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#4
Strategies for a swift deployment and conclusions

Towards eco-friendly operations
Acting now to reduce the climate impact of aviation

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Towards eco-friendly operations

Acting now to reduce the climate impact of aviation

Day-to-day flight operations are perhaps the least easily understood field of air transport. Yet, it is one of the most relevant levers for short-term actions intending to reduce the climate impact of air transport, since it can affect all in-service aircraft without requiring major technological breakthroughs.

But reducing the climate impact of aviation requires understanding it:

From this standpoint, climate science has made significant progress, allowing both to model and quantify the impact of carbon dioxide (CO_2) emissions, but also to better understand the effects of condensation trails their induced cirrus clouds, and to a lesser extent, those of nitrogen oxides.

Leveraging on these results, research in the field of flight optimisation shows that implementation of eco-friendly flight operations offers the potential to **reduce the climate impact of aviation by more than 10%** when considering only CO_2 effects, and over 20% when compounding all effects.

In order to achieve tangible gains as quickly as possible and take advantage of current air traffic conditions that are favourable to experimentation, reliance on **local ecosystems** willing to commit to the ecological transition of their operations is crucial.

TO MAKE THIS TRANSITION A SUCCESS, WE MAKE THREE MAIN PROPOSALS:

- First, **set up and disseminate a single source of truth**, reliable, neutral, objective, shared and transparent, enabling each party to assess the climate impact of its operations on each segment of each flight.
- Second, develop **operational and technological frameworks that enable continuous reduction of the environmental impact of these operations** by facilitating collaboration between pilots, airlines and air navigation services, starting through digital tools. To act quickly, deployment could be limited initially in space and/or time, and later extended to increase in scope.
- Third, for each local ecosystem, put in place as quickly as possible measures making such operations economically viable for each party, for example by **facilitating communications to passengers and investors** of the ecological performance of stakeholders' operations, or promote eco-friendly behaviour through **economic**.

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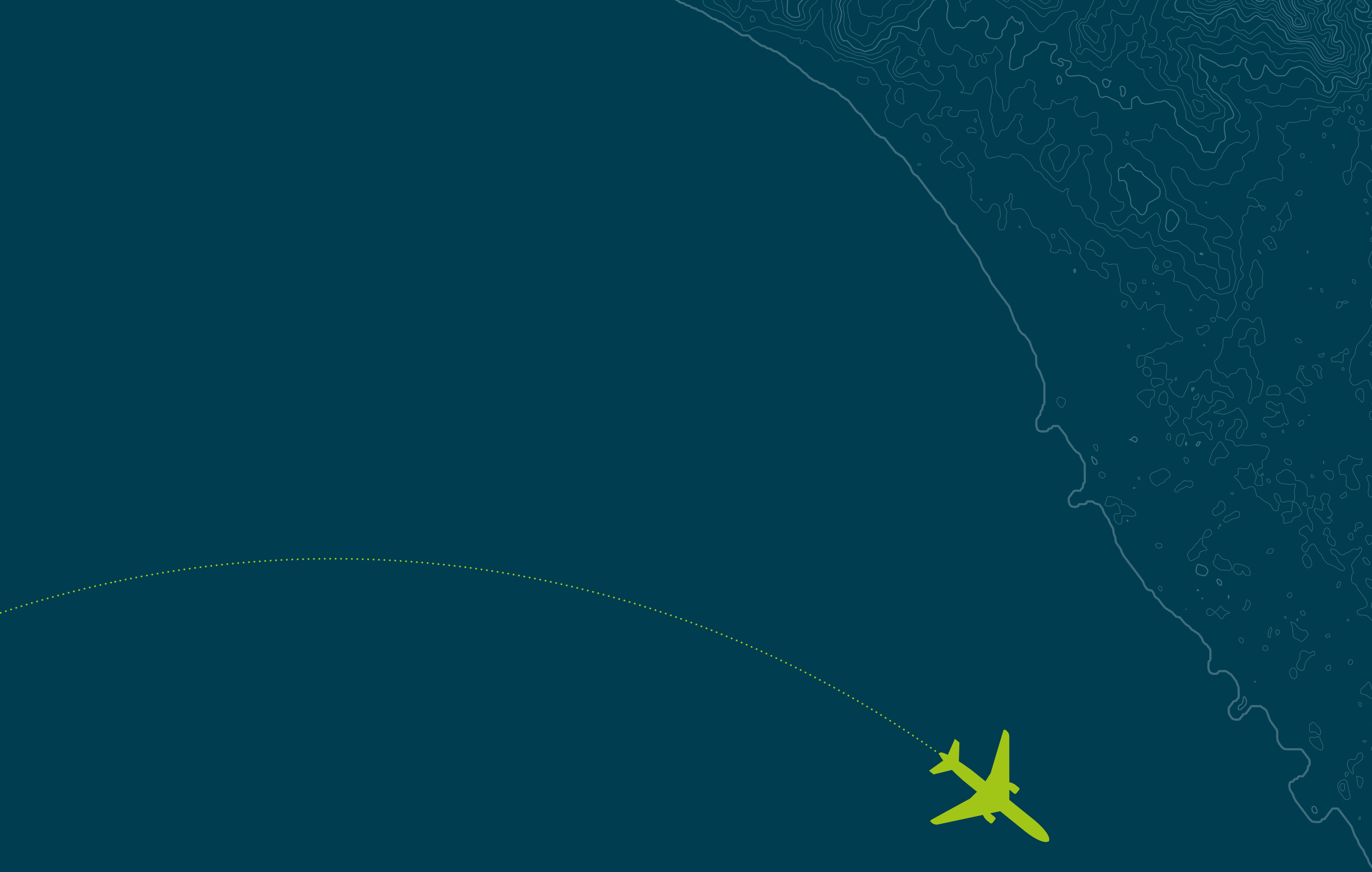

#4 Strategies for a swift deployment and conclusions

Towards eco-friendly operations

Acting now to reduce the climate impact of aviation

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Introduction

No one can deny the major role of aviation in the development of modern societies: it has brought people together and has contributed significantly to global economic growth.

However, like many human activities, air transport has an ecological footprint and more specifically a significant climate impact.

The International Council on Clean Transportation (ICCT) estimates the share of air transport at **2.4%** of 2018 global CO_2 emissions (Graver, Zhang, & Rutherford, 2018).

To reduce its environmental impact, the air transport community is thus actively working in four complementary directions:

- Develop low-carbon footprint aircraft: hydrogen, electric, hybrid...
- Introduce sustainable aviation fuels (SAF) compatible with existing aircraft: sustainable biofuels, synthetic fuels...
- Renew aging fleets with newer, more efficient in-production aircraft.
- ... and finally optimize flight operations of in-service aircraft in order to reduce their environment footprint.

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ECO-FRIENDLY FLIGHT OPERATIONS: ACT NOW, EVERYWHERE, AND AT LOW COST

While the first two approaches are obviously the most promising since they enable truly low-carbon air transport, they must overcome several significant challenges:

- On one hand, development of low-carbon aircraft requires major technological and logistical breakthroughs and experts do not anticipate mass production to start before the end of the next decade.
- On the other hand, deployment of SAF will necessarily be gradual: initially limited[1] to SAF based on the sustainable exploitation/recycling of biomass, their use will grow with the development of synthetic fuel. However, large-scale deployment of low carbon synthetic fuel is not foreseen before 2035 at the earliest. The positive impact of fleet renewal on air transport environmental footprint no longer needs to be demonstrated[2]. However the cost of such renewal for airlines is very high – A320neo list price is $110M – in a time when airlines' investment capabilities are seriously hampered by the COVID crisis.

Therefore, the fourth approach seems to be the most accessible in the short term while being cumulative with the three first ones: optimizing the day-to-day flight operation of in-service aircraft to reduce their ecological impact. Throughout the following of this document, we refer to such operations as eco-friendly operations.

WHAT ARE FLIGHT OPERATIONS?

Flight operations are probably the area of air transport that is the least easily understood by the general audience.

This document focuses more specifically on the subset of these flight operations having an impact on aircraft emissions,

- Strategic and pre-tactical flight planning activities:
  - Strategic flight planning carried out by airlines (flight scheduling) and consolidated/adjusted by Air Navigation Service Providers (ANSPs), the result being a validated flight plan filed for each aircraft.
  - Flight preparation, including the determination of the quantity of fuel carried and more generally flight related operational planning (catering, supplies…).
- Tactical flight execution activities:
  - Taxiing (for departure and arrival), carried out in collaboration between air traffic control and the crew, possibly with the help of a pushback tug.
  - The actual flight and its integration into air traffic, carried out in collaboration between the crew, air traffic control and the airline, based on the filed flight plan and taking into account the conditions of the day: weather, load factor...

