D1.1 – Definition of climate and performance metrics

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CLIMOP Consortium

CLIMOP Consortium consists of a well-balanced set of partners that cover all the needed competencies and the whole value chain from research to operations. ClimOp Consortium includes representatives from aviation industry (IATA, SEA), academic and research institutes (NLR, DLR,TU-Delft, ITU) and SMEs (DBL, AMIGO).

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Executive summary

The ClimOp project investigates, for the first time, in a sound research framework, which operational improvements do have a positive impact on climate, taking non-CO_2 effects into account. Subsequently, it will analyse and propose harmonised mitigation strategies that foster the implementation of these operational improvements. To this end, the ClimOp consortium builds on its knowledge and expertise covering the whole spectrum from aviation operations research as well as atmospheric science and consulting to airline and airport operations.

Deliverable D1.1 addresses the first task in the ClimOp project Work Package 1 (WP1), defining the climate and performance metrics to enable the assessment of the operational improvements. The main objective of WP1 is to identify and rank a set of operational improvements that result in a climate impact mitigation while balancing the interests of all stakeholders involved. To assess and rank each of the improvements, first the Key Performance Indicators (KPIs) are defined, which include both climate impact metrics as well as metrics representing stakeholders' aspects, to ensure a balanced assessment. This allows for a preliminary assessment of each of the proposed operational improvements for each of the KPIs.

Five assumptions have been set to support the exploration of KPIs and the identification of operational improvements to be considered in ClimOp:

- All KPIs should directly affect or be influenced by the aviation sector
- All tracked KPIs and stakeholders are operating under "business-as-usual", disregarding any out-of-norm airside operations
- Global climate projections should use benchmarks established in 2019-20
- The boundary of airside operations begins at the boarding gates of the airport
- Stakeholders use technology currently available at TRL 7 or above, disregarding non-matured breakthrough technologies.

With ClimOp's scope and assumptions in mind, we define in this report nine different stakeholders and up to 47 unique KPIs. The identified stakeholders include: society, airlines, air navigation service providers (ANSPs), airports, original equipment manufacturers (OEMs), governments, passengers, cargo forwarders, and residents near airports. Each of the stakeholders has a distinctive role in the aviation industry and challenges in the context of climate mitigation. Understanding their needs and capabilities helps to clarify the types of KPIs that will be most relevant to track and study. Quantitative KPIs were categorised into five groups: environmental, technical, operational, safety, and economical. While two qualitative KPIs were also emphasised to address the human factors in climate mitigation: human performance and social acceptance.

Quantitative KPI categories	Qualitative KPI categories
Environmental Technical Operational Safety Economical	Human performance Social acceptance

After this preliminary assessment, the most promising improvements will be selected for a more detailed analysis on their climate impact mitigation potential (WP2), and if their potential is confirmed, strategies leading towards their implementation will be developed and assessed by different stakeholders (WP3).

1. Introduction

1.1 Climate change in context of aviation

Aviation emissions of carbon dioxide (CO_2), water vapour (H_2O), nitrogen oxides (NO_X), sulphur oxides (SO_X), soot and sulphate aerosols, alter the concentration of atmospheric greenhouse gases (GHG) and trigger the formation of persistent contrails and cirrus clouds in ice-supersaturated regions [1, 2]. These alterations in the concentration of atmospheric GHG and contrails and cirrus clouds modify the radiative forcing[1], with potential implications on climate change. The share of aviation amongst all anthropogenic CO_2 emissions is about 2% [3], while the contribution of aviation to the total anthropogenic radiative forcing reaches approximately 5% when non-CO_2 emissions are taken into account [4]. If no actions are undertaken, the adverse impact of aviation on the environment and climate will significantly grow over the next decades with the projected increase in air traffic by 3-4% per year. For this reason, international organisations such as the International Civil Aviation Organization (ICAO), IATA, the Air Transport Action Group (ATAG), the European Aviation Safety Agency (EASA), Airports Council International (ACI), and the European Commission have indicated as a priority for the Aviation industry to identify and implement mitigation strategies to reduce the impact of aviation on the environment and climate [5]. As a consequence, global associations of the aviation industry, under the coordination of ATAG, committed to a set of ambitious high-level climate action goals [5]:

- An average improvement in fuel efficiency of 1.5% per year from 2009 to 2020.
- A cap on net aviation CO_2 emissions from 2020 (carbon-neutral growth).
- A reduction in net aviation CO_2 emissions of 50% by 2050, relative to 2005 levels.

To meet these goals, the aviation industry has set up a strategy based on four pillars:

1. The development of new technologies, including environmentally friendly aircraft technologies and sustainable aviation fuels.
2. Establishing more efficient aircraft operations.
3. Improving the infrastructure, including modernised air-traffic-management systems.
4. Establishing a single Global Market-Based Measure to fill the remaining emissions gap.

In line with this strategy, public and private organisations in Europe have put powerful efforts to reach the goal of climate-sustainable aviation within the next decades. In the framework of the Clean Sky and Clean Sky 2 programmes, aircraft manufacturers have been working on environmentally-friendly aircraft technologies in Europe (cf. Pillar 1 above). The harmonization of the European ATM system is being promoted by the SESAR and SESAR2020 programmes, respectively (Pillar 3). Moreover, in 2016 ICAO agreed on a Resolution for a global market-based measure to address CO_2 emissions from international aviation (Pillar 4), which paved the way for the so-called Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). CORSIA aims to stabilise CO_2 emissions at 2020 levels by requiring airlines to offset the growth of their emissions from 2021 (carbon-neutral growth). Specific actions have been identified and carried out to foster a climate-friendly growth of the aviation industry also at airport level.

1.2 ClimOp project

In the context of the European commitment to research new methods and technologies aimed at reducing the impact of aviation on climate, four projects were selected by the Innovation and

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[1] IPCC defines Radiative Forcing as "a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system and as an index of the importance of the factor as a potential climate-change mechanism." (IPCC AR4)

Networks Executive Agency (INEA) within the action “Aviation operations impact on climate change”. These four projects are:

1. GreAT (Greener Air-Traffic Operations).
2. ACACIA (Advancing the Science for Aviation and Climate).
3. ALTERNATE (Assessment on alternative aviation fuels development).
4. ClimOp (Climate assessment of innovative mitigation strategies towards operational improvements in aviation)

The four projects contribute to the general objective by focusing on complementary aspects. In particular, GreAT investigates new concepts to manage air traffic in a climate-friendly way, e.g. by using Trajectory Based Operations (TBO) and adapted airspace design, ACACIA’s objective is to improve the scientific understanding of the contribution of aviation to climate change, while the exploration of new aviation fuels considering technical, economic, and environmental aspects is pursued by ALTERNATE. The focus of ClimOP is the identification of the operational improvements (hereinafter OIs) that, if introduced in aviation operations, have the potential to produce an overall positive impact on climate.

More in detail, ClimOP specific objectives are:

1. To determine alternative most-promising sets of compatible state-of-the-art and innovative OIs to reduce climate impact taking CO_2 and non-CO_2 effects into account.
2. To quantify the climate impact of the alternative sets of OIs determined in Objective 1.
3. To evaluate the stakeholder impact of the alternative sets of OIs determined in Objective 1.
4. To develop a body of harmonised mitigation strategies for each alternative set of OIs determined in Objective 1.
5. To provide recommendations for target stakeholders on policy actions and supporting measures to implement the alternative sets of OIs.

The ClimOp consortium is adopting the following six-step strategy (summarised in Figure 1) to reach its objectives:

- To identify all stakeholders that are potentially involved in the implementation of OIs in the aviation industry (airlines, airports, ANSPs, manufacturers, passengers, etc.) and their needs.
- To define a list of impact indicators and a methodology which will be adopted to quantify the impact of the OI sets on climate and on each of the Aviation stakeholders.
- To compile a list of the OIs that are currently being considered and discussed, specify a realistic time horizon on which these improvements can be implemented in day-to-day aviation operations, and identify the most promising sets of compatible OIs that, when introduced, reinforce each other’s positive climate impact.
- By adopting appropriate modelling tools, to quantify the climate impact and the economic impact on the aviation stakeholders of alternative sets of OIs.
- To develop harmonised mitigation strategies for the alternative sets of OIs and define the methodology to validate such strategies
- To identify influencing target stakeholders, both from aviation and from the political and economic framework, specify their needs and interests, and derive recommendations (in terms of policy actions and supporting measures) for them to ease the implementation of the selected mitigation strategies.

