Sustainable climate scenarios for air transport

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Presentation of the session

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Agenda of this session

1. Presentation of climate issues specific to aviation and the CAST tool (30min)
2. Practical application of the CAST tool to simulate different scenarios (2h)

Summary

1. *Climate change challenge*
2. *Aviation and climate*
3. *Use of the CAST tool*

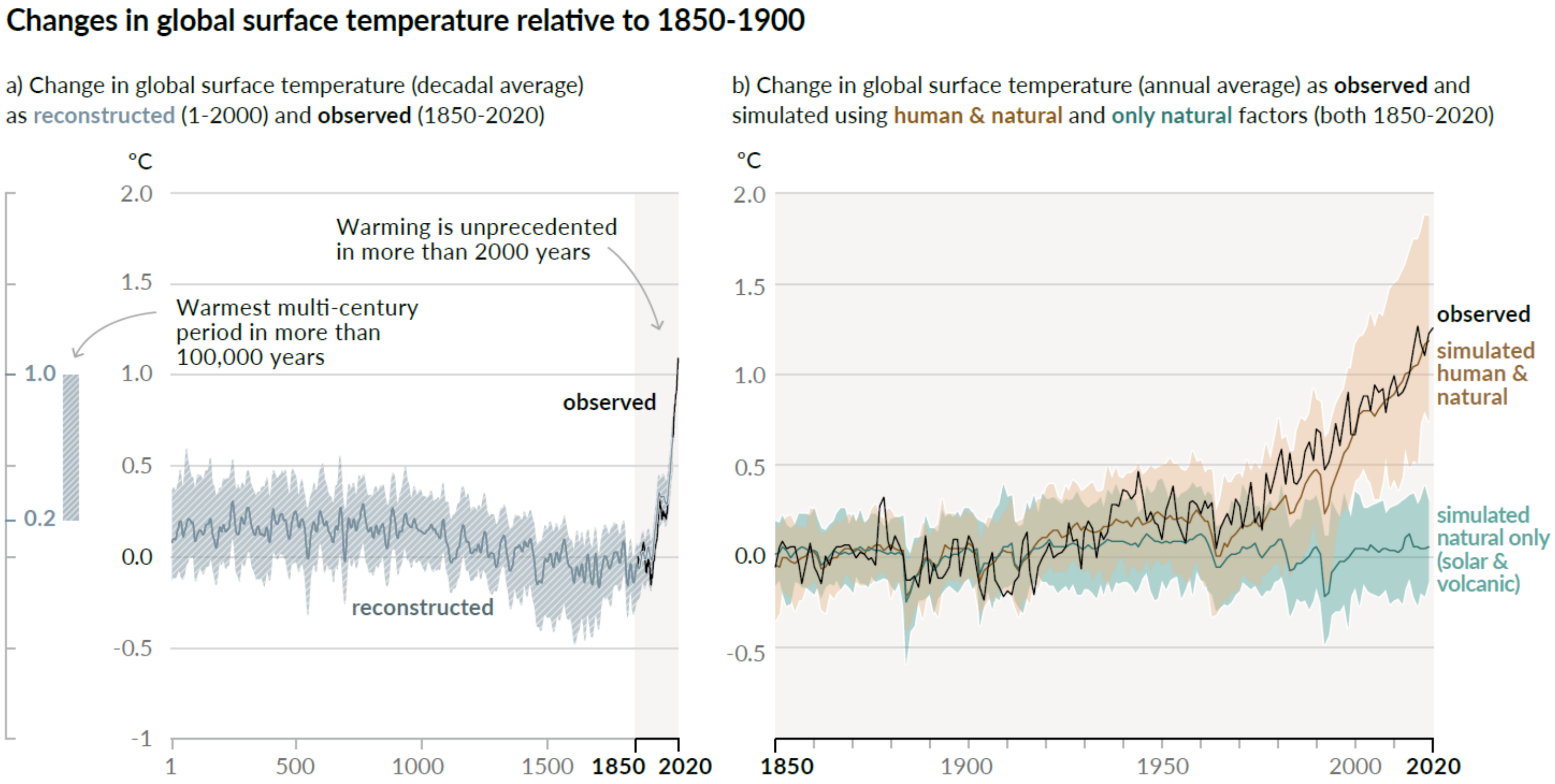
Climate change challenge

Global warming and its causes

Climate commitments

Concept of carbon budget

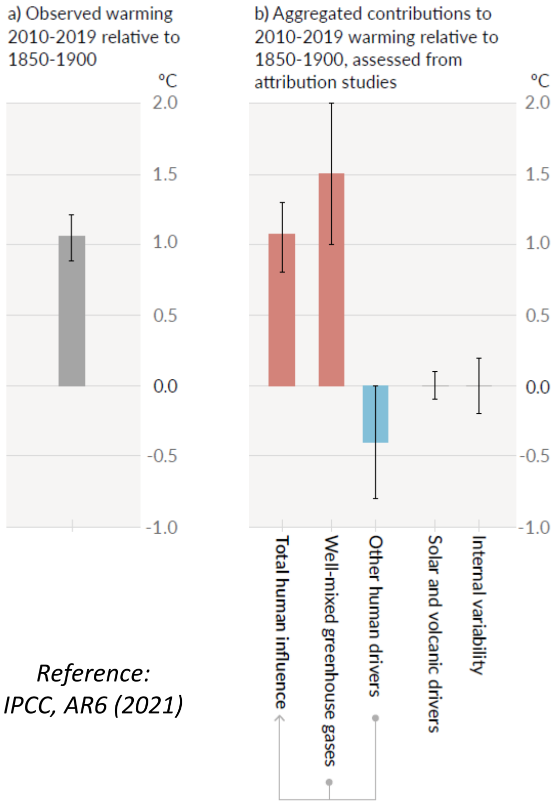
Observed and modeled global warming



Reference: IPCC, AR6 (2021)

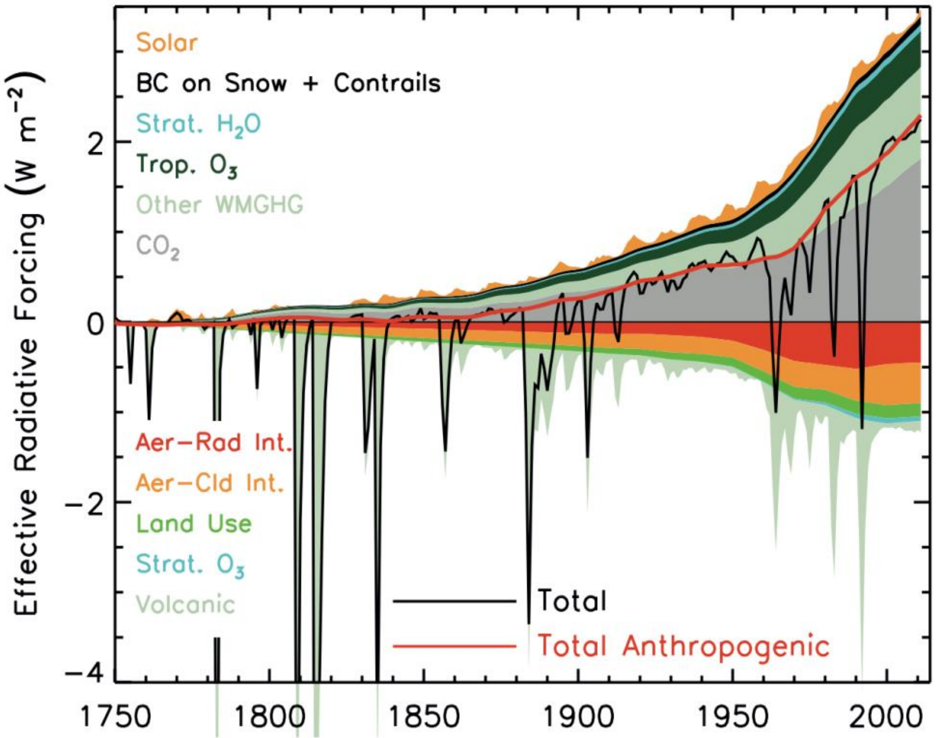
Climate change causes

Contributions to global warming



Reference: IPCC, AR6 (2021)