EVALUATE, EXPLORE, EXPERIMENT, DEPLOY...

This document thus aims at describing more precisely the challenges of the ecological transition of flight operations:

- We first summarize the methods for assessing the climate impact of aviation that has been developed by the scientific community and that are now widely recognized. We also show how the understanding of this impact itself is improving.
- Using these methods and state-of-the-art flight optimization research, we try to assess the order of magnitude of the potential for eco-friendly flight operations to reduce the climate impact of air transport.
- We then identify the challenges that air transport will have to face to deploy these eco-friendly operations.
- Finally, we introduce three proposals allowing to engage all air transport stakeholders in order to achieve these reductions as quickly as possible.

> **A few definitions**
> In the context of Air Traffic Flow Management, considering a D-day flight, the strategic phase includes dispatching and flight planning activities carried out between one year and D-7, the pre-tactical phase takes place between D-7 and D-1 and finally the tactical phase takes place on D-day.

[1] (EEA, EASA & EuroControl, 2020) estimates that, if the whole European biofuel production was dedicated to SAF, it would only account for 4% of kerosene consumption in Europe in 2019. It also states that the average use of SAF in Europe should not exceed 1% in the short term because of their high price.

[2] The latest generation A320neo is at least 15% more efficient than a classic A320 according to (Hensey & Magdalina, 2018). This number is probably underestimated as it doesn't take into account replaced aircraft's airframe and engine aging.

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Strategies for a swift deployment

Implementing eco-friendly operations is urgent, both because of the cumulative nature of global warming – requiring time for any action to have an actual observable impact on the climate– and because of the evolving context of air transport:

- Traffic conditions are more conducive to experimentation,
- More passengers are becoming aware of their climate footprint and that of the airlines they travel with,
- The awareness of institutions and citizens is wider, which may lead to favorable regulatory and structural conditions for eco-friendly operations.

To work within the complexity of air transport, we propose a strategy based on three principles:

- At least initially, **do not rely on large systemic actions:** while effective in the long term, they generally take a very long time to implement.
- Prioritize implementations within **local ecosystems** by parties committed to **a continuous reduction process** of their ecological footprint (see figure 1).
- Within these local initiatives, consider from the start the ability to **scale up**.

As these local initiatives will meet success, it will then become possible to scale up the most promising ones in order to increase their impact; up to a point they could become systemic.

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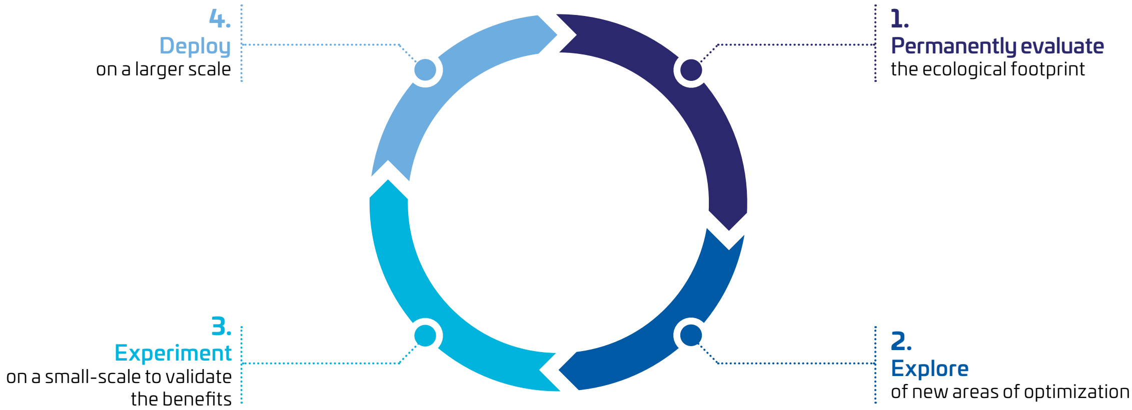
Figure 1

Cycle of continuous improvement of climate impact within a local ecosystem.



Successful and swift deployment of eco friendly operations requires implementation in **local ecosystems** and **incremental actions** designed so that they **can scale up.**

In order to achieve such a strategy, we propose the simultaneous implementation of three proposals:

- Proposal 1:
  Design, experiment, and widely distribute, a single source of truth for the assessment of the climate footprint of each segment of each flight, reliable, widely recognized by the community, and under the responsibility of an independent, trusted third party.
- Proposal 2:
  Within each local ecosystem, experiment and deploy, on ground and onboard, operational and technical solutions allowing planning and execution of eco-friendly operations, and the continuous reduction of their climate impacts.
- Proposal 3:
  With all stakeholders of these local ecosystems, establish mechanisms to make eco-friendly operations viable quickly and in a coordinated manner.

1.

PROPOSAL 1: SET UP AND DISSEMINATE A SINGLE SOURCE OF TRUTH

To make eco-friendly operations a reality, several types of stakeholders need to act and interact, each within their own framework. In order to ensure the consistency of their actions, it is crucial to structure them around a unique, reliable and shared measure. This measure will serve as a single source of truth in order to allow each of these stakeholders to build KPIs (Key Performance Indicators) dedicated to their own activities.

Evaluation or KPI?

There is often confusion between evaluation/measurement on one side and indicators (Key Performance Indicator or KPI) on the other. To make it simple, an evaluation / measurement is an actual, undisputed, transparent and fair data corresponding to an approximation of the reality, **without any intent or bias.** It could be built upon a direct measurement (e.g. temperature through a thermometer) or through indirect assessment (e.g. GWP based on models and simulation). Discussions on the relevance of an evaluation / a measurement are usually ruled by science and are usually related to its precision and validity.

On the contrary, a KPI is derived from such assessment/measurement in order to monitor progress or deviation. A KPI is thus associated with the action plan of a specific party or group of parties, and thus **with an intent.** Therefore, discussions between stakeholders on a KPI are far more complex as validating a KPI means validating the associated intent.

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Within this section, we will thus address the different aspects of this single source of truth:

- How to design it so that it could be accepted and disseminated within the air transport community?
- What are the existing tools for footprint assessment and what are their limitations?
- What challenges does its implementation need to overcome?

1.1. A UNIQUE SOURCE OF TRUTH SERVING ALL STAKEHOLDERS

The paramount goal of a single source of truth is to **build a consensus,** within each local ecosystem, on an assessment method. This consensus needs to go beyond the traditional air transport parties and include, for example, governmental and non-governmental climate organizations.

Once this consensus is reached, this single source of truth shall be put under the responsibility of an **independent and legitimate body,** allowing the various parties in the local ecosystem to derive actionable KPIs.

Building a consensus

Creating this single source of truth is a complex task, given the wide scope of its user base: regulators, states, airlines, airports, ANSPs, NGOs and even passengers, to name a few.

Each user is interested in a different dimension:

- Granularity: flight or set of flights, passenger travel, part of flight over a geographical area, part of flight within a control zone, set of flights during a timeframe...
    - The elementary unit of this single source appears to be the climate impact of any flight on any segment of its trajectory.
- Considered climate effects: CO_2 only, or including all, or some, of non-CO_2 effects.
    - The most recognized metrics for their characterization are individual effective radiative forcing (ERF) and GWP_{100} of each climate effects, knowing that the confidence level of some of these measures will be very low[3].

The most relevant single source of truth to serve all ecosystem parties is the **effective radiative forcing and GWP_{100} of any aircraft on any segment of its trajectory** for each climate effect.

From an evaluation to a single source of truth: the challenge of disseminations

The successful dissemination of this single source of truth relies on three key properties: usefulness, impartiality, and transparency.

To be useful, it must allow to **predict the impact of future flights or operational concepts,** in addition to evaluating flights already completed.

This forecasting capacity is essential:

- For airlines and ANSPs, to plan and execute eco-friendly flight operations.
- For the scientific and industrial community, in order to test and refine climate models and new optimizations, thus maximizing the speed of fulfilling the reduction potential of eco-friendly flight operations.

Impartiality requires from the outset an estimate of all flights departing, traversing or arriving in a given ecosystem, without exception:

- The assessment must be fair and apply to everyone.
- It must assess the global effects of local flight operations.

Finally, regarding transparency, the party in charge of the assessment must be independent, must guarantee the relevance of the calculation methods and estimate associated uncertainties. It could therefore either be in charge of:

- Producing the single source of truth,
- And/or certifying/approving the quality of the single source if it is produced by a third party.

This is why international organizations such as ICAO, EASA/FAA or national authorities seem natural candidates. Doing so, they would play the same role in reducing the climate impact of aviation as the role they played in improving the safety and efficiency of air transport.

To be widely disseminated, the evaluation process must be able to make **forecasts** in addition to **a posteriori assessments.** It must be **applicable to all** and **transparent** and therefore be produced or approved by an **independent entity.**

[3] Obviously, the fact that an effect is assessed/measured does not mean it has to be integrated within the stakeholder KPI.

