with mean and standard deviation of the results in consequence on small variations of the initial conditions.
With the ERA5 reanalysis data from ECMWF a consistent numerical 4D dataset is available in the public domain to describe the atmospheric state with a quite high resolution for a global dataset and is appropriate for the modelling of effects of OIs in ClimOP and finally an essential input dataset for the climate impact assessment. Further information on the ERA5 reanalysis can be found in [30] and in the online manual [31].

3.3.1.3 NCEP GFS

NCEP GFS (National Centers for Environmental Prediction – Global Forecast System) contains a research data archive. This dataset could be used to obtain weather information during a defined time period. In the dataset, the atmosphere is discretized on a 0.25° by 0.25° global latitude longitude grid to present the weather information on the corresponding areas. There are several components of the weather information, which are listed in the table below.

Table 12: Basic components of the weather information on NCEP GFS

Absolute vorticity	Cloud water mixing ratio	Geopotential height	Graupel
Ice water mixing ratio	Rain water mixing ratio	Relative humidity	Snow water mixing ratio
Temperature	Total cloud cover	u-component of wind	v-component of wind
Vertical velocity (geometric)	Vertical velocity (pressure)		

3.3.1.4 Airport ground measurements

Meteorological near-surface measurements at the airport areas are coded in the METeorological Aerodrome Report (METAR) standard and provided to airlines and pilots to ensure safe airport operations. The datasets contain current values of air pressure, temperature and dewpoint, wind speed and direction, cloudiness, precipitation and visibility. The recorded data of a large number of civil airports all over the world is freely available and can be downloaded in a formatted time series format as csv-file from the Environmental Mesonet Website of Iowa State University [32]. The availability of the weather data varies from last 50 to at least last 10 years with time intervals from 0.5 to 3 hours. National weather services like Koninklijk Nederlands Meteorologisch Instituut (KNMI) from the Netherlands and Deutscher Wetterdienst (DWD) from Germany also provide meteorological time series from their measurement stations (on airports) on their data servers public domain. This data can be useful for the assessment of the airport related OIs that were chosen for further investigation.

3.3.2 Climate impact

If climate functions are to be used to calculate the climate impact, two types of functions are available, climate change functions and algorithmic climate change functions.

3.3.2.1 Climate change functions

Climate change functions (CCFs) [33] describe the global climate impact to location- and time dependent aviation emissions. A chemistry-climate model is used to simulate the atmospheric impact of emissions released at specific locations and times, followed by calculating the respective radiative impacts. These represent the input to climate metric formulas which describe the global climate impact of the emission at each time-region grid point in terms of various climate metrics, e.g. Global Warming Potential (GWP), Global Temperature Potential (GTP) or Average Temperature Response (ATR) for time horizons of 20, 50 or 100 years. Climate change functions are available for the Northern Atlantic region, for a set of 8 characteristic weather situations and for the climate impacts of contrails, Ozone (O_3) and Methane (CH_4) from aviation NOx emissions and water vapour [33]. In general climate cost functions can be used for the optimisation of aircraft trajectories in the respective region. These climate cost functions are only valid for the respective weather situation. To enable the CCFs to be used more universally, algorithmic climate change functions are developed.

3.3.2.2 Algorithmic climate change functions

Algorithmic climate change functions (a-CCFs) are algorithmic approximations of CCFs described above. A-CCFs are calculated with an algorithm that uses standard MET information, e.g., geopotential, or atmospheric temperature as an input parameter, to calculate climate impacts. a-CCFs describe the climate impact of an emission unit at a specific location and time of emission using standard physical climate metrics, e.g., average temperature response (ATR). a-CCFs can be conveniently implemented in any Numerical Weather Prediction model, thereby serving as a means of advanced MET-information for flight trajectory planning.
$\boldsymbol{m}$^**2** / $\boldsymbol{s}$^**2** Eqn. (1) shows an example of a-CCFs, which calculates the ATR in 20 years for NO_x-O_3 effects as a function of temperature (T) in [K] and geopotential (Φ) in [m^2/s^2]. A full set of a-CCFs formulas, including effects from CO_2 (constant), NO_x effects (via ozone formation and methane depletion), water vapor, contrails separated from day/night, can be found in references [34] and appendix A of [35].