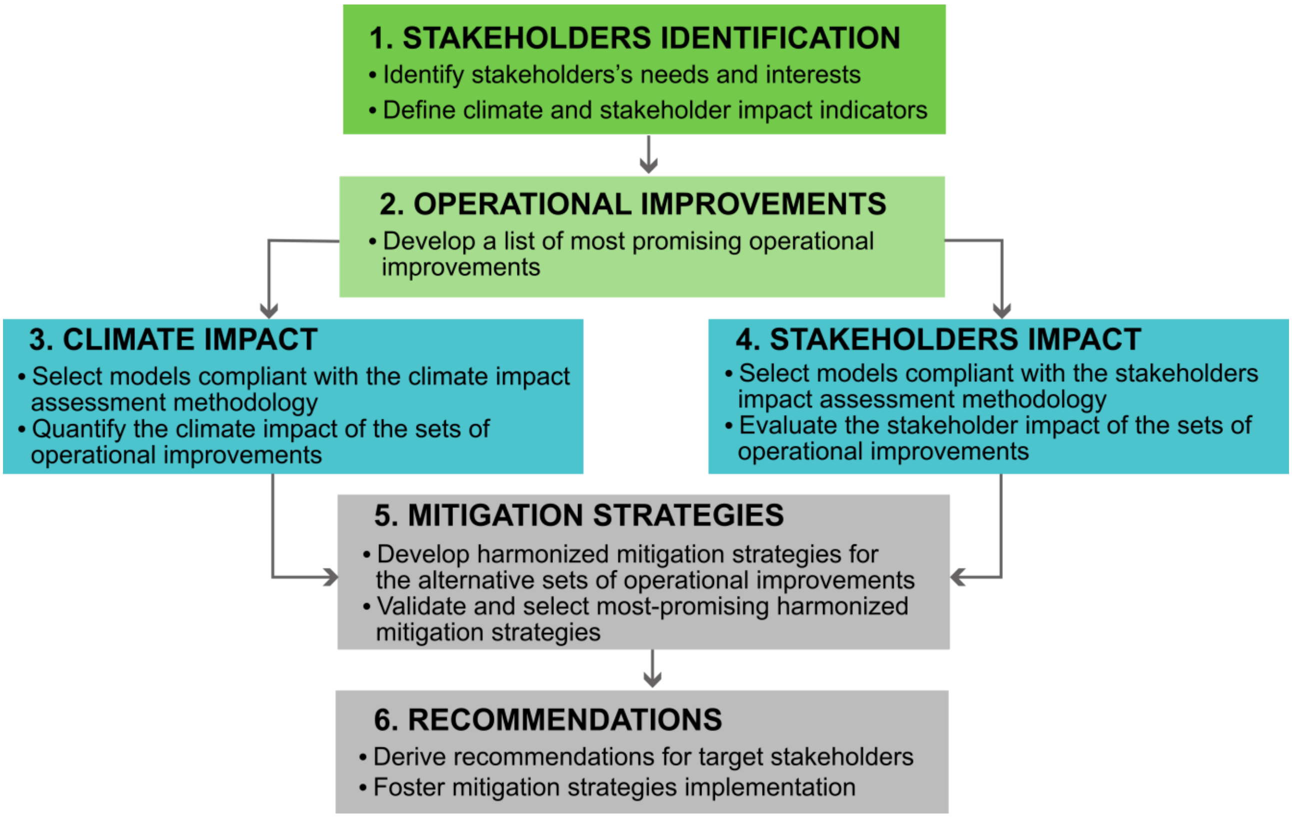

Figure 1 - ClimOp six-step strategy to reduce the impact of aviation on the climate.

1.3 Deliverable D1.1 in the project's context

The deliverable D.1.1 "Definition of climate and performance metrics" sets the foundation of the framework that will enable the assessment and ranking of the operational improvements. Critically, the objective of this report is to define the set of metrics to be used in ClimOp. The metrics identified will help quantify the benefits of different options for operational improvements according to a varied set of criteria and from various stakeholders' point of view.

The first step is to state the critical assumptions that are taken into consideration to scope the deliverable. Based on these established boundaries, all the relevant stakeholders are defined, clarifying their role and degree of influence on climate mitigation. Quantitative KPIs are listed and divided into five categories, independent of the stakeholders: environmental, technical, economical, operational, and safety-related. While qualitative metrics are considered, their effects are inherently difficult to track when exploring potential operational improvements. Nevertheless, these qualitative indicators can provide a different perspective on the effectiveness of mitigation strategies, and perhaps in the future, be indirectly estimated. Finally, stakeholders identified and metrics are summarised into a reference infographic in Section 4.3 for future works in ClimOp.

2. Climate and performance metrics selection process

A climate metric represents a method or tool that quantifies the greenhouse effect of a given emission on a common scale, which is relevant to climate change, so that the climate impact of different emissions species (long (e.g., CO_2) and short-lived (NO_x, water vapour, and particulates)) across a spectrum of sources can be compared. It should also be fairly easy to use by a non-specialist. An exhaustive list of climate metrics along with their relevance and drawbacks is covered by Fuglestvedt et al. [6]. The development of a suitable metric for short-lived emissions effects (e.g., NO_x, water vapour, and contrails) is certainly a major challenge as addressed by Forster et al. [7].

2.1 Scope of relevant climate metrics

A relevant metric needs to effectively estimate the performance of a mitigation option (on the basis of cost, time, climate effect, safety, etc.) as well as being easy-to-use and understandable by a non-specialist. There are various climate metrics but the choice of one is a compromise between societal relevance and uncertainty [8]. Figure 2 provides a standard cause and effect chain from emissions through physical changes. In general, as we move down the chain, the parameters become more relevant to the society. Such relevance of the phenomena increases for an individual, as the phenomena become more discreet and tangible. However, with this increasing personal relevance, also the uncertainty increases, in the sense of the effect experienced by an individual.

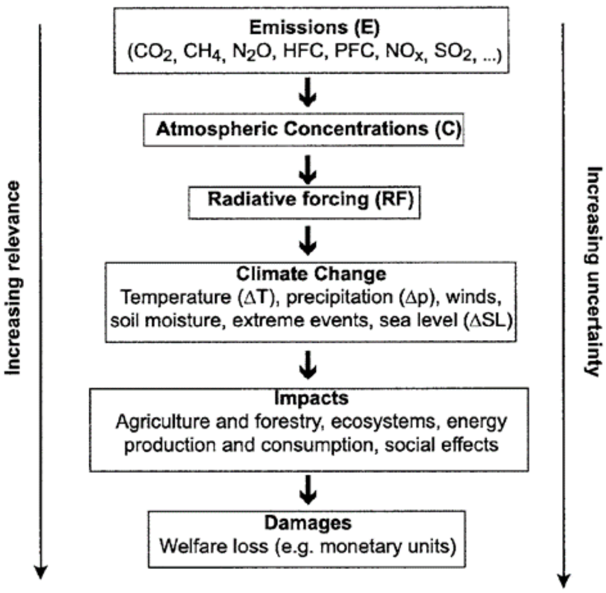

Figure 2 - Cause-effect chain from emissions to climate change and damages [8]

By framing a question, the corresponding climate indicator, time horizon and emission scenario can be chosen unambiguously [9]. Climate metrics corresponding to the different levels of Figure 2 include:

- Quantity of emissions (E), which causes changes in atmospheric concentrations (C): this can serve as the first indicator for comparing the relative important of various sources, but not for comparing different species;
- Radiative forcing (RF), which indicates the radiation change caused by a concentration change. While using RF, assumptions are already made, e.g., the emission scenario or the reference time. Also past emissions are often used to calculate the concentration change;
- Global Warming Potential (GWP), which sums up future impacts of radiation changes from today's concentration change to a chosen time horizon (e.g., 20, 50, 100 years).
- Global Temperature Potential (GTP), which translates the radiation changes caused by concentration change to temperature change at a selected time horizon;
- Average Temperature Response (ATR), which is the mean future temperature development over a period up to the chosen time horizon.

Compared to quantity of emissions, both RF and GWP allow a comparison on the same scale, though they don't yet consider the climate effects, i.e., temperature change. Therefore, GWP can be seen as a bridge between RF and Climate Change in Figure 2. To evaluate the effects on climate change, GTP and ATR are the most suitable. The main difference between these two is that using ATR reduces the dependency on the time horizon as compared to that of GTP. Considering one of the ClimOp objectives to assess the climate impact of operational measures, ATR is selected, at a time horizon of 20 years and 100 years indicating the effects of different entry into service time. The details on ATR will be described in section 4.1.1.

2.2. Key assumptions defining the scope

Assumptions are employed to ensure that the exploration of stakeholders and performance metrics is not overextending beyond the project scope. These boundaries guide the selection and use of indicators for relevant stakeholders.

All KPIs should directly affect or be influenced by the aviation sector

In effect, all performance indicators must relate to aircraft, airline, airport, or air traffic operations. Any metric that does not directly affect the aviation industry is considered irrelevant in the context of this project. Since climate mitigation is at the core of ClimOp, there can be the risk that any factors that influence the climate are taken into consideration. By focusing on the KPIs related to the aviation sector the scope of the climate mitigation effects can be directly correlated to the operational improvements (OI) researched in ClimOp. It should be noted however, that depending on the researched OI, this assumption should not be at the expense of neglecting interactions with other sectors.

All tracked KPIs and stakeholders are operating under "business-as-usual," disregarding any out-of-norm airside operations

Aviation is a dynamic industry that can dramatically shift due to global events. The most dramatic and contemporary example of this global effect is the COVID-19 pandemic, which has led to the mass grounding of aircraft. ICAO estimates an unprecedented global reduction in passenger seat capacity of 94% in April 2020 [10]. Since the consequences of such events are rarely so prolonged and affect the aviation sector to this extent, ClimOp will only consider normal air traffic operations. However, the pre-COVID-19 benchmark for "business-as-usual" may need to be re-evaluated if the global pandemic has a lasting effect on the industry.

Global climate projections should use benchmarks established in 2019-20

It is crucial to have a single benchmark for climate projections, to keep the analysis and collection of data for climate mitigation consistent. Thus, the latest available data such as the Intergovernmental Panel on Climate Change (IPCC) 2019 report should be used for understanding the current climate effects.

The boundary of airside operations begins at the gates of the airport

ClimOp will be mainly concerned with airside climate mitigation efforts comprising any activity beyond and including the gate operations of the airport, i.e. operational improvements during flight, taxiing and aircraft turnaround including ground power supply and ground service vehicle operations. We do not consider landside or other infrastructure outside of the airside, for example, landside integration with public transport, airport terminal passenger movement, or baggage/cargo logistics at the airport.

Stakeholders use technology currently available at TRL 7 or above, disregarding non-matured breakthrough technologies

The pace of adopting breakthrough technology is difficult to predict, as it is challenging to correctly assess the potential impact of these untested novel technologies. Hence, we cannot reliably assume implementing these solutions will lead to a stable new paradigm that improves the mitigation efforts. Therefore, only systems/subsystems that are, at the time of this project, of technology readiness level (TRL) of 7 or above will be used, these include tools currently in development or already launched in the market.

3. Stakeholders in climate mitigation

3.1 Society

Society as a stakeholder in this context specifically, both exercises influence on and experiences influence from the aviation sector. Today's society has a near-global geographical span, with consumption and production, where goods or life experiences are spaced all around the world and time between production and consumption is short. Aviation is the fastest mode of transport with global reach. It hence is key to globalisation and society, facilitating industrial supply chains and supporting the world business sector and leisure industry.

Any external events that trigger changes in the aviation system will see direct impacts onto supply chains, business and products, including food and medication supplies. Through the reduction of ease of travelling, there will be a reduced global exchange of culture, politics and science. These impacts are experienced either directly or indirectly by society.

Adverse climate impacts are broadly acknowledged, and mitigation measures to reduce the climate impact of the aviation system are under development (e.g. CORSIA offsetting excess CO_2 emissions). However, climate response is slow and will take a long time to reduce human-caused temperature rise within reasonable limits. Also, there is a geographical aspect and some areas in the world benefit more than others from aviation. In contrast, other areas will be most affected by climate change consequences e.g. higher risk of flooding.