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1.2. LIMITATIONS OF EXISTING TOOLS AS A SINGLE SOURCE OF TRUTH

Today, there are two main families of CO_2 emission assessment tools: CO_2 calculators on one side, and CO_2 emission reports on the other side.

> CO_2 calculators

CO_2 calculators usually estimate emissions from departure to arrival per passenger. Sovereign entities have developed several: ICAO Carbon Emission Calculator, Eurocontrol Small Emitters Tool, TARMAAC calculator by DGAC… Private or non-governmental entities have also integrated such features as part of ticket comparators or trip planners such as Google Flight.

These calculators determine CO_2 emissions as the product of two values:

- CO_2 emissions per passenger per kilometer (or flight time) depending on aircraft and sometime engine type.
- The great circle distance between departure and arrival airports.

However, these CO_2 calculators have limitations when it comes to assessing the climate efficiency of operations:

- They do not consider the actual flight: trajectory flown, weather and traffic conditions, thrust and flight level… and therefore cannot measure flight operation improvements.
- They cannot itemize emissions per geographical area: country, control zone… as required by parties such as governments and ANSPs.
- Non-CO_2 effects, when included, are flat rates that are not very relevant to assess the effect of contrails and induced cirrus clouds, for example.

> ETS and CORSIA emission reports

In order to comply with ETS and CORSIA regulations, airlines have to report their emissions based on actual aircraft fuel burn. However, these reports also come with limitations:

- Reports categorized by airline and departure/arrival pair are available to regulatory entities but not to the general audience as those data are considered as confidential.
- Emission reports are available only for intra-community flights for ETS and volunteer countries for CORSIA.
- These reports do not integrate non-CO_2 effects.
- While they are a very precise a posteriori measure, they cannot be used to simulate the impact of a new optimization on an upcoming flight.
- Finally, as CO_2 calculators, they cannot itemize emissions by geographical area.

If not relevant as single source of truth, **CORSIA and ETS emission reports** (and to a lesser extent CO2 calculators) could be used to **benchmark** the single source of truth.

1.3. CREATING A SINGLE SOURCE OF TRUTH

The development of a reliable single source of truth to evaluate the climate footprint of flight operations needs to overcome two difficulties: collecting the data necessary for the evaluation on the one hand; and defining models to convert this data into climate effects on the other.

> Data collection: collaborative or not?

As discussed in section 1.3 on page 6, climate models require estimates of engine emissions on each segment of the trajectory and corresponding environmental conditions.

The data collection strategy depends very much on the nature of the chosen evaluation system:

- In a collaborative evaluation system, all parties agree to share their data anonymously. These can flow from existing aircraft systems – onboard sensors, flight data recorders… – or new ones, such as a "green box".

> **The "green box"**
>
> In the same way that the Safety Management System uses flight data from the Quick Access Recorder, one could imagine deploying a "green box" and new sensors onboard any aircraft. This "green box" would not only collect existing onboard data – e.g. thrust level and fuel flow – but also aircraft emissions and atmospheric conditions through new dedicated sensors[4].

- A non-collaborative evaluation system uses whatever data is available without need for collaboration[5]. Missing data – typically thrust – are extrapolated using available data such as weather conditions, aircraft

[4] *IAGOS (In-service Aircraft for a Global Observing System) is an early example of this type of approach: the IAGOS consortium deploys specific sensors onboard a few aircraft from partner airlines (around twenty planes) and provides the data to researchers to further high altitude climate science.*
[5] *For example, aircraft and engine type, trajectory from ADS-B data broadcast by each aircraft, inflight weather conditions…*

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trajectory, standardized aircraft modeling such as OpenAP *Sun, Hoekstra, & Ellerbroek, 2020* and possibly using default values for missing parameters. Examples of such an approach are described in *Alligier, Gianazza, & Durand, 2015, Lopez-Leones, et al., 2017* and *Dalmau, Prats, Ramonjoan, & Soley, 2020.*

Collaborative systems are obviously more accurate, but are generally slower to implement since stakeholders need to participate either voluntarily or by obligation.
Non-collaborative systems are less accurate, but are immediately deployable globally.

In order to support fast implementation, the following three-step approach is thus recommended:

- As a first step, experiment and deploy a **non-collaborative solution** based on available actual data, possibly benchmarked with ETS/CORSIA reports or even with real flight data provided by airlines. This replacement for the CO_2 calculators makes it possible to objectify the ecological efficiency of a flight or a flight segment.
- Second, to progressively make the assessment system **more collaborative** and therefore more accurate by integrating actual data provided:
  - By volunteer airlines: for example takeoff weight and actual fuel flow, precise ratio of SAF per flight, individual aircraft condition…
  - By volunteer aircraft or engine manufacturers: aircraft performance models, engine emissions models...
- Last, transition from estimates to actual measurements with data from **specific sensors** onboard the aircraft – "green box" – or elsewhere: satellites, ground radars…

Non-collaborative data from observation satellites

Observation from space is a good source of data for non-collaborative systems. It is quite possible to observe the formation of contrails from space, as shown in the image below captured by NASA's SeaWiFS satellite over the Atlantic in 2002.

From collecting data to assessing climate impact: the need for model tuning

Regarding climatic phenomena, there are already a large number of commonly used models: aircraft emission models, physicochemical models of emission-atmosphere interactions, and finally climate models associated to these interactions.

However, while CO_2 climate effect models are now mature, those for non-CO_2 effects have limitations and uncertainties that must be taken into account when determining the climate impact of any segment of a trajectory:

- Regarding the physicochemical interaction models, uncertainties lie in the interactions between several phenomena resulting from the same emission – O_3 and CH_4 effect induced by NO_X or interactions between contrails generated by several aircraft – or the interaction between these phenomena and meteorological phenomena, such as interactions between contrails and natural clouds.
- Regarding climate models, their resolution will need local improvements to make them directly applicable to any flight segment (this is the case, for example, for models for the formation of artificial cirrus associated with contrails).

Swift deployment of a single source of truth for **non collaborative** assessment is therefore **perfectly possible.** This assessment could be **limited to CO_2 effects** initially and could then **evolve over time** to include non CO_2 effects.

Validating models

As discussed in section 1, there are many climate models, especially for non-CO_2 effects. In addition to a reliable single source of truth, the selection and validation of climate models (and their evolutions) requires a dedicated **scientific committee.**

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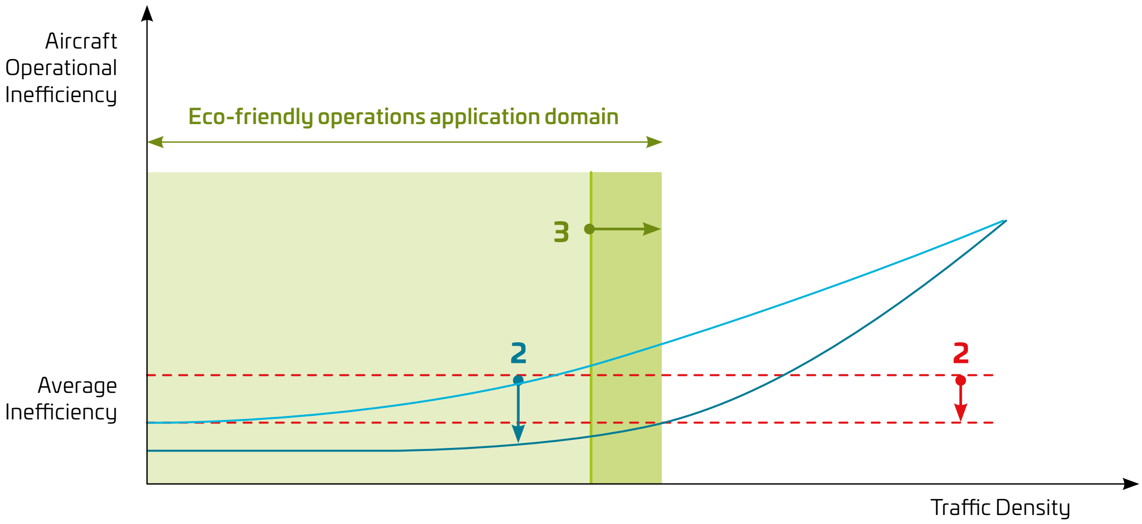
Figure 2

Increase of the average climate efficiency (arrow 1) through continuous improvement in eco-friendly operations within the eco-friendly operations application domain (arrow 2), and then extension of this application domain in space and time (arrow 3).

The blue curves show the climate efficiency of flight operations as a function of traffic density. The dotted red lines show their average climate efficiency. The green area shows their application domain extension.



2.