$$\boldsymbol{\widetilde{aCCF}_{O_3}(T,\emptyset) = -5.20 \times 10^{-11} + 2.30 \times 10^{-13} \times T + 4.85 \times 10^{-16} \times \emptyset - 2.04 \times 10^{-18} \times T \times \emptyset}$$

$$\boldsymbol{aCCF_{O_3} = \begin{cases} \widetilde{aCCF}_{O_3}(T,\emptyset) & for\ \widetilde{aCCF}_{O_3}(T,\emptyset) > 0 \\ 0 & else \end{cases}} \qquad \textbf{(1)}$$

3.4 Airport ground fleet data

The climate impact assessment of GHG emissions under direct control of airport operators requires data from different sources, including:

- The number, class, mileage and typical fuel consumption of the airport's ground vehicles. This is sensitive data and varies for different airports. SEA Milan will confidentially make a dataset available of the information related to its controlled aerodromes (Linate and Malpensa). This data will be processed, simplified and anonymised to make it representative of a typical medium-size airport. To validate the model outcome, analogous information from other airports will be collected through the ClimOP Advisory Board members (the airports of Ibiza and Schiphol and ACI Europe).
- The conversion factors and equations to compute the amount of GHG emissions from ground operations vehicles based on their fuel consumptions. Many references are available in the literature, including the "EMEP/EEA air pollutant emission inventory guidebook 2019" [19], the COPERT software [36], [37] or numerical simulations and analytical approaches based on average consumption values for vehicles of given classes and detailed tests in realistic traffic conditions (e.g. [21], [22], [24], [38], [39]).
- The data on energy demand of electric vehicles are available for example from the life cycle assessments of the manufacturers [40] or in multiple literature studies that estimate the benefits of electrification of the personal car, bus, or taxi fleet in different countries (e.g. [22], [41] - [44]).
- Data on the European mix of electricity production sources [25], [45].

To investigate the correlation between air traffic and ground emissions, SEA Milan will make available its air traffic statistics of recent years (e.g. number of flights to and from the airports, number of passengers, number of staff involved in airport operations). Aggregated air traffic statistics for multiple airports until 2019 are available e.g. on Eurostat [46].

3.5 Social acceptance

The ClimOP project aims to identify OIs which are not only mitigating the climate impact of the aviation sector but that are also acceptable for the stakeholders, including passengers. In particular, ClimOP plans to investigate the perception of the climate change issue, of the contribution coming from aviation, and the social acceptance of the proposed OIs. To collect these pieces of information, a survey is currently in preparation which will be carried out in the second half of 2021. This survey is primarily meant for airline passengers and aims at gathering opinions about the OIs selected by ClimOP. The results will be used by the consortium to understand how much passengers are willing to tolerate changes in their flight experience knowing that it is for fighting climate change.

The survey will be distributed to an intended pool of at least 300 respondents via mailing lists, social media and other digital means of communication. The ClimOP Consortium intends to gather answers distributed as evenly as possible throughout the European Union. The preliminary set of questions of the survey are listed in Table 1 together with the expected answer category, such as a number, an answer from a multiple-option menu, an open text, a value in a 1 – 7 likert scale, etc.

The questions in the ClimOP passengers' acceptance survey investigate the passenger background information and their inclination to prefer flight solutions adopting ClimOP OIs rather than standard flights. The questions that cover the background information focus on travel habits (like the preferred mode of transportations for daily travels, the one employed for their journeys and the frequency with which they were taking flights before the pandemic), and the awareness of the climate change issue. The second part of the questionnaire gathers information on the degree to which the changes introduced with the OIs are acceptable to passengers, for example: higher ticket prices, longer or multi-segmented flights, baggage restrictions, less frequent and more crowded flights, and the attitude towards more control on the climate impact of aviation by the government bodies.

The questions listed in Table 13 represent a preliminary set of items that intends to provide an example of how the ClimOP social acceptance survey will be structured and appear to the respondents. However, before making the survey public, the Consortium will detail the questions to make them more accurate and valid from a statistical point of view. Also, contextual information about costs and benefits of the proposed OIs will be added to better clarify the implications of the possible answers to a non-expert audience.

Table 13: Preliminary list of questions of the survery to investigate the social acceptance of ClimOP proposed OIs.