Other long-term and global climate impacts of anthropogenic emissions include temperature and sea-level rise and may result in societal risks such as broken food supply chains and the endangerment or extinction of natural habitat and reduced diversity of animals and plants

The aviation sector experiences impacts from societal dynamics, which may dictate how society responds but also influences changes in the aviation industry. The society contributes to KPI's of aviation such as RPK's and RTK's expressing demand for mobility. Simultaneously, it also affects climate impact KPI's due to aviation. Recently the public's view on aviation has changed, and negative images arise for practices like frequent flying, even though the industry as a whole contributes only 2-3% of the global CO_2 emissions. Conversely, having the freedom to choose and personal interest still dominate decision making and behaviour.

Disruptive changes in the aviation industry could affect the economy, globalisation and connection network, which might impact the import and export market, but also the connectivity to other countries and regions.

3.2 Airlines

Airlines have always had a natural incentive to reduce fuel burn, as fuel is the largest item in their direct operating costs. This has a direct beneficial impact on CO_2 emissions, which are proportional to fuel burn as this is equivalent to fuel saving. To mitigate the impact of aviation on climate change, all sectors of the aviation industry, including the airline community represented by IATA, committed in 2009 to the high-level climate action goals described in Section 1.1 (fuel efficiency improvement in the short-term, carbon-neutral growth from 2020 and 50% reduction in global net emissions by 2050). Contributions from all pillars of the IATA strategy are needed to achieve these challenging goals:

New aircraft technology continuously improves fuel efficiency. Reducing fuel burn is a main driver for airlines in their decisions for replacing older aircraft with more modern ones. Further fuel efficiency improvements can be achieved by airlines in everyday flight operations, as well as through improvements of airport and airspace infrastructure, including ATM systems. Operational and related infrastructural measures are the subject of the ClimOP project.

These measures together have led to a fuel efficiency improvement of 2.0% per annum in average between 2009 and 2019, exceeding the short-term industry goal. However, with the continuous annual air traffic growth (4% – 5% in the past, 3% – 4% forecast), more carbon emission reductions are required. Sustainable Aviation Fuels (SAF) generate typically 80% lower lifecycle carbon emissions than fossil jet fuel. Over 40 airlines have used SAF since the first commercial flights in 2011. In 2019, more than 200 000 flights have been operated using a SAF blend. Nevertheless, SAF is not yet available in sufficient quantities at an affordable price to allow the desired breakthrough.

In addition to these measures reducing physical emissions within the aviation sector, market-based measures are needed to close the remaining gap. ICAO has established the global carbon offsetting mechanism CORSIA to address the increase in total CO_2 emissions from international aviation.

Focusing more concretely on the topic of ClimOP, a variety of operational procedures and improvements allow airlines to improve achieve better fuel efficiency in everyday flight operations. Pilots optimize flight trajectories for each flight as far as possible within the constraints of ATC and in agreement with them. Ground operations (e.g. using ground power instead of APU) and operational aircraft weight optimisation offer airlines further efficiency potential. At a flight management level, optimizing passenger load factor is an important element of flight efficiency. Airline network optimization, often in cooperation with partner airlines, offers further efficiency improvement potential. Airlines would benefit from better predictability of the operational situation in order to plan and execute flights more efficiently and sustainably, in line with the European Commission's Green Deal initiative.

3.3 Air navigation service providers (ANSP)

The ANSP as an essential body of air traffic management provides air traffic services during all phases of flight. The service they provide starts early on a strategic planning level, to ensure safe and efficient execution of the flight. As a consequence, safety is undoubtedly the most important key performance area for ANSPs. Additionally, the ANSP also plays a vital role in reducing aviation's environmental impact. The current measures are to provide optimum routings for the reduction of fuel consumption (hence the CO_2 emissions), noise and local air quality. Whenever the capacity situation permits, air traffic controllers apply direct routes allowing the pilot to fly without any further detour to a waypoint, which avoids unnecessary extra fuel burn and CO_2 emissions. Also, dedicated airspace, so-called Free Route Airspace (FRA), to enable more direct operations in distinct areas is successively implemented.

As for the climate impact of aviation, a MET service function, which provides the information on aviation's climate impact as a function of the local weather conditions, is currently subject of research (concept level) and could potentially be used by ANSP in future for routing planning considering tradeoffs between CO_2 and non-CO_2 emissions. As studies have shown, en-route navigation charges levied by ASNP also affect the routing of airlines. For instance, the inhomogeneous unit charges across Europe due to the various involved local ANSP make some airlines circumvent expensive airspace and cause detours and additional CO_2 emissions. Hence, it falls under the responsibility of the ANSP to define navigational charges in a way to incentivise a reduction of the climate impact of a flight. An extreme implementation of this function would be to set very high unit cost, particularly in climate-sensitive areas, where the risk of contrail formation or the impact of emissions of NO_x or water vapour is particularly high due to the local atmospheric conditions. Also, the definition of restricted airspaces would be a measure to be taken by the ANSP, that could make an airline avoid those climate-sensitive areas.

3.4 Airports

Airports are immovable facilities, embedded in their territories, they are critical nodes in the global air transport system that present some of the largest and most complex infrastructure in the world. Each airport is unique, has specific characteristics and operates within a specific context.
At airport level, emissions of greenhouse gases (GHG) caused for example by gasoline and diesel fuel for airport vehicles and ground support equipment, fossil fuel for electricity and heating, jet fuel for auxiliary power units for aircraft at airport gates, and other sources. CO_2 makes up the majority of GHG emissions, with smaller contributions from nitrous oxide, methane, refrigerants, and other compounds. Through a series of reports, tools[2] and guidelines to measure and reduce Scope 1 and 2 emissions[3] over time ACI International has committed to lead the transition to Net Zero Carbon airports by 2050 [11, 12].

Moving to Net Zero Carbon airports by 2050 is an environmental, political and increasingly commercial necessity. Without a commitment to reach Net Zero Carbon, the European airport sector puts at risk not only its licence to grow but also to operate. As the “Net Zero” concept does not allow for carbon offsetting, making the transition to Net Zero Carbon operations at European airports will be a gradual process for technical and commercial reasons. To facilitate this process while accounting for the fact that each airport is unique and operates within a specific context, the “ACI EUROPE Sustainability Strategy for Airports” [12] provides general direction and guidance to the sustainability efforts of European airports. More specifically, the Resolution issued by ACI EUROPE on 26 June 2019 [13] states that European airports:

- Call on the aviation industry, ICAO and governments to work towards net zero emissions aviation,
- Commit to reach net zero carbon emissions for operations under airport operators’ direct control (Scope 1 and 2) by 2050,
- Call on governments to accelerate, where relevant, the transition towards a clean energy system as a key enabler for airports to reach net zero emissions.

The ACI Europe Sustainability Strategy for Airports [12] is based on a review of existing airport sustainability strategies, sustainability frameworks, relevant technological, economic and political developments as well as societal expectations. Due to the uniqueness and specificity of each airport, the Strategy does not include individual aspects and therefore does not define any mandatory actions: it aims at providing a general direction and guidance to the sustainability efforts of European airports.

For most airports it is already technically feasible to move towards zero emissions, but the ease and costs with which this objective can be achieved will likely vary considerably between different countries within Europe. Each individual airport will have to estimate and balance the timescale and costs required to reach net zero emissions operations. As suggested by the Sustainability

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2 ACI, Airport Carbon and Emissions Reporting Tool (ACERT)
3 GHG Emissions are subdivided as follows:
- Scope 1 - Direct emissions associated with sources owned or controlled by the Group’s companies, such as fuels used for heating and operational equipment necessary for airport activities.
- Scope 2 - Indirect emissions associated with the generation of electricity or thermal energy acquired and consumed by the Group’s companies.
- Scope 3 - Other indirect emissions deriving from the activities of the group’s companies but produced by sources not belonging or not controlled by the companies themselves, such as personnel work trips and home-work travel.