PROPOSAL 2: IMPLEMENTING OPERATIONAL AND TECHNICAL SOLUTIONS ON GROUND AND ON BOARD ALLOWING THE CONTINUOUS IMPROVEMENT OF OPERATIONS' IMPACT

As seen in section 2.1 on page 7, research has already largely addressed the field of eco-friendly operations, with the partial deployment of CO_2 effects reduction.

The issue is therefore not only the design but also the gradual deployment of these operations in a considered local ecosystem, taking into account the many challenges detailed in section 3 :

- A flight generally crosses several portions of airspace whose structure is governed by a set of agreements and responsibilities.
- The objectives of stakeholders – airline and ANSP for instance – may diverge on a given flight.
- Competition with other performance indicators, such as capacity (of an Air-Traffic Service Unit or ATSU) or economic efficiency (of a flight) shall be handled.

However, despite this complexity, the aviation ecosystem has been able to put in place strategies that allow deep – and sometime very fast – transformation (see section 3.1 on page 14).

We propose to draw inspiration from these strategies for the implementation of eco-friendly flight operations:

- In terms of implementation (section 2.1),
- In terms of operational concepts (section 2.2),
- In terms of technical solutions (section 2.3),
- Finally in terms of continuous improvement process (section 2.4).

2.1. AN IMPLEMENTATION BASED ON GRADUAL DEPLOYMENT

The implementation of eco-friendly operations requires the deployment of new operational concepts, possibly new technical enablers and new processes. In order to enable their swift implementation, we propose to apply the gradual deployment strategies successfully implemented between ANSPs and airlines for the continuous improvement of air traffic management.

The deployment of these strategies could thus be initially:

- Limited to selected portions of airspace, as implemented for free route airspace[6] deployment, for instance in less complex and less dense areas.
- Limited in time, such as Continuous Descent Operations: at night, during certain periods of the year…

[6] *Free route airspace are volumes in which users can freely plan a trajectory between entry and exit points. Its deployment in Europe proceeds gradually from one ATSU to the next.*

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These initial operational deployments can then be extended geographically (to national-, continental- and worldwide-level) and time according to their success.

Let us call eco-friendly operation application domain the limited – in space / time – domain in which eco-friendly operations are deployed. Figure 2 describes the two moves to implement in order to improve the average climate efficiency of operations (arrow 1 of figure 2).

- Efficiency improvements within the eco-friendly operations application domain (arrow 2 on figure 2): within the eco-friendly operations application domain, implementation of a continuous improvement of eco-friendly operations as defined on figure 1 page 10 (evaluate/explore/experiment/deploy).
- Extension of the eco-friendly operation domain (arrow 3 of figure 2) in space and time.

The reduced air traffic due to the COVID-19 crisis creates particularly favorable conditions for such a deployment. However, on one hand the return to a normal traffic and, on the other hand, the extension of the eco-friendly operation domain to denser traffic area will require the design of new operational processes to maintain satisfactory climate performance while ensuring capacity and safety.

> **Example: the Green Flag concept (1/4)**
>
> In the domain of robotics, new functions are released in a specific domain including space, time, and weather conditions. This is called **Operating Design Domain**. In the same way, eco-friendly operations could be implemented in a given area for a given time period. In the Green Flag concept, when specific conditions are met – typically traffic conditions – an area can be declared Green Flag by the Air Traffic Control (ATC). When in **Green Flag**, eco-friendly operations are implemented by default in this area as a priority only second to safety. Such implementation relies typically on improved collaboration between pilots and controller and/or also between controllers.

Deployment of eco friendly flight operations may be **initially limited in space and time,** with an application domain expanding over time

2.2. AN OPERATIONAL CONCEPT LEVERAGING GROUND/FLIGHT COLLABORATIVE DECISION MAKING

While flight planning and standardization are key to the air traffic management paradigm, executing flights as climate-perfect as possible (as described in section 2) requires much greater collaboration between pilots and controllers before and more importantly during the flight.

> From strategic planning to collaborative and agile execution

Getting as close as possible from a climate-perfect flight requires continuous adaptation of its trajectory to inflight weather conditions, in the four dimensions:

- Within the time plane: the climate-perfect flight requires optimum use of engine thrust, removing ability to adjust cruise speed to make up for hazards – such as headwinds – and leading to uncertainty concerning the timeliness of its trajectory and separation with other aircraft.
- Within the vertical plane: the climate-perfect flight requires frequent changes in cruise flight level to take advantage of favorable winds and temperatures, and to avoid non-CO_2 effects such as contrail formation. The position of the top of descent allowing an idle thrust descent may also vary depending on wind foreseen during this descent.
- Within the horizontal plane: the climate-perfect flight may require significant adjustments to the filled flight plan in order to take advantage of the most favorable winds but also to avoid the non-CO_2 effects.

Moreover, the time and vertical dimensions of this climate-perfect flight should be adjusted to take into account the specific performance of each individual aircraft and engine type – this performance varying with aging – but also the specific configuration of each flight, such as onboard weight and balance.

Whether they occur just before or during the flight, these adjustments make planning more complex, and require agile collaboration between pilots, controllers and airlines, and even airports.

Eco friendly flight operations are **complex to plan preflight** and require a far more significant and **agile collaboration** between pilots, controllers, airlines and airports **during their execution.**

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Finally, beyond collaboration challenges, the climate-perfect flight's continuous climb cruise involves crossing many altitude blocks, which could require controllers to adapt their ways of working. Likewise, climate change optimizations of the lateral trajectory may conflict with airline strategies for minimizing overflight fees[7].

Collaboration, a common practice in air transport

Setting-up frameworks to improve air transport efficiency through collaboration between players is old news. Such collaboration framework has indeed been successfully implemented in several areas:

- On the one hand, collaborative Decision Making (CDM) has been deployed at airport level to better manage aircraft turn around on ground through the involvement of airports, caterers, ANSPs, airlines. It has also been implemented at network level to manage the Single European Sky between ANSPs, Eurocontrol's Network Manager and airlines.
- On the other hand, a form of inflight collaboration already exists at airline level between crews and airlines' operational control centers.

Eco-friendly flight operations may thus involve the creation of a Climate/Environmental-related collaboration allowing pilots, controllers and airlines to collaborate during flight execution, reducing together the climate impact of flights in areas where and when eco-friendly operations are deployed.

> **Example: the Green Flag concept (2/4)**
>
> In the Green Flag example, this new type of climate/environmental-related collaboration could be activated when an area is declared in Green Flag by the ATC.

Collaboration between pilots, controllers and airlines could lead to the emergence of a **Climate/ Environment collaboration** in places with deployed **eco friendly operation application domains.**

Figure 3

An Operation Control Center (OCC) – American Airlines' OCC here – provides live support to crews during their flights in order to deal with disruptions such as bad weather, delays…

2.3. A TECHNICAL SOLUTION BASED ON DIGITAL TECHNOLOGIES

Within the framework of continuous efficiency improvement, airlines and ANSPs have set up specific processes and tools (often digital), outside the scope of critical systems and approved by specific processes. Such processes and could be extended within the framework of eco-friendly flight operations.

For instance:

- In the cockpit: Electronic Flight Bags (EFB) could host new applications to assist the pilot with the execution of these eco-friendly flight operations.
- In control centers: the digital applications that are being gradually deployed in order to support ATC could be extended to new functions dedicated to eco-friendly operations.

[7] For economic reasons, some airlines fly around areas with high overflight fees, significantly increasing the flight distance and therefore its ecological impact.

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These different digital tools could then be connected, taking benefit of the growing deployment of onboard connectivity. As such, they can serve as the basis for new collaborative optimizations between crews and controllers – or even between controllers themselves – in order to execute eco-friendly operations.

As the scope of eco-friendly operations expands to areas and periods of higher traffic, it may become necessary to connect and integrate these features into more criticalsystems – for example the onboard flight management system and/or ground-based ATM systems – in order to allow greater automation and reduce the workload of pilots and controllers.

> **Example: the Green Flag concept (3/4)**
>
> In the Green Flag example, this collaborative optimization enabled by the tools could be activated when an area is declared in Green Flag by the ATC.

Fast deployment of the type of **collaborative optimization** required to achieve eco friendly operations could be made possible by the connection of crew and controllers dedicated digital tools.

Figure 4

Example of an Electronic Flight Bag (EFB): specific processes support the approbation of the software running on this tablet.

2.4. A CONTINUOUS IMPROVEMENT PROCESS INSPIRED BY FLIGHT SAFETY

To maintain the highest standards in terms of flight safety, airlines and ANSPs have implemented a continuous improvement process through a Safety Management System (SMS).

> **The Safety Management System**
>
> According to ICAO, SMS "is defined as a systematic approach to managing safety, including the necessary organizational structures, accountabilities, policies and procedures". It relies on safety performance objectives, rather than compliance with regulations. Like a quality management system, it constantly monitors compliance with target performance, detects and analyzes deviations, and requires adjustments that may affect procedures, skills, organizations, or even equipment.