#	Question	Answer category
1	What is your age?	Open (number)
2	What is your gender?	Multiple option
3	In what country did you spend most of your lifetime?	Open (text)
4	What is your level of education?	Open (text)
5	Average net income?	Multiple option
6	Professions?	Multiple option
	Travel habits	
7	Which is your preferred mode of transportation on daily travels?	Multiple option
8	What mode of transportation do you prefer for your journeys?	Multiple option
9	Before the pandemic, how often did you travel by airplane?	Multiple option
	Perception of climate change as an issue	
10	How much do you feel climate change as an issue?	Likert scale value
11	How much do you think climate change is an issue for the people around you?	Likert scale value
12	How much are you favouring to take action on climate?	Likert scale value
	Environmentally friendly behaviour	
13	On a daily basis, how many decisions do you take preserving the environment?	Multiple option
	Awareness	
14	Could you tell any European initiatives to fight climate change?	Multiple option
15	Could you name any initiatives taken from your country to fight climate change?	Open (text)
16	Could you say any aviation initiatives to fight climate change?	Open (text)
	Perception of climate impact of aviation	
17	If the total impact of human activities on climate change is set to 100, how much do you think is the share of aviation?	Multiple option
18	If the total projected impact of human activities on climate change in 2050 is set to 100, how much do you think will be the share of aviation?	Multiple option
19	How much would you be in favour of introducing measures to reduce the climate impact of aviation?	Likert scale value
	Flying low (and slow) → higher ticket price	
20	Flying at a lower altitude would reduce the climate impact of the greenhouse gases emitted by the aircraft. However, this would increase the expenses for the airlines and thus the ticket prices. Knowing that this is beneficial to fight climate change, how much would you be in favour of paying more for flying to a European destination?	Likert scale value

21	Knowing that this is beneficial to fight climate change, how much would you be in favour of paying more for a transoceanic flight?	Likert scale value
	Flying low (and slow) → longer flights	
22	The GHG emissions of aircraft depend on the cruise speed. Up to a certain extent, on average the faster an aircraft travels, the more fuel it burns and consequently the more GHG it emits in the atmosphere. Reducing the typical cruise speed would reduce the emissions of GHG. However, this would also increase the duration of the flights. Knowing that this would be beneficial to fight climate change, how much would you be in favour of increasing the duration of your flights?	Likert scale value
	Strategic planning/intermediate stop-over → multi-segments instead of direct	
24	An optimised network of connections between airports can potentially reduce the impact of aviation of GHG emissions on climate. However, this would imply that direct connections could be cancelled and replaced by multi-segment flights. Knowing that this would be beneficial to fight climate change, how much would you be in favour of having 2/3-segment flights instead of direct flights to reach your destination?	Likert scale value
25	How much would you be in favour of taking segmented flights with longer stopovers to spend some time exploring the intermediate city?	Likert scale value
	Weight limitations/baggage restrictions	
26	The aircraft emissions of GHG are proportional to the weight of the aircraft. If you reduce the weight of an aircraft, the GHG emissions of this flight would be reduced too. This could be achieved by allowing passengers to a maximum of 3kg of luggage (i.e. just a small hand baggage). Knowing that this would be beneficial to fight climate change, how much would you agree to baggage limitations?	Likert scale value
	Strategic planning (merge flights) → larger aircraft + less frequent, crowded flights	
27	Fully loaded and larger aircraft on popular routes can reduce the climate impact of aviation. Knowing this, how much would you agree to have less frequent flight connections? How much would you agree to travel on larger aircraft fully booked?	Likert scale value
	Electrification of ground operations	
28	Several airports are currently transitioning to completely electric ground operations, which will cut to almost zero the local GHG emissions from ground vehicles. In addition, these airports are committed to producing and using renewable energy, so that they are effectively climate-neutral. Would you prefer to travel from an airport, if you knew that this airport is climate neutral?	Likert scale value
	Regulatory OIs: promoting climate-friendly flights	
29	How much would you be in favour of introducing regulations promoting flights that are more climate friendly (e.g. tax discounts for aircraft that avoid climate-sensitive trajectories)?	Likert scale value
30	If the government would put in place a transparent and objective	Likert scale value

	system to assess the "climate friendliness" of the operations of different aviation companies, would you consider choosing your flights based on the climate reputation?	

This survey will give the ClimOP consortium a better understanding of the passengers' opinions on the proposed OIs. In addition, the results could in principle be used to refine the impact analysis of the proposed changes in terms of a "cost function" which would allow rank and prioritise the OIs, being equal to their impact on climate.

4. Derivation of a common air traffic scenario

Based on the requirements formulated by each respective operational improvement (chapter 2) working group and the available data described in chapter 3, this chapter will highlight similarities between the different OIs' workflows and derive which input data and assumptions could be used to process the different case studies such that a comparability is guaranteed. Due to the heterogeneous nature of the different OIs (note that we have airline network level, trajectory-level, and ground level OIs, while one OI addressing the regulatory level has been merged into one of the others), it is not reasonable to aim at defining one single set of input data for all studies, but rather try to maximise the overlap between the different sets of data that could be used for the case studies.