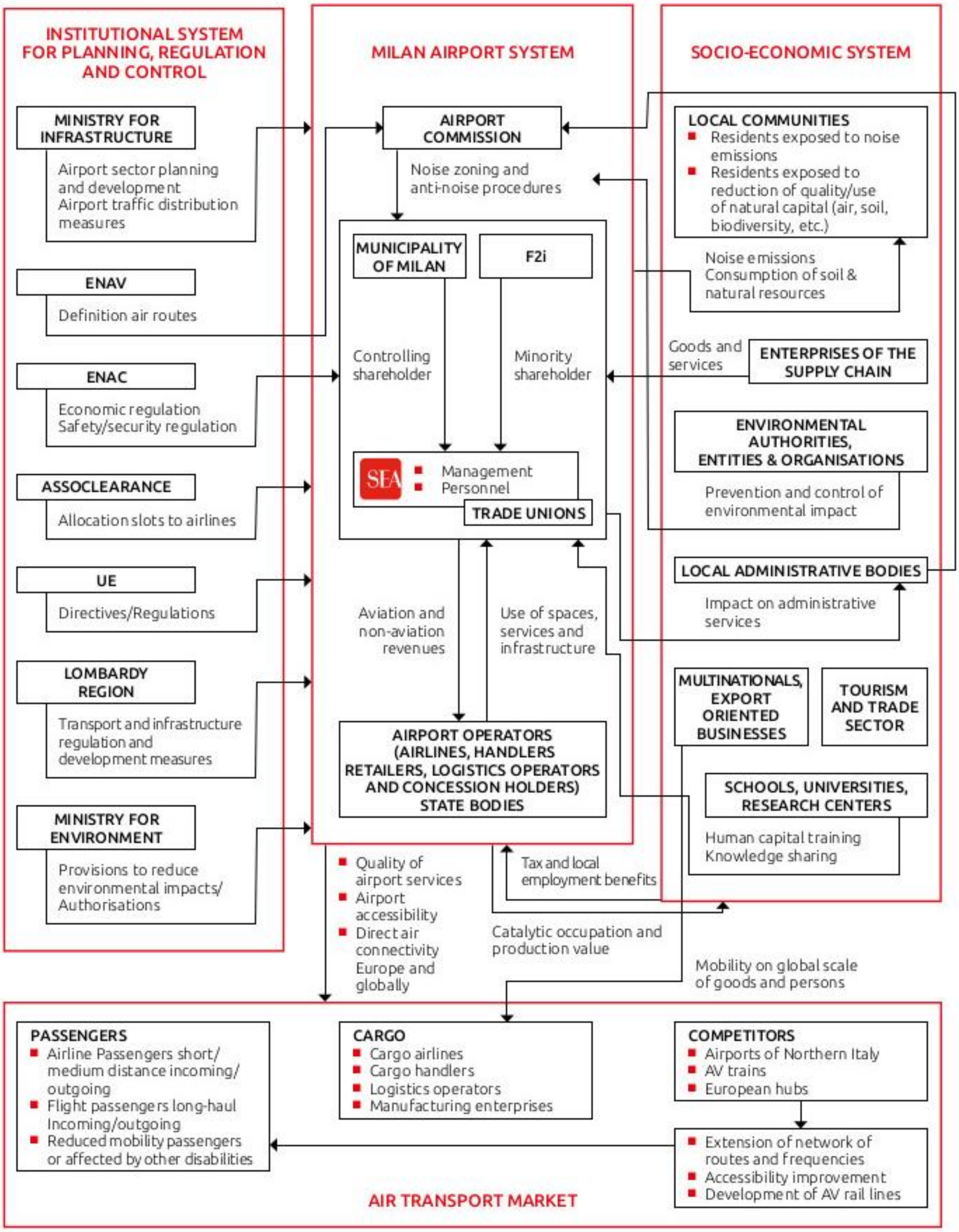

Figure 3 - SEA first level stakeholders

Strategy for Airports, besides relating their sustainability actions with the Sustainable Development Goals [14], Airports will have to perform a "materiality assessment". For this purpose, Airports should refer to Global Reporting Initiative (GRI) [15]. Through the materiality assessment, Airports will set the priorities of their commitment to the 2030 Agenda for Sustainable Development promoted by the UN in 2015. Airports will also have to carry out an assessment to identify which of the 17 Sustainable Development Goals are relevant to their activities, in order to align their Business Plan's strategic vision with the materiality assessment issues.

Because an airport belongs to a complex network of many stakeholders, any decision-making process needs to account for the interests and expectations of the different stakeholders. This applies also to decisions and operational changes related to climate mitigation. As an example of the complexity of the stakeholders' network, Figures 3 shows the analysis performed by SEA, one of ClimOp partners. SEA has been committed for many years to a series of actions for the control and reduction of direct and indirect emissions of CO_2 at the airport and deriving from airport management activities. Figure 3 shows SEA's first-level stakeholders map, which includes the stakeholders with the closest and most direct relation to SEA.

3.5 Original equipment manufacturers (OEM)

The primary goal of aerospace manufacturers is to optimize its commercial success by selling high-quality airframes and engines that optimally meet the requirements of their customers, are highly reliable and have an excellent safety record, while being highly cost-efficient in development and production.

Fuel efficiency has always been amongst the most important requirements from airline customers as fuel is the highest single direct operating cost (DOC) item for an airline. With the increasing focus on the environmental impact of aviation, fuel-efficient products also contribute highly to the reputation of their manufacturers in the broad public, as the first step to an eco-efficient product is a fuel-efficient design. This can be realized by a combination of engine efficiency, optimized aerodynamics and lightweight structure. A fuel-efficient aircraft design will directly reduce the upcoming DOC for the airline as the OEM's customer. The longer the potential operating period of the certain aircraft will be, the higher the importance of tolerable recurring operating costs compared to the initial investment costs for the airline.

Various airports already take care of the environment by pricing their service fees related to the aircraft's eco-efficiency in terms of noise and local air pollution. ICAO has introduced in 2017, in addition to the long-standing certification rules on noise and local air pollution, an aircraft certification standard limiting CO2 emissions, applicable to both new and in-production aircraft types. In addition, market-based measures such as emissions trading (EU-ETS) and carbon offsets (ICAO's CORSIA) oblige aircraft operators to submit CO2 compensation payments, which depend on fuel burn and thus incentivise the use of more fuel-efficient aircraft. These air transport infrastructure fees and political regulations are an additional incentive for OEMs to increase their efforts towards greener products, as these result in lower operational costs for their airline customers.

3.6 Governments

A government carries the responsibility to balance the potentially different needs of individuals, the community and businesses. Concerning managing the climate impact of aviation, this involves representing societal needs while facilitating a competitive aviation industry that satisfies customer demand and expectations. Aviation is often an international activity, requiring compliance with international standards for safe, efficient and environmentally friendly operations of aircraft.

The International Civil Aviation Organization (ICAO), a specialized organization of the United Nations, produces Standards and Recommended Practices and policies in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector. ICAO has 193 Member States, whose governments support the ICAO in policymaking, implement and execute the standards and policies in national structures. This global harmonisation avoids a patchwork of different regulations across the countries, which would be very detrimental to international aviation.

The government's responsibilities related to aviation and environment are summarized in Table 1.

Table 1 - General tasks of the government

Overall Task	**Regulations, policies and means to exercise tasks**
Environmental Protection	• Noise monitoring and regulations • Local air quality monitoring and regulations • Implement operational procedures and restrictions • Exercise environmental protection •
Spatial Planning	• Urban planning, build-up areas • Land-side transport and infrastructure (rail, road, etc.)
Safe, secure, effective, efficient and feasible organisation of the airspace	• Law and rulemaking, import/export facilities: customs, taxes/charges/levies, slot allocation, airport authorities, navigation authorities, • Safety: inspection and rulemaking, enforcing rules/amendments • Security: passport control and inspection of goods • Infrastructure (navigation, airports) • Education and training • Communication: publishing information concerning safe operations and navigations: "aeronautical information publications" and noise contours and environmental assessment reports • Negotiations of bi-lateral agreements, EC links. • Facilitate collaboration between local stakeholders: o aviation authorities o environmental authorities o airlines o airports o air navigation service providers o statistical departments o fuel providers

Aviation facilitates economic growth by enabling the efficient transport of people and goods for trade. Changes in aviation (such as airspace re-regulation) could impact economies and trade relations, and aviation should, therefore, be a key concern for governments.

The governments can influence aviation on both an international and national level. On a global scale, agreements between States can manifest in, for example, the implementation of carbon offsetting (CORSIA) and ICAO environmental certification for aircraft and engines. These agreements also determine critical parameters for the industry, such as the availability and capacity of airspaces. On a national level, the government regulates aviation through similar means, with concentrated focus exercised on the nationwide emissions inventory and thus the national contribution of aviation to climate impact. The government can motivate or obstruct the development of “greener” aviation through infrastructure facilitation. The government can also impact demand for domestic aviation through alternative modes of transport made available.

ICAO State Action Plans are developed to enable all governments of ICAO Member States to establish a long-term strategy on climate change for the international aviation sector. These parties are encouraged to cooperatively define a quantified baseline scenario and, select appropriate emissions mitigation measures from ICAO's basket of measures [16]. No specific targets for non-CO_2 climate impact has been set by ICAO. The ICAO framework for State Action Plans assists governments in:

- development of a better understanding of the share and projections of international aviation CO_2 emissions;
- enhanced cooperation between all aviation stakeholders that can positively reflect on their operational areas;
- identification of the most relevant mitigation actions;
- streamlining of policies;
- enhancing stakeholders’ support and understanding for policy decisions;
- establishment of cross-sectoral partnerships;
- promotion of capacity building;
- multiplication of the environmental effects of mitigation measures;
- facilitation of technology transfer; and
- identification of assistance needs.

The government has a key responsibility to investigate the need for action on climate change and to influence behaviour and outcomes through regulations and policies. The implementation of the operational improvements identified in WP1 could be supported by such measures

3.7 Passengers

According to ICAO, around 4.3 billion passengers were flown in the year 2018 alone [17]. The sheer volume of passengers makes them one of the largest stakeholders in aviation. However, their influence is varied because of the diverse individuals of this group.

A few examples of passenger surveys are given here to identify typical behaviour: Mehta et al. surveyed to capture passengers’ preferences. Several characteristics were tracked to capture their effect on passengers’ choices [18]. These descriptive traits depend on age, income, frequency of travel, risk-taking tendencies, gender, education level, seat type, the purpose of flight, and frequent flier category. Due to the variability in these characteristics, it can be challenging to homogenise their preferences as a single entity. However, Kurtulmuşoğlu et al. also conducted a survey with similar features being tracked, but further included up to 27 decision criteria in the questions asked [19]. The results concluded with a ranking of these criteria, where the top three critical factors for passengers were found to be (most to least): the ticket price, punctuality, and online booking.

While the discussed surveys have an extensive list of decision factors, they did not include climate-related criteria. This lack of climate factors in passenger decision-making is because passenger satisfaction is most of all based on the service quality of the airline [20]. Also, information about CO_2 emissions from flights is only starting to be available to passengers. However, with increasing awareness of air travel contribution to climate change, there is an increased willingness in passengers to pay for offsetting their CO_2 emissions [21]. Brouwer et al. researched the motivation of these travellers for paying these offset fees, and found that traveller responsibility, environmental concern, care for future generations, and avoiding disasters were among the most important reasons [21]. Furthermore, this willingness to pay varied based on the region, where Europe spends the highest mean offset per flight, followed by North-America and then Asia [21]. Although climate offset cost is a voluntary form of passenger contribution towards mitigation, there are still sceptics. About 58% of the respondents believe that the offsets are not effective [22]. Hence, there needs to be improved transparency of mitigation effectiveness to increase the support and participation of passengers in voluntary programs.

3.8 Cargo forwarders

In 2018, the air cargo market transported 58 million tonnes, according to ICAO [17]. While that is only 1% of the total global trade by volume, it represents 35% of the value [23]. Hence, the air cargo industry is a vital part of the economy, demonstrating that even a 1% increase in air cargo connectivity can bring about 6% more trade.

Cargo forwarders are one of the actors involved in the air cargo supply chain, others being cargo handlers and airline. Forwarders arrange the transport of goods to and from the airport, and thereby they link the original shippers and the cargo handlers/airline. Additionally, they have other obligations, such as customs [24]. Shippers primarily care that their product is transported to the right location at the right time, and cargo handlers make sure that the aircraft of the airline is appropriately loaded and unloaded. The primary purpose of the forwarders is to optimise the shipments by combining multiple sources on to the same flight and minimise the price per volume or weight charged by the airline [24].