This SMS could be extended to include ecological objectives and thus become an ESMS (Environment and Safety Management System), or become a source of inspiration for the integration of flight operations into an EMS (Environmental Management System), such as the one recommended by the ISO 14001 standard and by the European Eco-Management and Audit Scheme (EMAS).

> **Example: the Green Flag concept (4/4)**
>
> In the Green Flag example, the **EMS** of the airline could for instance monitor its climate efficiency when Green Flags are activated. On the ANSP side, the EMS could for instance monitor the time spent in Green Flag and the ANSP climate efficiency when Green Flag is activated.

Deployment of eco friendly operations could rely on an **Environment Management System** inspired by the Safety Management System used for flight safety.

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3.
PROPOSAL 3: **MAKE ECO FRIENDLY OPERATIONS ECONOMICALLY VIABLE**

Tensions between economic interests and environmental goals, detailed in section 3.2 on page 15, shows that air transport players need to be supported to make eco-friendly operations economically viable. This support would probably involve players beyond the air transport ecosystem: governments, investors and even citizens. However, the large organizations that federate this ecosystem – IATA, ICAO… – also have a role to play because, as seen in section 3.1, they can be powerful drivers for change[8].

Initiating the ecological transition of flight operations within each local ecosystem requires thus to promote eco-friendly behavior among all stakeholders: airlines, ANSPs, airports, passengers, controllers, pilots, regulators… This section focuses on three of them: airlines, ANSPs and individuals – passengers, controllers and pilots. For each of them, we will try to identify meaningful levers for such engagement.

> **Dissociating ANSPs and airline ecological performance**
>
> While eco-friendly operations are a common goal shared by ANSPs and airlines, it might be useful to dissociate the contribution of each of them to monitor improvement separately. This is still a research question.or even equipment.

3.1. A CONTINUOUS IMPROVEMENT PROCESS INSPIRED BY FLIGHT SAFETY

Promotion of airlines' eco-friendly operations could be driven by three types of stakeholders: customers, investors, and regulators.

> ...Through customers

If they can make an informed airline choice, the growing population of passengers or corporations who care for their ecological impact could favor eco-friendly airlines and give them an economic advantage.

To inform airline customers, *Baumeister & Onkila, 2017* suggests establishing a label to allow:

- Customers to compare the ecological footprint of several flights,
- Airlines to communicate to the public about the ecological performance of their operations.

The operation part of such a label could be based on KPIs derived from the single source of truth. The environmental label under consideration at EASA is an example.

> **Specific label or existing label?**
>
> An alternative to a specific air transport label would consist of integrating KPIs characterizing environmental performance into existing labels, such as the Dow Jones Sustainability Index *S&P Global, 2020*, the Carbon Trust Standard *Carbon Trust, 2020* or the European EMAS system.

> ...Through investors

More and more investors are sensitive to the ecological dimension of their investments, whether they are traditional financial players[9] *Mooney & Temple-West, 2020*, or players in the "green" finance sector.

A specific environmental label or the upgrade of existing labels could also influence investors towards airlines with more eco-friendly behavior.

> ...Through regulators

Many countries or supranational organizations are studying, and some are even deploying, measures to promote eco-friendly behavior among air transport players.

These generally involve taxes or mandates:

- **Taxation-based solutions** aim at making eco-friendly behavior viable through economic incentives in the territory under their responsibility.

  As seen in section 3.3.1 on page 16 related to airlines' economic situation induced to the COVID crisis, tax increases do not seem credible in the short term. However, incentivization of eco-friendly behavior through the modulation of existing taxes is much more likely to succeed. Several existing taxes or fees are well suited to this type of approach, such as overflight and landing fees or eco-taxes on plane tickets that exist in some countries (for example in France since 2019).

  Those modulations could be based on KPIs derived from the single source of truth.

[8] For example, ICAO has implemented a worldwide system of compensation for air transport CO_2 emissions, known as CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation).
[9] For example Black Rock, the largest investment fund in the world, announced it was making sustainability its new standard for investing (Helmore, 2020).

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The fuel tax, an imperfect measure

While the idea of a fuel tax seems wise at first glance (CO_2 emissions are proportional to fuel burn), there are two limitations:

- The first is that reducing fuel burn does not always correlate with reducing climate impact, for example when reducing contrails and the cirrus clouds they induce.
- The second stems from the spread in fuel prices between countries, leading to competitive biases and nuisance practices such as tankering.

- **Constraint-based solutions** coerce a stakeholder to comply with obligations – for example in terms of emissions[10], processes, equipment… – threatening to limit or even revoke stakeholder's ability to operate in some airspace areas.

Air transport enforces this type of practice to ensure flight safety – for example equipment compliance, internal processes, operator qualification, and maintenance… – or to ensure proper integration within the ruled airspace (for example through requirements on aircraft navigation performance).

Strategies must be adapted to the realities of each local ecosystem; however, the most promising in terms of impact involves regulators **incentivizing eco friendly behavior through tax modulation.**

Two examples of constraint-based strategies

Regulations for condensation trails inspired by noise regulations:

- The principle of noise regulations is the following: aircraft must follow Noise Abatement Procedures; otherwise, they must pay fines. The same type of approach could apply to contrails and artificial cirrus clouds, requiring planes to follow avoidance procedures. Aircraft that do not respect such procedures would be fined based on their climate impacts according to the unique source of truth.

Environmental management regulations like safety management regulations:

- To ensure flight safety, regulators require stakeholders to implement safety management systems (SMS), and audit these systems for relevance. Regulators could mandate airlines to deploy environmental management systems (EMS), using the unique source of truth to quantify progress.

3.2. PROMOTE ECO FRIENDLY ANSP OPERATIONS

ANSPs are public or private entities in charge of regulating air traffic over a given geographic area. Their economic model is evolving and has gradually shifted from state-funded to airspace user-funded through airspace fees and even commercial services *Materna, 2019*.

The impact of ANSPs' ecological transition is very different from that of airlines. There is no direct conflict between ecology and economy for ANSPs as there is for airlines. Rather, what affects ANSPs is the implementation of measures to enable these climate-perfect flights, possibly increasing costs and/or reducing income:

- First, a climate-perfect flight requires more controller interactions with the aircraft, and therefore a higher workload – although tools such as the ones described in section 4.2.3 page 22 can mitigate this impact. It is therefore reasonable to think that a climate-perfect flight may actually cost more to control.
- Some measures can also affect a key metric of air traffic control, that is to say capacity. Indeed, capacity is a cornerstone of their economic model, since income increases with the number of airspace users. However, as seen in previous sections, a systematic deployment of more climate-perfect flights may require reducing traffic density, and therefore ANSPs' income.

There are thus two means to promote eco-friendly ANSP behavior:

- **Governance:** ANSPs currently commit to meet performance indicators such as punctuality; a first step would add indicators characterizing ecological performance based on the single source of truth.
- **Economic incentives:** Such incentivization could be given by states to offset increased costs and loss of revenue, as a function of ANSP climate-performance based on the single source of truth.

Short term measures involve integrating into the **governance** of ANSPs KPIs associated with the **climate impact of the regulated flight operations.**

3.3. PROMOTE ECO FRIENDLY INDIVIDUAL BEHAVIOR

The ecological transition is also a matter of individual behavior. Awareness of the climate impact of decisions made by everyone – passenger, pilot or controller – is potentially a powerful incentive.

[10] *For example, the ICAO CO_2 standard defines the minimum ecological performance required to authorize production of an aircraft (ICAO, 2017).*

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Passengers

Passenger awareness of a trip's climate impact – and thus the ability to compare various trip options – is a simple means to enable an actual change of behavior.

Besides the labeling of airlines suggested in section 4.3.1, new players – Google Flight, EasyVoyage, FlyGrn… – propose passengers climate impact comparisons for various travel options: means of transport combinations (land or air), itinerary, operator, all of which have an impact on CO_2 emissions (see box below).

> **From comparing flights to comparing travels**
>
> The complexity of the transport systems is a good reason for comparing travels:
>
> - It is irrelevant to compare the climate impact of two Paris to London flights, one departing from Orly and arriving at Heathrow and the other departing from Beauvais and arriving at Luton, without taking into account the land travel component: if it involves a combustion engine vehicle, the climate impact of this part of the trip may be equivalent to the air component.
> - Likewise, it may be better in terms of climate impact to take a direct flight from Marseille to Reunion Island with an older aircraft and less optimal operations, than to take a flight with a stopover, for example Paris, even if it is carried out with recent aircraft and more eco-friendly flight operations. This is because of the additional emissions induced by the extra distance, a second take-off ... And what if the optimal solution was a train trip from Marseille to Paris, then a flight to Reunion?
>
> These two examples highlight both the importance and complexity of a travel comparison.