4.1 Similarities between the individual OIs' requirements to the air traffic scenario

During the various working group meetings, many facets of the modelling workflows have been discussed, from which it can be observed that there are primarily four dimensions that characterize the boundary conditions of the study, i.e., the geographic scope, the temporal scope, the character of the flights to be modeled and the data sources. With the findings from section 2.2. Table 14 presents an intercomparison between the different OIs with respect to those four dimensions.

In terms of the geographic scope, it can be seen that most OIs have a focus on Europe or parts (e.g., selected airspaces or airports) of it, while the Climate-optimised ISO is probably rather addressing a global scope or at least long-haul flights departing from or arriving in Europe. A focus on Europe also makes sense as ClimOP is a research and innovation action funded by the European Commission and its consortium is made up of solely European partners. The definition of Europe will need to be precise, as there are e.g., differences between the political and geographical Europe and the area of responsibility of EUROCONTROL, for instance, does not coincide with geographical Europe.

In terms of the temporal scope, the studies differ. While the trajectory-level OIs are reasonably carried out for a number of individual days that ideally represent the characteristic weather situations that could occur while reducing the amount of flights to consider, the airline network-related OIs should rather be studied on a longer period of time assuming climatological average atmospheric conditions. This also holds for the ground-related OIs.

With respect to the question, whether aggregated schedules or individual flights should be analysed, a clear correlation to the temporal scope can be recognized. Obviously, the trajectory-level OIs, which are studied on an individual day basis, should be investigated relative to individual flights considering accurate flight track data as a baseline. For the network-related OIs, the use of aggregated flight schedules with simplifying assumptions regarding e.g., the horizontal flight route and vertical profile, seems to be sufficient. For the ground-level OIs, the airport perspective and the flight plan from an individual airport operations view would be required. Here, depending on the models' level of detail, aggregated flight schedules or individual daily flight plans can be used.

Table 14: Characteristics of the OIs regarding their requirements to the common reference scenario including technological and operational boundary conditions and air traffic sample.

	Geographic scope	Temporal scope	Aggregated schedule vs. individual flight	Data sources
Flying Low and Slow	Pan-European flights	A number of days with characteristic weather in 2018	Individual flights (on the selected days), point profiles	EUROCONTROL R&D archive (point profile data), ECMWF ERA5 weather data
Free Routing	Several en-route airspaces in the ECAC area	A number of days without additional NOTAMs in the corresponding airspaces (or/and considering characteristic weather situations)	Individual flights (on the selected days), point profiles	EUROCONTROL R&D archive (point profile data), NCEP GFS wind/weather data (or another wind/weather data source)
Climate-optimised Flight Planning	Northern Hemisphere focusing on the North Atlantic Flight Corridor (= US/Europe)	Multiple seasons, i.e. a number of days with characteristic weather in 2018	Individual flights (on the selected days), flight track data	Climate change functions, EUROCONTROL R&D archive (point profile data) amended by ADS-B data, ECMWF ERA5 weather data
Wind/Weather-optimised Flight Planning	Several en-route airspaces in the ECAC area	A number of days with characteristic wind/weather situations	Individual flights (on the selected days), point profiles	EUROCONTROL R&D archive (point profile data), NCEP GFS wind/weather data (or another wind/weather data source)
Strategic network planning	Selected airport network (Europe)	A longer period of time, climatological mean values	Aggregated schedule (flight plan)	Sabre Market Intelligence schedule data, passenger demand data, airport capacity data
Climate-optimised ISO	Global flights > 2500NM	A longer period of time, climatological mean values	Aggregated schedule (flight plan)	Sabre Market Intelligence schedule data, ECMWF atmosphere
Taxiing	Europe, selected airports (e.g. Milan Malpensa)	A longer period of time, climatological mean values	Airport operations incl. individual flights	Airport flight operations data
Electrification of ground vehicles / operations	Europe, Milan Malpensa, Linate	Typical year of operations	Standard airport operations	Airport operation and fuel consumption data, Eurostat
Upgrade of airport infrastructure	Europe, Milan Malpensa	Typical meteorological year, future conditions	Standard airport operations	Airport data (incl. building geometry and equipment), CMIP5 climate data

The data sources result from the above mentioned scenario dimensions but may slightly differ based on individual partners' preferences and capabilities.