With the multiple actors participating in the transport of goods, cargo forwarders tend to value efficiency. As a consequence, research has been conducted on collaboration among the airlines, handlers, and forwarders for mutual benefit, particularly looking at a horizontal vs vertical integration [25]. The most collaborative framework would see vertical integration among all actors. This type of close relationship will eventually mean that even airline priorities and KPIs become closely tied with that of the forwarders. Nevertheless, it should be noted that following the scope set in Section 2, the external infrastructure, with the shipper for instance, including multimodal transport to the airport, is out of the scope of ClimOP.

3.9 Residents in proximity to airports

In the last thirty years the increase of aircraft operations in the majority of European and World airports deals with the unavoidable environmental impacts on both a local and a global scale.

At a local level, emissions and noise nuisance are big concerns both for citizenship and airport workers. According to WHO (WHO, 2018), health impacts for both emissions (i.e. respiratory and brain diseases, as well cancers) and noise (i.e. hearing impairment, hypertension, ischemic heart disease, annoyance, stress and sleep disturbance) are well known and scientifically validated. At a global level, ICAO is the Civil Aviation authority for Environmental noise. Annex 16 to the Convention[4] volume 1 contains the rules to manage the impact of noise in proximity of airports.

The regulation of environmental effects of Civil aviation for noise focuses on the so called "Balanced approach" (ICAO, 2017). The four themes are: (i) reduction of noise at source, (ii) land use planning and management, (iii) noise abatement operational procedures, and (iv) operating restrictions.

[4] The ICAO Convention established rules for Civil Aviation. It is divided in articles and it is supported by nineteen annexes containing standards and recommended practice.

By “reduction of noise at source” regulation refers to technological progress. New aircraft like the Airbus A320neo may contribute to reduce the impact of noise. Despite that, the increase in air traffic numbers brings a strong impact on population. According to EEA, estimates calculate that in the 85 major airports more than 4.1 million people are exposed to Lden[5] levels above 55 dB (EEA, 2014).

Concerning the “land use planning and management”, Environmental Noise Directive (END) plays a big role in Europe. Every five years strategic noise maps should be calculated by airports. These maps should be published to inform population about environmental noise. On the basis of the results of the maps noise action plans should be planned in order to manage this issue.

The line between the practices related to noise abatement operational procedures and to airport operating restrictions exhibit a significant level of integration. The regulation refers basically to (i) flight curfews at nights, (ii) constrained flight paths for take-over and landing, and (iii) no-fly times.

Additionally, the sustainability pathway designed by ACI Europe to reach zero emissions by 2050, focuses on measuring the airports’ contribution to the pollutant concentrations in their vicinity and designing mitigation actions accordingly. The atmospheric impact of airport activities relates to a series of main emission sources, including vehicular traffic inside and outside of the airport grounds, equipment used for loading/unloading of aircraft and ground handling operations, and aircraft Landing and Take-Off (LTO) cycles. Airport operators are not directly involved and cannot control airline-specific processes, such as the technological evolution of the fleets, their emissions efficiency or the definition of flight routes and scenarios. Nor can they directly control the amount of external vehicular traffic that is closely correlated with the level of intermodality of the region in which the airport is located.

Airports are encouraged to extend the coverage of their local air quality management and outline possible actions to support emissions reductions by third parties. It must be noted that many of the measures relevant to CO_2 emissions reductions also produce co-benefits in terms of reducing pollutant emissions, and vice versa. To ensure effective air quality control several stations can be placed to monitor atmospheric pollutants, including mono-nitrogen oxide (NOx).

4. Key performance indicators (KPIs)

4.1 Quantitative performance metrics

4.1.1 Environmental

Relevant environmental metrics for the purpose of ClimOp are quantitative parameters that can be used to compare various climate mitigation strategies (and policies) based on how they affect the environment. Various factors can influence the choice of environmental metrics, for instance, the type of emissions, time dependency, and spatial dependency.

CO_2 is a long-lived emission specie. The climate impact of CO_2 emission is proportional to the emitted amount of CO_2 and is independent of where the emission occurs. Therefore, the emission quantity calculated in tonnes per year will be used as one of the environmental metrics for CO_2 emission.

On the other hand, the non-CO_2 effects from NO_x (ozone and methane), water vapour and contrails, depend not only on the quantity of emissions but also on the emission time, geographical location, flight altitude and the background atmospheric concentrations. To enable a fair trade-off between CO_2 and non-CO_2 emissions, a common scale for the climate impact of CO_2 and non-CO_2

[5] Lden (day-evening-night level) is an acoustic metric based on energy equivalent noise level (Leq) over a whole day with a penalty of 10 dB(A)for night time noise (22.00-7.00) and an additional penalty of 5 dB(A) for evening noise (19.00-23.00) *source EEA glossary*.

effects is required. As discussed in section 2.1, an appropriate metric to use is the Average Temperature Response (ATR, calculated by Eq. (1) as the mean future temperature change over a time period up to a selected time horizon), as it allows considering the impact chain (see Figure 2) from emissions to concentration change up until the effects on climate, represented by surface temperature change. Furthermore, ATR is less dependent on the time horizon as other metrics like, e.g. global warming potential.

$$ATR_{spec}(H) = \frac{1}{H}\int_{t_0}^{t_0+H} \Delta T_{spec}(t)dt \qquad (1)$$

where, t_0 is the reference time (year), and ΔT_{spec} is the global surface temperature change induced by the specimen as a function of time. Hence we will be using ATR as an environmental performance metric providing a quantitative information on climate impact. In a similar way efficiencies can be calculated by relating associated (total) climate impacts to e.g. passenger-km or tonne-km similar as done for other performance metrics (e.g. section 4.1.2). The time horizons of 20 and 100 years will be selected to fairly consider the trade-off between CO_2 and non-CO_2 species associated to their lifetime differences. Also, the usage of two time horizons could reflect the effects of different entry into service time for given operational measures.

4.1.2 Technical

Technical key performance indicators are metrics that are directly linked to the efficiency and performance of the aircraft and can primarily be quantified by the fuel consumption that is itself a relevant part of the direct operating costs (DOC). But also, the frequency of cost-intensive non-service periods due to maintenance intervals play an important role.

The technology used on the aircraft, primarily engines and aerodynamics, influence the fuel flow KPI during operations. The amount of fuel burned per time unit is the most important technical KPI, highly dependent on the operational mode of the aircraft, proportional to the CO2 and water vapour emission flows and a crucial part of the DOC of an airline. Further KPIs related to fuel efficiency in terms of flight distance and load are fuel burn per km and fuel burn per passenger-km (RPK) or tonne-km (RTK, which allows to aggregate passenger and cargo transport).

Since technical metrics are difficult to separate from operations, we will consider also the number of LTO cycles per week/month/year. This is an indication on the utilisation of the aircraft. LTO cycles are also relevant for the assessment of DOC, as frequent LTO operations increase the wear of the technical components of an aircraft and require more frequent maintenance and overhaul service intervals. The number of planned and unplanned maintenance events is a KPI for “out of order” periods. Furthermore, aircraft operation time, or the number of operating hours of an aircraft coincides with the time of emissions. Therefore, a time optimized flight mission reduces, in general, the time of emission release, and beyond that, a maintenance event is required when a certain threshold of operating hours will be reached.

4.1.3 Safety

To evaluate the safety of the selected Operational Improvements (OIs) ClimOP will adopt the Safety Assessment Methodology (SAM) [26].

SAM is a framework, supported by a toolbox, containing methods and techniques to develop safety assessments of changes to functional systems. SAM has been developed by Eurocontrol to reflect best practices for safety assessment of Air Transport Systems and to provide guidance for their application. SAM is considered an “acceptable mean of compliance” to the EUROCONTROL Safety Regulatory Requirements (ESARR4) [27].

SAM should potentially support the demonstration that safety in aviation is being managed within safety levels, meeting at least those levels approved by the designated authority ("tolerable" risk). However, SAM aims at supporting Aviation Stakeholders to achieve an acceptable level of risk while implementing the new Operational Improvements.

The SAM methodology consists of three major steps:

- FHA (identify hazards, assess their effects and the related severity);
- PSSA (fault tree analysis, event tree analysis, common cause analysis, etc.);
- SSA (documentation of the evidence, collecting data, test and validation, etc.);

Figure 4 shows the relationships between the three SAM steps and the overall System Life Cycle.

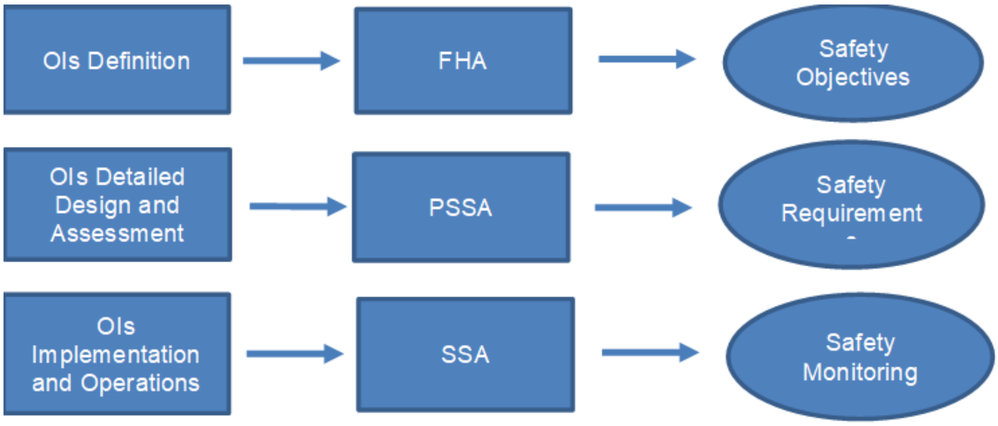

Figure 4 - Relationships between the Safety Assessment Process and the OIs Life Cycle

In the ClimOp project, just the FHA and PSSA steps will be relevant, since the project covers OIs definition and design, not the actual implementation and operations. A complete and iterative SSA will not be carried out.

A more detailed description of FHA and PSSA is reported below.