However, these comparators rely on flat rates (see sections 4.1.2 relative to CO_2 calculator) and often provide inadequate results due to lack of data.

Therefore, "feeding" the flight part of these travel comparators – Google Flight, EasyVoyage, and FlyGrn… – with the single source of truth should provide a more relevant alternative to flat rate assessments:

- It provides passengers with a much more accurate awareness of true climate impact of the flight part of their trip.
- It gives airlines an opportunity to promote the eco-friendliness of their flight operations to passengers.

Replacing the flat rates used in **travel comparators with the single source of truth** is a simple way to entice passengers towards more eco friendly choices.

Pilots and controllers

Pilots and controllers are key stakeholders in ensuring the ecological transition of flight operations: making them aware of their own impact could thus be transformational.

Several tools could be derived from the single source of truth to achieve such result:

- For pilots, one can imagine a tool showing the ecological performance of their actual flight compared to a climate-perfect flight, possibly comparing this performance to their historical performance. Similarly, onboard decision support tools could be augmented with a continuous assessment of the climate footprint of each of their decision.

  Annual impact can take the form of a personal assessment, compared with previous years, or even compared with the average performance achieved within the airline.

- Similarly, for controllers, one can imagine a tool showing the climate performance of the controlled flight compared to climate-perfect flights. Controllers' digital decision support tools could also be augmented with a continuous assessment of the climate footprint of each of their decision.

  As for pilot, annual impact can take the form of a personal assessment, compared with previous years, or even compared with the average performance achieved within the control center.

Providing **pilots and controllers** with tools enabling them to **assess the climate impact of their decisions** is a simple and effective means to support their engagement in the ecological transition of flight operations.

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Conclusions

Eco-friendly flight operations have a significant theoretical potential for reducing the ecological footprint of air transport: about **10%** when taking into account only CO_2 effects, probably more than **20%** when including non-CO_2 effects. Unlike other approaches identified in the introduction, they also offer the advantage of allowing swift and large-scale action.

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THREE KEY PROPOSALS

To initiate a continuous improvement cycle, we introduce three proposals inspired by practices that have been shown to be very effective by the past to improve flight safety and operational performance:

- Proposal 1: `
  Implement and disseminate **a single source of truth for evaluating the climate impact** of emissions by any aircraft on any segment of its trajectory, controlled by a neutral and independent party.
- Proposal 2:
  Implement technical and operational solutions on ground and onboard for **the continuous improvement to the climate impact of flight operations** relying on the **collaboration between pilot and controllers.**
- Proposal 3:
  Implement strategies to **make eco-friendly operations viable** and promote eco-friendly behavior of airlines, ANSPs and individuals.

AN INCREMENTAL APPROACH TO INITIATE THE TRANSITION IMMEDIATELY

To initiate the ecological transition of operations as soon as possible, we recommend mobilizing local ecosystems including airlines, ANSPs and regulators wishing to make a collective commitment to reduce their climate footprint.

This concern for speed leads to the following recommendations for the implementation of the three proposals:

- Regarding proposal 1:
  Start with the better-known effects, and set up a **single source truth for the non-collaborative assessment of CO_2 effects.**
- Regarding proposal 2:
  In each ecosystem, favor **quick and incremental ground and onboard digital approaches,** independent of critical systems, drawing inspiration from those deployed in the field of operational performance: EFB and digital controller tools.
- Regarding proposal 3:
  Define conditions for **fast implementation** tailored to the dynamics of **each ecosystem.**
  Communicate to passengers and investors on the ecological performance of the various parties. Provide measurements of their impact to the various parties, and **incentivize airlines and ANSP** to favor eco-friendly behavior.

Reducing the ecological footprint of air transport by 10% seems a goal **within reach,** if the willingness of **key local ecosystems** – airlines, ANSPs, regulators – to engage in the ecological transition of operations is leveraged to initiate a continuous improvement cycle.

By showing **practical results,** their example will pave the way to **larger deployment** and thus to greater impact.

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Appendices

BETTER UNDERSTANDING THE CLIMATE IMPACT OF AVIATION

This appendix describes in detail the different elements used to measure the climate impact of an emission and their mutual relationships: radiative forcing, effective radiative forcing, concentration trajectories, global warming and temperature change potential. It then introduces the reference climate models used to calculate the impact of CO_2, NO_X and contrails.

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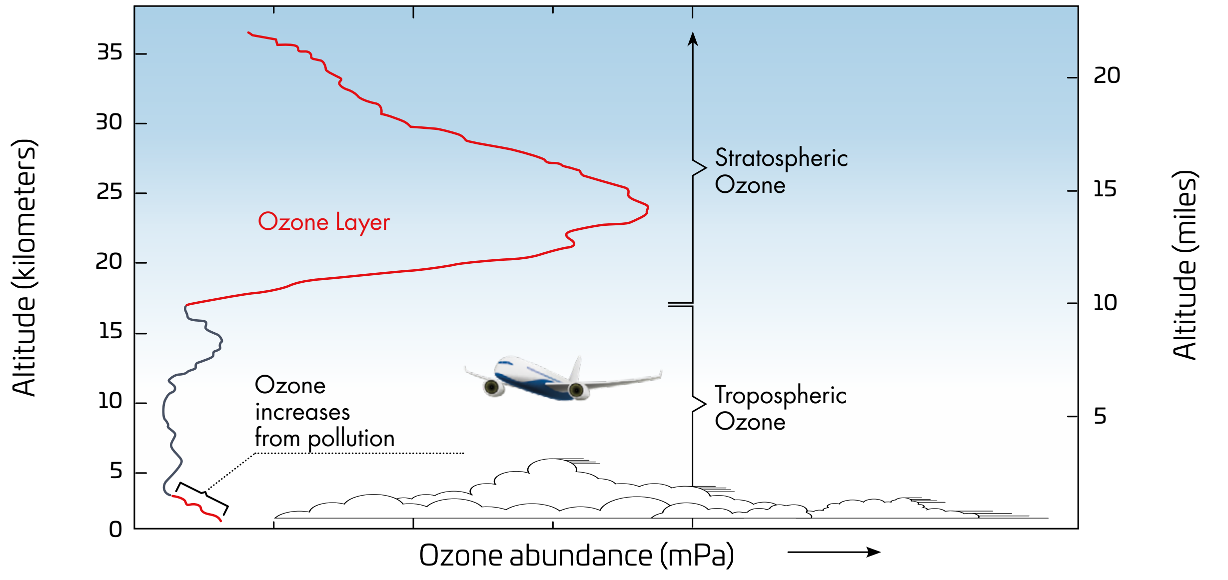
A.1. RADIATIVE FORCING

Radiative forcing (RF) can be conceptually defined as a change in the energy equilibrium of earth system, caused by a perturbation – gas or aerosol emission. It is a flux expressed in $W.m^{-2}$.

In a quantitative way, RF is therefore an incident flux difference caused by a perturbation on Top of Atmosphere (TOA) or at the tropopause.

Figure 5

Ozone abundance in the atmosphere as a function of altitude (Atmosphere Monitoring Service, 2020)

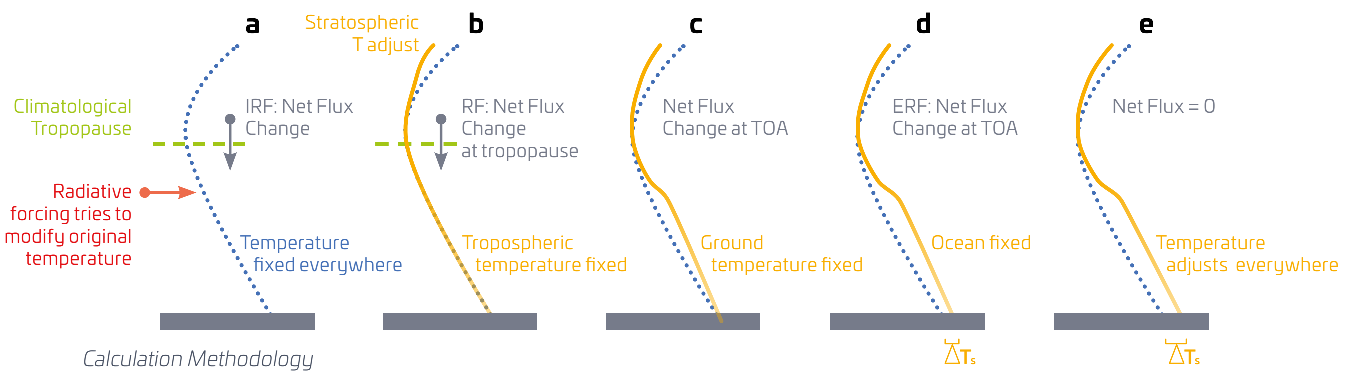


The energy state of the Earth's climate system results from the difference between the radiative power flux incoming from the sun and that reflected or emitted by the earth. Disturbances cause the system to shift towards a new equilibrium, with measurable changes in temperature at different altitudes.