4.2 Suggestions for a common reference air traffic and ground management scenario

As described in the previous section, similarities in the way the OIs should be addressed can be observed. Where differences are found, it would be preferable to at least maximise the overlap between the required datasets in the above mentioned scenario dimensions.

Looking at the geographic scope, it seems reasonable to decide to base all studies on the ECAC area, which is the geographic region the EUROCONTROL is responsible for. Hence, flight track data is available here. For the aggregated schedule, a corresponding excerpt of the ECAC-related flights can be generated as well. For some OIs the EUROCONTROL R&D archive shall be used. Here, there are some important limitations with regard to the data availability that have an influence on the selection of the temporal scope. So far, only the years 2015 to 2018 are covered in the database, which is why the selection of the calendar year 2018 is suggested. It is to date the most accurate data set available, not too outdated and still provides an unimpeded pre-pandemic picture of the European air traffic. It has to be noted that only the months March, June, September and December are provided as datasets in the database. Also, weather data is available for 2018 from all meteorological databases mentioned above. Also, future climate data (typical meteorological year) can be used, e.g., for the airport-related OIs. Regarding the modelling of flights for the simulation of a particular OI, the trajectory simulators available to the consortium support the use of EUROCONTROL's Base of Aircraft Data family 4. Wherever no full coverage is required, it is reasonable to reduce the number of modeled flights by focusing on the most impacting flights, typically those with the highest contribution to the Available Seat Kilometres (ASK). Aircraft models contained in BADA 4 are usually those that contribute most to the ASK.
Table 15 provides a summary of the derived suggestions for a common reference dataset considering air traffic, operational and technological boundary conditions, such as the aircraft type aspect.

Table 15: Suggestions for a common reference dataset considering air traffic, operational and technological boundary conditions.

<table>
<tr><th></th><th>Trajectory-related</th><th>Airline network-related</th><th>Airport-related</th></tr>
<tr><td rowspan="2">Geographic scope</td><td colspan="3">ECAC area</td></tr>
<tr><td>Intra-ECAC</td><td>From/To ECAC</td><td>Milan Malpensa, Linate</td></tr>
<tr><td rowspan="2">Temporal scope</td><td colspan="3">2018</td></tr>
<tr><td>Selected days (Mar/Jun/Sep/Dec)</td><td>Entire year</td><td>Typical meteorological year</td></tr>
<tr><td rowspan="3">Flight data, Aircraft types & filter criteria</td><td>Individual flights</td><td>Aggregated schedule</td><td>Airport operations plan</td></tr>
<tr><td colspan="2">Most impacting flights (e.g., covering ~95% ASK during the selected period)</td><td>All flights</td></tr>
<tr><td colspan="2">Aircraft models included in BADA 4 database</td><td>All aircraft</td></tr>
</table>

5. Conclusion and future work

This deliverable presents the description of a common reference scenario including the air traffic, technological and operational boundary conditions as a baseline for conducting the climate impact assessment of different operational improvements. The document provides the context to the overall ClimOP project as well as a detailed description of different types of data available to the consortium partners. Those databases cover the whole spectrum from air traffic data in different levels of granularity, e.g. flight schedule or ADS-B data, through different types of weather and climate data, including climate change functions for an efficient calculation of the climate impact to airport data. For the different OIs the deliverable elaborates on the preliminary modelling workflows that have been used to derive the necessary input data. Based on that an intercomparison of the individual requirements was done resulting in the identification of similarities in the way the OIs should be addressed. To derive a common reference air traffic scenario, where differences occurred, the overlap between the required datasets with respect to the geographic and temporal scope as well as flight and aircraft data was maximised. The suggested reference air traffic scenario has a clear geographic focus on the ECAC region, while in the temporal dimension the year 2018 has been identified to be a reasonable period, as it is characterized by a good data availability for various data types.

While this document provides the results of a harmonization attempt of the various individual requirements to the modelling and simulation exercises towards one common air traffic scenario, it should be considered as an initial collection of ideas and suggestions on how to address the different operational improvements in the most aligned way to ensure a high degree of comparability between the results. However, the working groups, which have formed in the course of this activity, will continue their work on elaborating the required modelling workflows and may need to specify the input data more precisely as they are entering in-depth discussions. Advanced specifications of the modelling workflows and data inputs and outputs will be provided in the upcoming deliverable D2.2.

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