The *Functional Hazard Assessment* (FHA) is a top-down iterative process, initiated at the beginning of the design and development of new Operational Improvements for Aviation. The objective of the FHA process is to determine how safe the system needs to be. The process identifies potential failure modes and hazards. It assesses the consequences of their occurrences on the safety of operations, including ATM, aircraft and airport operations, within a specified operational environment. The FHA process specifies overall *Safety Objectives* of the system, i.e. specifies the safety level to be achieved by the system. As a reminder, a Safety Objective (within ESARR4) is a qualitative or quantitative statement that defines the maximum frequency or probability for a hazard to be "acceptable" to occur.

The *Preliminary System Safety Assessment* (PSSA) is a mainly top-down iterative process, initiated at the beginning of a new design or modification to an existing design of an Air Transport System and/or Operational Concept. The objective of performing a PSSA is to demonstrate whether the assessed system architecture, business, operational procedures and processes can reasonably be expected to achieve the Safety Objectives specified in the FHA.

A Safety Requirement in ESARR4 is a risk mitigation mean, defined from the risk mitigation strategy that achieves a particular safety objective. Safety requirements may take various forms, including organisational, operational, procedural, functional, performance, and interoperability requirements or environment characteristics. Safety Requirements can support the identification of suitable Safety Key Performance Indicators (KPIs) to assess the Safety level of an OIs.

Safety has two different dimensions: the safety outcome of the ATM system, i.e., occurrence of accidents and incidents, on the one hand; and the safety management practices and culture on the other hand. Both are monitored through specific KPIs. The first set of KPIs monitoring the Occurrence of accidents and incidents are reported in the Table below and derived by the SESAR Performance Framework [28].

	KPIs / PIs		Unit
SAF1 Total number of estimated accidents	**MID-AIR COLLISION – EN-ROUTE**		% Change in count of events[6] or Frequency of occurrence per fh
	SAF1.1	Mid-Air Collisions	
	SAF1.2	Imminent Collisions	
	SAF1.3	Imminent Infringements	
	SAF1.4	Crew/Aircraft Induced conflicts	
	SAF1.5	Planned conflicts	
	SAF1.6	ATC Induced Tactical conflicts	
	SAF1.7	Pre-Tactical conflicts	
	MID-AIR COLLISION – TMA		% Change in count of events or Frequency of occurrence per fh
	SAF2. 1	Mid-Air Collisions	
	SAF2.2	Imminent Collisions	
	SAF2.3	Imminent Infringements	
	SAF2.4	Crew/Aircraft Induced conflicts	
	SAF2.5	Planned conflicts	
	SAF2.6	ATC Induced Tactical conflicts	
	SAF2.7	Pre-Tactical conflicts	
	RWY-COLLISION ACCIDENT		% Change in count of events or Frequency of occurrence per flight or movement
	SAF3.1	Runway Collisions	
	SAF3.2	Imminent Runway Collisions	
	SAF3.3	Runway Conflicts	
	SAF3.4	Runway Incursions	
	SAF3.5	Imminent Runway Incursions	
	SAF3.6	Potential Runway use	
	TWY-COLLISION ACCIDENT		% Change in count of events or Frequency of occurrence per flight or movement
	SAF4.1	Taxiway Collisions	
	SAF4.2	Imminent Taxiway Collisions	
	SAF4.3	Imminent Taxiway Infringement	
	SAF4.4	Taxiway Conflicts (planned, induced)	
	SAF4.5	Pre-Tactical Taxiway Conflicts (planned, induced)	
	SAF4.6	Strategic Taxiway Conflicts	

[6] % reduction/increase in the number of <event> per year (or after a certain period) with respect to the year of reference.

	KPIs / PIs	Unit
	CFIT ACCIDENT **SAF5.1** Controlled Flight Into Terrain **SAF5.2** Imminent CFIT **SAF5.3** Controlled Flight Towards Terrain **SAF5.4** Flight Towards Terrain commanded by pilot **SAF5.5** Flight Towards Terrain commanded by systems **SAF5.6** Flight Towards Terrain commanded by ATC **SAF5.7** Flight Towards Terrain commanded by ANS	% Change in count of events or Frequency of occurrence per flight or movement
	WAKE related ACCIDENT (Final APP) **SAF6.1** Wake induced accidents **SAF6.2** Wake encounter (moderate, severe, extreme) **SAF6.3** Imminent wake encounter under fault-free conditions **SAF6.4** Unmanaged under-separation **SAF6.5** Unmanaged under-separation induced by ATC through inadequate selection and management of separation mode **SAF6.6** Imminent Infringement (during interception, on final approach) **SAF6.7** Crew/Aircraft induced spacing conflict during the interception **SAF6.8** Crew/Aircraft induced spacing conflict on the final approach path	% Change in count of events or Frequency of occurrence per flight or movement
	RWY-EXCURSION ACCIDENT (landings) **SAF7.1** Runway Excursions **SAF7.2** Touchdown outside TDZ **SAF7.3** Unstable touchdown (hard, bounce landing) **SAF7.4** Approach to a non-suitable runway **SAF7.5** Approach to a weather affected runway **SAF7.6** Unstable approach	% Change in count of events or Frequency of occurrence per flight or movement

More *qualitative* KPIs, monitoring the overall Aviation Safety Culture are derived from the Single European Sky Performance Scheme [29].

SAF2 Effective Aviation Safety Management and Safety Culture	SAF2.1	Effectiveness of Safety Management (both Regulators and ANSPs).
	SAF2.2	Use of automated safety data recording systems by air navigation service providers, when implemented
	SAF2.3	Air Traffic Flow Management over-deliveries above the declared capacity limits where ATFM regulations are imposed.

	SAF2.4	Level of occurrence reporting.

4.1.4 Operational

Operational KPIs are metrics that relate to the tactical and strategic operations of the stakeholder. Tactical and strategic operations refer to different timescales, the first being day-to-day tasks, and the other may cover several months, seasons, or even years. The relevant operational KPIs will be defined with the appropriate unit with the associated stakeholder.

As the stakeholder that directly operates the aircraft, airlines consider a vast range of KPIs. From the aircraft perspective, aircraft utilisation, aircraft on ground time, turnaround time, and on-time performance are all factors to be considered. Airlines also plan their networks to have a certain capacity to accommodate the projected demand or use. These network morphologies can be quantified using indices such as the Gini concentration index and the Freeman network centrality index [30]. As passengers and freights are flown, there will be emissions related to each flight or flight hour, related to CO_2, NO_x, H_2O, or particulate matter (PM).

- Emissions – total, per unit time, or per flight CO_2, NO_x, H_2O, or particulate matter (PM) emitted by the exhaust of engines or other equipment on the airside
  - Tonnes (total, per cycle, or per unit time)
- Throughput – the amount of passengers or tonnes of freight transported in the network
  - Number of passengers
  - Tonnes of freight
- Network capacity – total seats or freight volume available to be carried over the distance flown by the network
  - Available Seat Kilometre (ASK) - passenger
  - Available Tonne Kilometre (ATK) - cargo
- Network use – total amount of passenger or tonnes of cargo carried over the distance flown by the network
  - Revenue Passengers Kilometre (RPK) - passenger
  - Revenue Tonne Kilometre (RTK) – cargo
- Network traffic concentration – measuring the concentration of frequencies at the main airports of the network
  - Gini concentration index
- Network morphology - measuring the network shape as the degree of inequality with respect to a perfect star network
  - Freeman network centrality index
- Load factor – the ratio of used capacity (demand) and available capacity (supply), it is the efficiency of the network capacity
  - Revenue Passenger Kilometre / Available Seat Kilometre - passengers
  - Revenue Tonne Kilometre / Available Tonne Kilometre - cargo
- Aircraft utilisation – the time spent, per day, by the aircraft operating and generating revenue
  - Flight hours
  - Flight cycles
- Aircraft on ground time – time spent by the aircraft out of operations and not generating revenue, especially in cases of maintenance or servicing requirements
  - Hours

- Days
- Turnaround time – duration from the point of aircraft arriving at the gate, to the point of pushback
  - Time (per event or average over unit time)
- On-time performance – adherence to the scheduled time of the flight plan
  - Delay in time (per event or average over unit time)
  - Number of cancellations
- Fleet composition – the types of aircraft flown by the airline to serves its network
  - Fleet composition (i.e, number of aircraft of each type)
  - Fleet age
  - Fleet commonality index

Air navigations service providers deal with the movements of aircraft. Hence, they need to ensure that their respective sectors of the airspace have enough movement capacity, while also accommodating the most efficient route for each flights. However, capacity is the driving constraint in ANSP operations.

- Movements – number of aircraft operating in a sector of airspace
  - Number of movements
- Airspace capacity – number of aircraft allowed in an airspace at a particular time
  - Movements per unit time
- Routing efficiency – degree of divergence from the optimum route for a flight
  - Added flight distance or time
  - Number of instructions

Airports are in a symbiotic relationship with the airlines, as the number of destinations offered by the airport is their main product. Hence, if the airlines operate smoothly, the airport benefits considerably. Airports try to broaden their portfolio of destinations by either increasing their capacity (movements, gates, runways, stands) or enhancing airline operations (quick connection times and facilities).

- Capacity – varied constraints of the airport at a particular time in terms of gates, stands, taxiways, or runways
  - Number of available gates
  - Number of available stands
  - Movements per unit time (for taxiways and runways)
- Traffic – amount of aircraft, passengers, or cargo, landing at or taking off from the airport
  - Movements per unit time
  - Passengers per unit time
  - Cargo tonnes per unit time
- Connection time – duration required for unloading and loading passengers or cargo from one flight on to the next flight
  - Time (per event or average over unit time)
- Network connectivity – number of destinations served by the airport
  - Number of destinations offered with 0 or 1 intermediate stops
  - Number of OD pairs served (possible connection at the reference airport)

OEMs are the supplier to airlines and maintenance, repair, and overhaul (MRO) organisations, both with the aircraft asset itself and the after-market service. Hence, they play a key role in enabling the airlines' growth and utilisation, by ensuring all the parts of aircrafts are produced and delivered in an efficient and timely manner.