The following figure shows different boundary conditions for the return to equilibrium.

Figure 6

Altitude vs. temperature graphs showing different boundary conditions for the return to equilibrium



Radiative Forcing (RF) and Effective Radiative Forcing (ERF) correspond to two types of boundary conditions, described in the table below.

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Table 1

Boundary conditions corresponding to radiative forcing and effective radiative forcing.

	RF	ERF
Altitude	Tropopause	TOA
Free variables	Stratosphere temperature - Water vapor - Cloud cover - Surface temperature	- Atmosphere temperature
Fixed variables	- Surface temperature - Troposphere temperature - Water vapor - Cloud cover	- Surface temperature (partially)

The ERF/RF ratio is sometimes used to characterize which element is most disturbed, such as surface temperature.

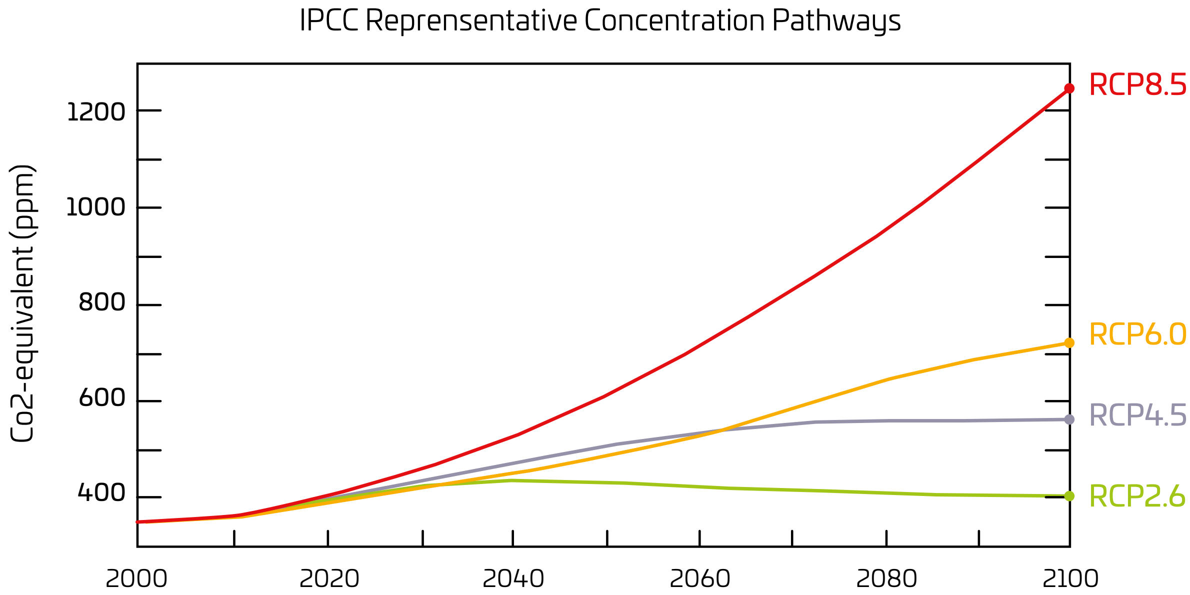
A.2. REPRESENTATIVE CONCENTRATION PATHWAY

In its fifth report, IPCC established four RCP (Representative Concentration Pathway) trajectory scenarios of radiative forcing to the 2100 horizon *Intergovernmental Panel on Climate Change, 2014.*

Each RCP scenario forecast climate changes likely to result from different assumptions regarding greenhouse gas emission over this century. Their names correspond to the predicted radiative forcing reached in 2100: the RCP2.6 scenario corresponds to a radiative forcing of +2.6 $W.m^{-2}$, the RCP4.5 scenario to +4.5 $W.m^{-2}$, and so on for RCP6 and RCP8.5 scenarios.spreading over wide areas (see figure below).

Figure 7

The four RCP scenarios considered by the IPCC (Intergovernmental Panel on Climate Change, 2014)



Each RCP scenario has different effects, as shown in the following table. The climate community widely deems the RCP8.5 scenario (also called "business as usual") as unlikely, because of climate actions already undertaken. RCP4.5 roughly matches current global warming trends, while climate agreements aim for RCP2.6 or better.

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Table 2

Changes in temperature and sea level for each RCP scenario, according to IPCC (Intergovernmental Panel on Climate Change, 2014).

Scenario	Temperature change (°C)	Sea level rise (m)
RCP 2.6	+0,3°C to +1,7°C	+0,26m to +0,55m
RCP 4.5	+1,1°C to +2,6°C	+0,32m to +0,63m
RCP 6.0	+1,4°C to +3,1°C	+0,33m to +0,63m
RCP 8.5	+2,6°C to +4,8°C	+0,45m to +0,82m

A.3. CALCULATIONS

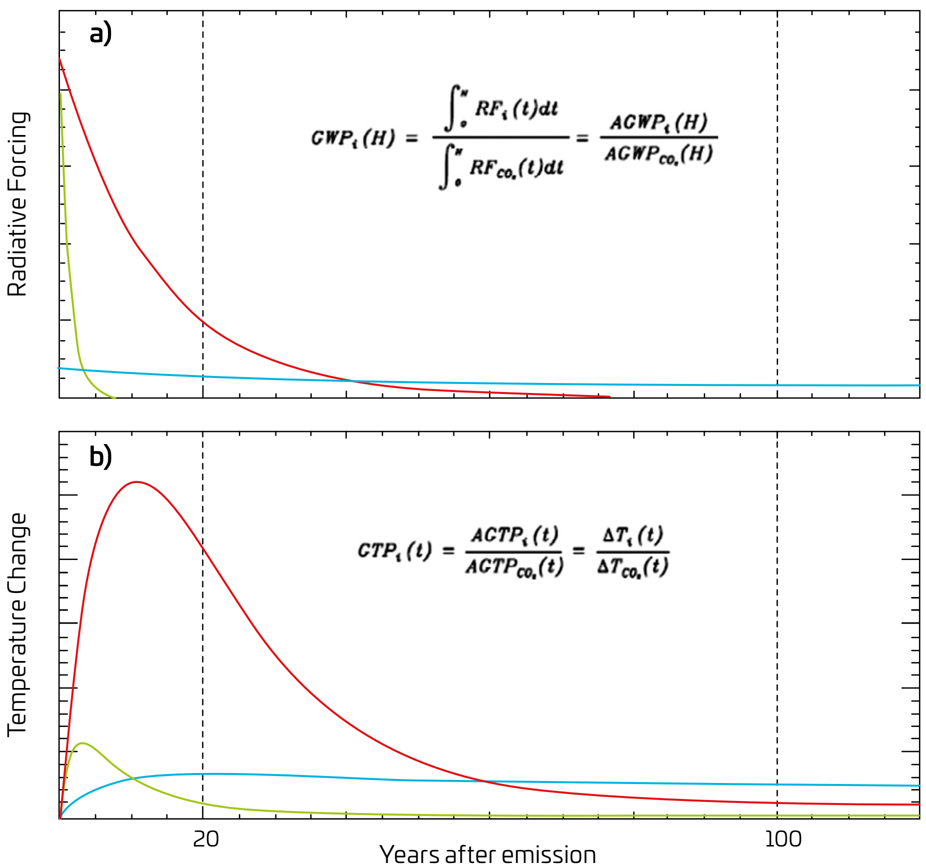
Climate change estimate can range over different time horizons, typically 20 to 100 years.

The Global Warming Potential (GWP) represents the overall energy added to the climate system because of pollution, compared to reference CO_2 emissions. In figure 6, the blue curve represents the radiative forcing of CO_2 in time, the green and red curves that of other pollution with shorter but more intense effects. GWP is the integration of radiative forcing over the considered period, and gives the equivalent CO_2 (CO_2-eq) emissions to various pollutions over a given period.

The Global Temperature change Potential (GTP) represents the global average change in surface temperature at a given time in response to a pulse of given type of emissions compared to CO_2.

Figure 8

Global Warming Potential (GWP) and Global Temperature change Potential (GTP) according to (Intergovernmental Panel on Climate Change, 2014)



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A.4. APPLICATION TO AIR TRANSPORT

Air traffic emissions include emissions of CO_2, NO_X, water vapor, contrails cirrus, aerosols and soot. The RF can be calculated from changes in emission concentration in the atmosphere, or attenuation of solar radiation, especially when complex phenomena are involved (interactions, exchanges...).

› RF calculation for CO_2 and associated uncertainty

The RF of CO_2 is a function of fuel burn, according to the stoichiometric coefficients of the combustion reaction[11]. The CO_2 dilutes in the atmosphere and results in a concentration measured in parts per million (ppm).

Natural sinks capture the CO_2 according to kinetics approximated by Impulse Response Function (IRF) models. The Beer-Lambert formula thus computes the RF:

$$RF = \alpha . \ln \left(\frac{C_0 + \Delta C}{C_0} \right)$$

Where C_0 is the reference concentration in 1940 and α is a constant equal to 5.35 $W.m^{-2}$ *Myrhe, Highwood, Shine, & Stordal, 1998.*

For each year, given the quantity of fuel burn, we can deduce CO_2 emissions, the resulting CO_2 concentration in the atmosphere, and the IRF, which can predict CO_2 concentration over time. We can finally integrate the latter over the chosen duration.

When *Lee, et al., 2020* identify an average RF of 34 $mW.m^{-2}$, it corresponds to the RF of CO_2 accumulated between 1940 et 2018 in the atmosphere, deduction made of the CO_2 captured by natural sinks.

In addition to fuel burn uncertainties, calculation uncertainties arise in the atmosphere carbon cycle and carbon capture impulse response models.

› RF calculation for NO_X and associated uncertainty

In atmospheric chemistry, NO_X refers to the sum of NO and NO_2. In the presence of light, two cycles of coupled chemical reactions between NO_X and HO_X produce ozone (O_3) and consume methane (CH_4) and carbon monoxide (CO) *Isaksen, et al., 2014*. These well-known phenomena lead to positive forcing for ozone and negative forcing for methane.

Models with different biases exist, to account for both short-term and long-term effects. They lead to a high degree of uncertainty in the estimates and the when combining the two effects.

› RF calculation for contrails, and associated uncertainty

Aviation creates artificial clouds induced by the formation of contrails in an atmosphere supersaturated with ice[12] through nucleation, mainly on combustion soot particles. There are two disturbances: linear contrails and artificial cirrus resulting from their fusion.

Calculating the RF of contrails and the artificial cirrus clouds they induce relies on a global climate model. Required inputs include cloud cover, volume and length of the trail, the ice/water ratio and the concentration of ice crystals. A reference model is the ECHAM5-CCMod *Bickel, Ponater, Bock, Burkhardt, & Reineke, 2020*. There are two types of uncertainties:

- › The response of artificial cirrus clouds to solar illumination (flux transfer model in particular in the presence of ice crystals, cloud homogeneity, impact of the presence of soot),
- › Mechanisms of formation of artificial cirrus from contrails (supersaturation rate, lifetime, interactions with natural clouds).

[11] *The commonly used ratio is 3.16kg of CO^2 emissions per kilogram of kerosene burned (Graver, Zhang, & Rutherford, 2018).*
[12] *Quenching a saturated solution results in a supersaturated solution.*

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A.2. ABBREVIATIONS

- **AIC**
  Aircraft Induced Cloudiness (cloud formation induced by combustion soot)
- **ANSP**
  Air Navigation Service Providers
- **APU**
  Auxiliary Power Unit
- **ATAG**
  Air Transport Action Group
- **ATM**
  Air Traffic Management
- **ATSU**
  Air Traffic Service Unit
- **CDM**
  Collaborative Decision Making
- **CORSIA**
  Carbon Offsetting and Reduction Scheme for International Aviation
- **DLR**
  German Aerospace Center (Deutsches Zentrum für Luft- und Raumfahrt e.V.)
- **EASA**
  European Aviation Safety Agency
- **EFB**
  Electronic Flight Bag
- **EMAS**
  Eco-Management and Audit Scheme
- **ERF**
  Effective Radiative Forcing
- **ETS**
  European Emission Trading System
- **FABEC**
  Functional Airspace Block – Europe Central
- **FMS**
  Flight Management System
- **GHG**
  Green House Gases
- **Gt**
  Gigatons (106 metric tons)
- **GTP**
  Global Temperature change Potential
- **GWP**
  Global Warming Potential
- **ICAO**
  International Civil Aviation Organization
- **ICCT**
  International Council for Clean Transportation
- **IPCC**
  Intergovernmental Panel on Climate Change
- **IRF**
  Impulse Response Function
- **KPI**
  Key Performance Indicator
- **LCC**
  Low-Cost Carrier
- **MODIS**
  Moderate Resolution Imaging Spectroradiometer
- **NM**
  Nautical Mile
- **RCP**
  Representative Concentration Pathway
- **RF**
  Radiative Forcing
- **RPK**
  Revenue Passenger Kilometers
- **RTK**
  Revenue Ton Kilometers
- **SAF**
  Sustainable Aviation Fuel
- **SESAR**
  Single European Sky ATM Research
- **SMS**
  Safety Management System
- **SSOT**
  Single Source of Truth
- **TOA**
  Top Of Atmosphere

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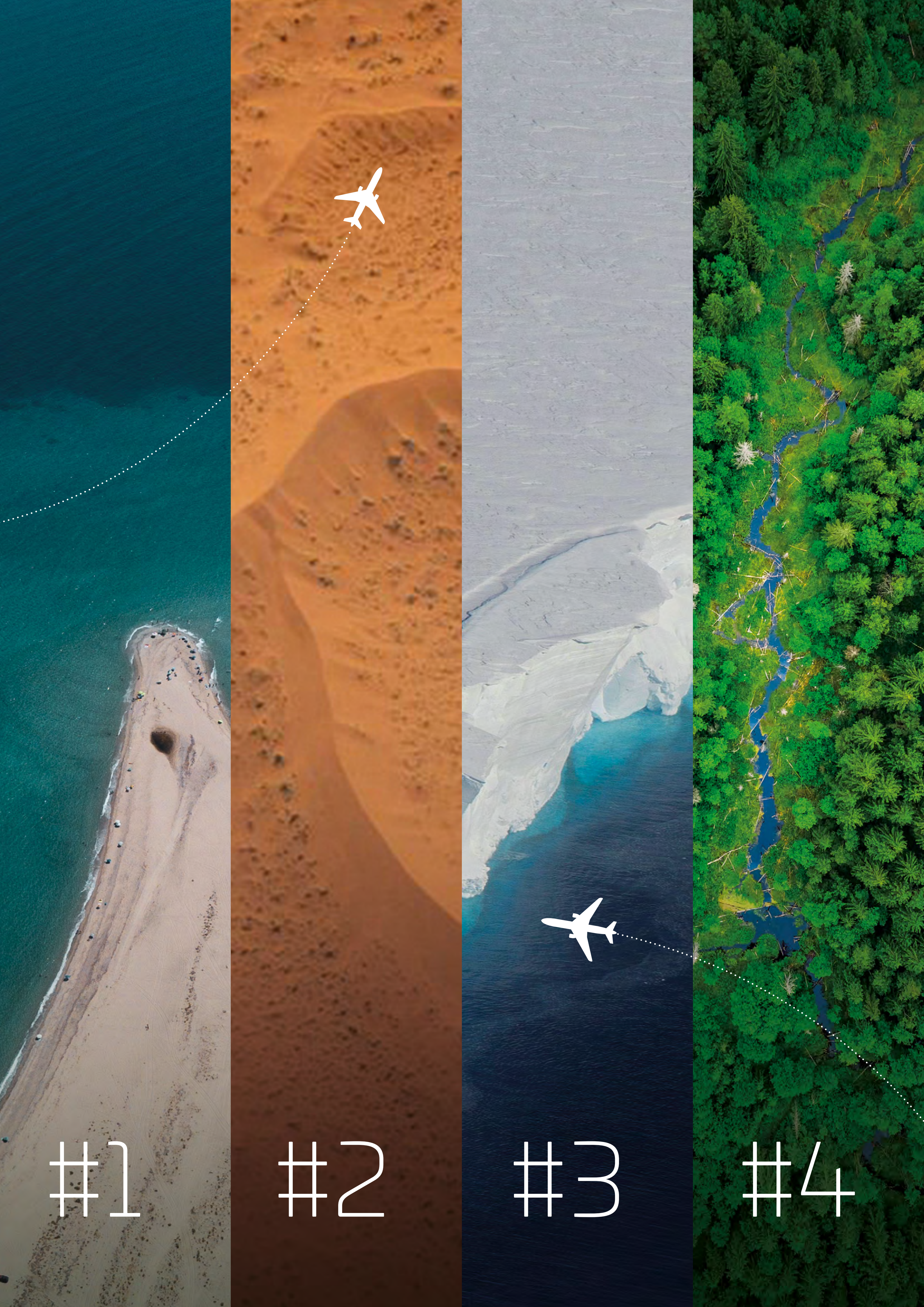
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