- Aircraft lead time – the duration between point of aircraft order and delivery to airline or lessor
  - Time between point of aircraft order and delivery to airline or lessor
- Supply chain lead time – the duration between point of spare part order and delivery to customer
  - Time between order and delivery to customer
- Production capacity – the amount aircraft or parts the manufacturer is capable of producing
  - Number of aircraft per unit time
  - Number of parts per unit time
- Production volume– the amount aircraft or part the manufacturer is producing
  - Number of aircraft per unit time
  - Number of parts per unit time

The customer experience of passengers and cargo forwarders is directly affected by the airline and airport performance. In addition, the customers deeply care about the total travel time and the complexity of their travel, because they want their experience to be as smooth as possible

- Travel time – total duration of travel from point of departure till arrival
  - Time (per event of average over unit time)
- Itinerary complexity – the number of transfers or directness of the flight plan to their destination
  - Number of intermediate stops

4.1.5 Economic

For evaluating economic performance, there are standard measures of passenger traffic and airline operation. Typically, passenger airline traffic is measured in revenue passenger kilometres (RPK). One RPK corresponds to one paying passenger transported 1 km, obtained by multiplying the number of revenue passengers on a flight by the total distance travelled. The fare paid by passengers is affected by different factors such as distance, season, booking time, conditions, and characteristics of the fare product. Passenger yield is a measure to quantify the average fare paid by all passenger per kilometre flown for an airline. It is calculated by dividing the total passenger revenues by the RPK carried. The unit of yield is € per RPK.

Available seat kilometres (ASK) is another standard measure of airline output. One ASK refers to one available seat flown 1 km: multiply the number of available seats on a flight by the total distance travelled. The average operating expense of an airline can be measured via cost per available seat kilometre (CASK): total operating expense divided by the ASK produced by an airline. Similarly, the average operating income can be measured via revenue per available seat kilometre (RASK). The unit of CASK or RASK is € per ASK.

The utilization ratio of the available seats is the load factor. This parameter is used for analysing passenger service levels: revenue passenger kilometres (RPK) divided by available seat kilometres (ASK).

Although we have presented the performance measures from the perspective of passenger transportation, similar metrics can be applied to cargo air transportation. For example, cargo traffic carried is measured in revenue tonne-kilometres (RTK). Cargo airlines provide output in available tonne-kilometres (ATK), and both yield and cost per available tonne kilometres can be defined from the standpoint of cargo transportation.

RTK and ATK are also used for total traffic volume (passengers and cargo combined), counting each passenger (with checked and hand luggage) with the ICAO recommended weight value of 100 kg.

Price elasticity and time elasticity are two measures that affect the pricing and scheduling strategies of airlines. These measures can also be used for evaluating economic performance for passengers and airlines. Price elasticity is defined as the percent change in market demand that occurs with a 1% increase in average pricing change. Similar to price elasticity, time elasticity is the percent change in total O-D demand that occurs with a 1% increase in total trip time.

Another stakeholder in the aviation industry is the airport. The sources of airport revenue consist of aeronautical and non-aeronautical user charges and other fees [31]. Aeronautical user charges mainly contain the landing fee, aircraft parking and hangar fee, airport noise charge, passenger service charge, cargo service charge, security charge, ground handling charge, and concession fees for aviation fuel and oil [31]. From the perspective of this project, the total revenue originating from aeronautical user charges can be used to evaluate the income of an airport.

The EUROCONTROL's Central Route Charges Office (CRCO) is responsible for the cost recovery of air traffic services. The CRCO bills and collects route charges and terminal charges on behalf of EUROCONTROL's Member States, air navigation charges on behalf of some non-Member States of EUROCONTROL, and navigation charges in the Shanwick area [32]. The total amount of route charges and terminal charges can be used to calculate the revenue of an air traffic control service. For each flight in the EUROCONTROL airspace, a route charge is levied. This charge is obtained by multiplying three variables that are the distance factor, aircraft weight factor, and unit rate of charge [32]. The distance factor is calculated as the number of kilometres in the great circle distance between the entry and exit point of the charging zone divided by one hundred. The weight factor is determined as $\sqrt{MTOW/50}$, where $MTOW$ refers to the certified Maximum Take-Off Weight. Only the departure flights are considered when levying the terminal charge. The calculation of the terminal charge depends on the region. Generally, the formula is in the form of $(MTOW/50)^{0.7} \times Unit\ Rate$ [32].

From the standpoint of manufacturers, sale of the new aircraft and equipment, overhaul and replacement charges are sources of the revenue. These measures can be used to evaluate the economic performance of manufacturers.

4.2 Qualitative performance metrics

4.2.1 Human performance

Human Performance (HP) denotes the human capability to accomplish tasks and meet job requirements. The capacity of a human to successfully achieve their working tasks depends on several variables that are investigated within the discipline of "Human Factors (HF)". These factors are: procedure and task design, design of technical systems, tools and physical work environment, individual competences and training background as well as recruitment and staffing. HP also depends on how Social Factors and issues related to Change & Transition are managed. Adequate considerations of HF and HP are critical during the development of ClimOP Operational Improvements (OIs).

To evaluate the Human Performance of the selected Operational Improvements (OIs), ClimOP will adopt the SESAR Human Performance Assessment Methodology, developed within the SESAR programme and adopted by standard methodology in the SESAR 1 and SESAR 2020 activities.

The purpose of the HP assessment process is to ensure that all HP aspects related to the technical and procedural implementation of the selected OIs are systematically identified and managed. All the necessary actions are conducted to provide adequate confidence that an innovative climate-friendly aviation concept of operation, service or system is compatible with human capabilities and fully accepted by users. To achieve this, the HP assessment process will provide arguments and necessary evidence to show that airborne and ground Aviation stakeholders will contribute to the ClimOP expected environmental benefits and will describe how results from HP assessment should be used in the development process, with the aim of improving the concept and technology.

The HP process consists of 4 main steps: 1) Understand the OI concept; 2) Understand its HP implications; 3) validate and improve from an HF perspective the OI concept; 4) Collate findings and support implementation and deployment phases (or, more generally, the reaching of higher maturity levels of the OI).

The HP assessment process will vary in relation to the maturity level of the considered OIs, but the analysis will cover in any case the 4 areas below:

- *Roles, responsibilities, operating methods and human tasks*: the HP assessment process will ensure that roles and responsibilities of human actors are clear and exhaustive; operating methods are exhaustive and support human performance, and human actors can achieve their tasks in a timely and accurate way;
- *Technical support systems and Human-Machine Interface:* the HP assessment process will support the appropriate allocation of tasks between the human and the machine (i.e. automation level) and will ensure that the high-level design of the human-machine interface supports the human actors in carrying out their tasks;
- *Team structures and team communication:* the HP assessment process will ensure that effects on the team composition are identified; that there is an appropriate allocation of tasks between human actors; and that the communication between team members supports human performance.
- *Potential transition factors*: the HP assessment process will analyse the preliminary identification of issues related to acceptance and job satisfaction, changes in competence requirements, impact on staff levels and shift organisation, and the need for re-location of the workforce.

For each area of analysis and OIs maturity level, different HF techniques for data collection and assessment of HP issues can be used: ranging from Task Analysis to Cognitive Walk-through, Focus Groups and Envisioning Sessions to Real-time Simulation (complemented by log-analysis, over-the-shoulders observations and debriefings). It is important to notice that due to the relatively low maturity level of OIs in ClimOP no Real-time Simulation will be carried out, but mainly other HF techniques will be used.

4.2.2 Social acceptance

In addition to technical and economic aspects, it is essential to include an analysis of the social aspects that influence the acceptance of clean technologies and mitigation measures by passengers and citizens in the aviation domain. Operational Improvements (OIs) proposed by ClimOP that are technically, operationally and economically feasible in a given context (e.g., country or specific airport) may not be successfully implemented due to social resistance, lack of awareness of the technology and its environmental benefit, etc. For example, the communities living in the neighbourhood of an airport may protest against the high noise levels and oppose to any project of airport expansion even if this could in principle bring economic benefits[7]. Also, the growing prominence of public movements calling for limitations to air travel because of its environmental impact might have contributed in the past year to a decline of the number of passengers in domestic flights in some north-European countries[8]. In a similar way, passengers might find some OIs difficult to accept because of a perceived deterioration of the flight experience, due for example to an increased flight duration or more expensive travel fares. Airport neighbours might be negatively impacted if a fuel-saving OI route leads to higher noise in some areas around the airport.

Social or public acceptance is generally defined, as a positive attitude towards technology or measure, which leads to supporting behaviour if needed or requested, and the counteracting of resistance by others.

According to Wüstenhagen et al., social acceptance has three main sub-components, forming the so-called "*triangle of social acceptance*" [33]:

- Community acceptance
- Market acceptance
- Socio-political acceptance

From the recent literature, we derived the most relevant aspects influencing social acceptance in all the three above-mentioned components [34].

Awareness

1) Awareness of environmental and energy problems (climate change, pollution, energy consumption, etc.).
2) Perception of the aviation impact on climate.
3) Knowledge of the OIs/technology/innovative business models/incentives.
4) Efficacy of the OIs/technology/innovative business models/incentives.

Individual factors influencing decision making

5) Perceived costs on passengers in implementing the OIs/technology/innovative business models.
6) Perceived risks in implementing the OIs/technology/innovative business models.
7) Perceived benefits and usefulness in implementing the OIs/technology/innovative business models.

Local Context influencing decision making

8) Social norms and community influence (herding behaviour, are your neighbour/friends/colleagues/relatives in favour and/or adopting the technology?)
9) Facilitating conditions (public incentives/discounts)
10) Trust in decision-makers and other relevant stakeholders
11) Fairness of the decision-making process

Acceptance and Adoption

12) Citizen acceptance: in favour of public innovations, collective implementation of technologies

ClimOP will analyse all the above-defined aspects through a survey conducted with EU citizens, both frequent flyers, less frequent passengers and travellers that prefer other transport modes with respect to aviation.

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[7] For example, demonstrations and protests have taken place for example against the expansion of Heathrow Airport and have recently contributed to the expansion plan of Bristol Airport.

[8] E.g. https://www.reuters.com/article/us-airlines-sweden-idUSKBN1Z90UI

A first version of the social acceptance survey will be conducted around M12 of the ClimOP project. A second and third round of the survey will be launched during the mid-project (M21) and end-project (M42) phases, to assess changes across time.

The comparison between initial and final answers, collected among the different groups (some working as control-groups, depending on the question), will inform the ClimOP Consortium about the project success in terms of:

- awareness level concerning the impact of aviation on climate change and current initiatives
- acceptance level concerning OIs and mitigation strategies in aviation
- aviation stakeholders' and passengers' engagement level linked to specific business models

overall assessment of the project communication and dissemination strategy with respect to the general public.

4.3 Relating KPIs to stakeholders

The Single European Sky SES 'Performance Scheme' defines key performance indicators and sets mandatory local and EU targets in the fields of environment, safety, efficiency and capacity while taking into account their interdependencies. The scheme captures the relationship between flight routing and environmental impacts through two KPIs. These involve measuring horizontal flight efficiency by comparing the great circle (shortest) distance against (1) the trajectory in the last filed flight plan (KEP) and (2) the actual trajectory flown (KEA). These KPIs are regarded as reasonable proxy measures of Air Navigation Service Provider efficiency. In the same context, the Stakeholders defined in Chapter 2 have a specific relationship with respect to the KPIs defined in the previous sections, which must be taken into account for the assessment of operational improvements.

The stakeholders discussed in Chapter 2 have a different role and, therefore, different interests and responses to climate mitigation of aviation. Thus, different operational improvements and thereon following mitigation strategies will reflect in different ways to the various stakeholders. In order to select the most promising mitigation strategies, the individual operational improvements must be identified as the most promising for all the stakeholders collectively. To assess their individual interests, costs and benefits properly, the KPIs defined in the previous Sections (4.1 and 4.2) are related to each Stakeholder.

To facilitate the mapping of the KPIs to the different stakeholders, labels will be assigned to each individual KPI defined in Section 4.1 and 4.2. These labels consist of a letter "K", that denotes a KPI, followed by "X.Y." where X represents the number of the main KPI and Y the number of the subgroup of the KPI. The overview of these labels and KPI's can be found in Table 2.

The KPI's are mapped to the different stakeholders, in the sense that either they exercise influence on the respective KPI, or they experience direct effect from a change in this KPI. The involvement includes experiencing the consequences of those aspects changed due to climate impact mitigation strategies. In the case that a stakeholder does not have a direct relation to a KPI but might experience effects from the change of a KPI indirectly, the label is put between parenthesis in Figure 5.

It must be noted that certain KPI's have a different degree of relation to certain stakeholders than to other stakeholders. This involvement depends on the scenario and context assessed and will become more apparent in Deliverable 1.3.

Table 2 - Consolidated list of KPIs

Code	KPI	Details	
K1.1	ATR20	Average Temperature Response	
K1.2	ATR100	Average Temperature Response	
K2.1	Emissions	CO_2	Tonnes (total, per cycle, or per unit time)
K2.2		NOx	
K2.3		H_2O	
K2.4		particulate matter (PM)	
K3	Fuel flow	Fuel per unit time	
K4	LTO cycle	cycles per unit time	
K5.1	Maintenance frequency	Number of planned maintenance events	
K5.2		Number of unplanned maintenance events	
K6	A/C operation time	Operating hours of aircraft	
K7	Route efficiency	measure of detour w.r.t. great circle distance	
K8	Sulphur content	mixing ratio of Sulphur in fuel	
K9	Biofuel use	Percent of biofuel used in industry	
K10.1	Accident rate - airborne	% change in count of events	
K10.2		frequency of occurrence per flight hour	
K11.1	Accident rate - ground and TMA	% change in count of events	
K11.2		frequency of occurrence per flight hour	
K12.1	Throughput	passengers transported in the network	Number of passengers
K12.2		freight transported in the network	Tonnes of freight
K13.1	Network capacity	seats available in network	ASK
K13.2		freight volume available in network	ATK
K14.1	Network use	seats carried in network	RPK
K14.2		freight volume carried in network	RTK

K15	Network traffic concentration	concentration of frequencies at the main airports	Gini concentration index
K16	Network morphology	shape by inequality of the network	Freeman network centrality index
K17	Aircraft utilisation	time spent, per day, aircraft operating and generating revenue	hours, cycles
K18	Aircraft on ground time	time spent by the aircraft out of operations	hours, days
K19	Turnaround time	duration from the point of aircraft arriving to pushback	Time (per event or average over unit time)
K20	Connection time	duration required for unloading and loading	Time (per event or average over unit time)
K21.1	On-time performance	adherence to the scheduled time of the flight plan	Delay in time (per event or average over unit time)
K21.2			Number of cancellations
K22.1	Fleet composition	types of aircraft flown by the airline	Fleet composition (i.e, number of aircraft of each type)
K22.2			Fleet age
K22.3			Fleet commonality
K23	Movements	aircraft operating in a sector of airspace	Number of aircraft
K24	Airspace capacity	aircraft allowed in an airspace at a particular time	Movements per unit time
K25.1	Routing efficiency	divergence from the optimum route for a flight	Added flight distance or time
K25.2			Number of instructions
K26.1	Airport capacity	constraints of the airport at a particular time	Number of available gates
K26.2			Number of available stands
K26.3			Movements per unit time (for taxiways and runways)
K27.1	Airport traffic	amount of aircraft, passengers, or cargo, landing at or taking off	Movements per unit time
K27.2			Passengers per unit time
K27.3			Cargo tonnes per unit time
K28.1	Network connectivity	number of destination served by the airport	Number of destinations offered with 0 or 1 intermediate stops

K28.2			Number of OD pairs served (possible connection at the reference airport)
K29	Aircraft lead time	aircraft order and delivery	Time
K30	Supply chain lead time	spare part order and delivery	Time
K31.1	Production capacity	amount aircraft or part the manufacturer is capable of producing	Number of aircraft per unit time
K31.2			Number of parts per unit time
K32.1	Production volume	amount aircraft or part the manufacturer is producing	Number of aircraft per unit time
K32.2			Number of parts per unit time
K33	Travel time	duration of travel from point of departure till arrival	Time (per event of average over unit time)
K34	Itinerary complexity	number of transfers or directness of the flight plan	Number of intermediate stops
K35	Passenger traffic volume	RPK	
K36	Passenger yield	EUR/RPK	
K37	Airline transport capacity	ASK	
K38	Airline expense	CASK	
K39	Airline revenue	RASK	
K40	Passenger load factor	RPK/ASK	
K41	Cargo traffic volume	RTK	
K42	Cargo transport capacity	ATK	
K43	Cargo yield	EUR/RTK	
K44	Cargo load factor	RTK/ATK	
K45	Price elasticity	(dimensionless)	
K46	Time elasticity	(dimensionless)	
K47	Airport charges landing, parking, hangar, noise, pax service, cargo service, security, ground handling, fuel	EUR	

STAKEHOLDERS	KPI's
Society	K1.1, K1.2, K2.1, K2.2, K2.3, K2.4, K9, K10.1, K11.1, K11.2, K12.2, K14.2, K23, K24, K27.1, K27.2, K27.3, (K47)
Airlines	K2.1, K2.2, K2.3, K2.4, K3, K4, K5.1, K5.2, K6, K7, K8, K9, K10.1, K11.1, K11.2, K12.1, K13.1, K14.1, K16, K17, K18, K19, K20, K21.1, K21.2, K22.1, K22.2, K22.3, K25.1, K25.2, K28.1, K28.2, K33, K34, K35, K36, K37, K38, K39, K40, K45, K46, K47
ANSPs	K5.2, K6, K10.1, K10.2, K11.1, K11.2, K15, K16, K17, K18, K19, K20, K21.1, K21.2, K23, K24, K25.1, K25.2, K26.1, K26.2, K26.3, K27.1, K27.2, K27.3, K28.1, K28.2, K33, K34, K35, K36, K37, K38, K39, K40, K45, K46, K47
Airports	K2.1, K2.2, K2.3, K2.4, K4, K11.1, K11.2, K12.1, K13.1, K14.1, K15, K16, K17, K18, K19, K20, K21.1, K21.2, K22.1, K22.2, K22.3, K26.1, K26.2, K26.3, K27.1, K27.2, K27.3, K28.1, K28.2
OEM's	(K2.1), (K2.2), (K2.3), (K2.4), K3, K4, K5.1, K5.2, K6, K7, K8, K9, K22.1, K22.2, K22.3, K29, K30, K31.1, K31.2, K32.2
Governments	K1.1, K1.2, K2.1, K2.2, K2.3, K2.4, (K12.1), K12.2, K13.1, K14.1, K14.2, K15, K16, K17, K18, K23, K24, K27.1, K27.2, K27.3
Passengers	K10.1, K11.1, K11.2, K12.1, K13.1, K14.1, K15, K16, K20, K21.1, K21.2, K28.1, K28.2, K33, K34
Cargo forwarders	K2.1, K2.2, K2.3, K2.4, K3, K4, K5.1, K5.2, K6, K7, K8, K9, K10.1, K11.1, K11.2, K12.2, K13.2, K14.2, K15, K16, K17, K18, K19, K20, K21.1, K21.2, K22.1, K22.2, K22.3, K25.1, K25.2, K28.1, K28.2, K33, K34, K41, K42, K43, K44, K45, K46, K47
Residents near airports	K1.1, K1.2, K2.1, K2.2, K2.3, K2.4, (K10.1), (K10.2), K11.1, K11.2, K15, K16, K17, K18, K19, K23, k24, K26.1, K26.2, K26.3, K27.1, K27.1, K27.2, K27.3, K47

Figure 5 - KPIs with respect to stakeholders

5. Conclusion and future work

5.1 Review of deliverable D1.1

Deliverable 1.1 describes in detail the definition of climate and performance metrics. This has been done in a comprehensive way starting with the discussion of the main ideas of ClimOP and WP1. This is followed by a section expressing the ideas and assumptions influencing the choice of relevant metrics with respect to climate and performance. Subsequently, all the pertinent nine stakeholders and their sphere of influence on climate mitigation are characterised in detail. Finally, the 47 Key Performance Indicators (KPIs) are categorised into environmental, technical, economical, operational and safety; where each of them are perused in sufficient detail and related back to the stakeholders.

5.2 Links to work package WP1

Work package 1 consists of five tasks with task T1.1 “Definition of climate and performance metrics” has been covered by this report. T1.2 “Inventory of operational improvement options” involves the same contributors as T1.1, and both tasks ran in parallel but independent of each other. At month 4, T1.3 Assessment of operational improvement against identified KPIs will begin, combining the output of T1.1 and T1.2. The objective will be to use the KPIs defined in this report to assess the potential benefits and disadvantages of each of the operational improvements identified in T1.2. Further on, WP1 will continue with the output of the other tasks for T1.4 and T1.5, but naturally, the content of D1.1 will still be a reference point moving forward.

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