Evolution of effective radiative forcing (ERF) since 1750

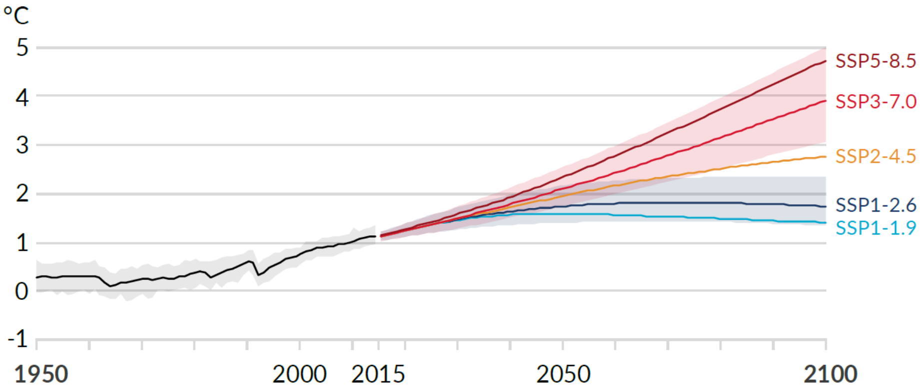


Reference: IPCC, AR5 (2013)

Future evolution and et climate commitments

Different scenarios of global surface temperature evolution

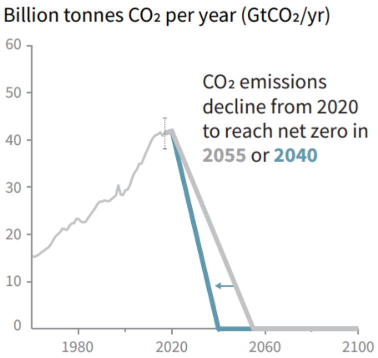
Reference: IPCC, AR6 (2021)



COP21 · CMP11
PARIS 2015
UN CLIMATE CHANGE CONFERENCE

Paris Agreement
Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C

Reduce our emissions



Concept of carbon budget

Definition of a carbon budget

Amount of CO_2 that can still be emitted globally to remain below a limit temperature (e.g. for +2°C)

Carbon budget values

Starting in 2020, for different uncertainties for the TCRE coefficient

Limit temperature	Carbon budget (50%)	Carbon budget (67%)
+1.5°C	500 Gt	400 Gt
+2°C	1350 Gt	1150 Gt

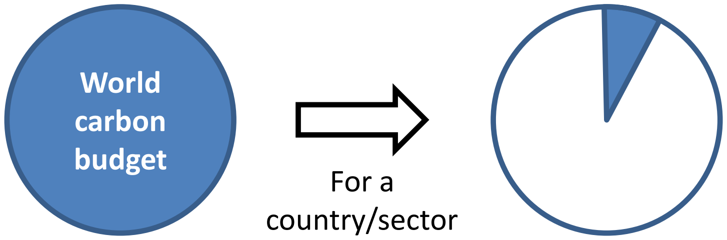
Reference : IPCC, AR6 (2021)

Carbon budget allocation

Allocation rules between countries/sectors
→ Complex political choice

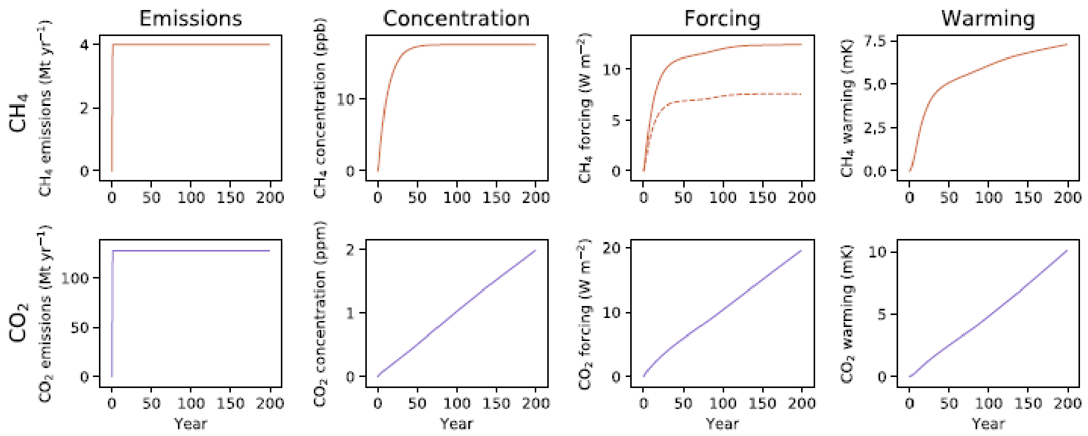
The simplest assumption
→ If a country/sector represents 5% of emissions, it is allocated 5% of the world carbon budget

Distribution taking into account other aspects
→ Social, economy, technology…



Concept of GWP/GWP*

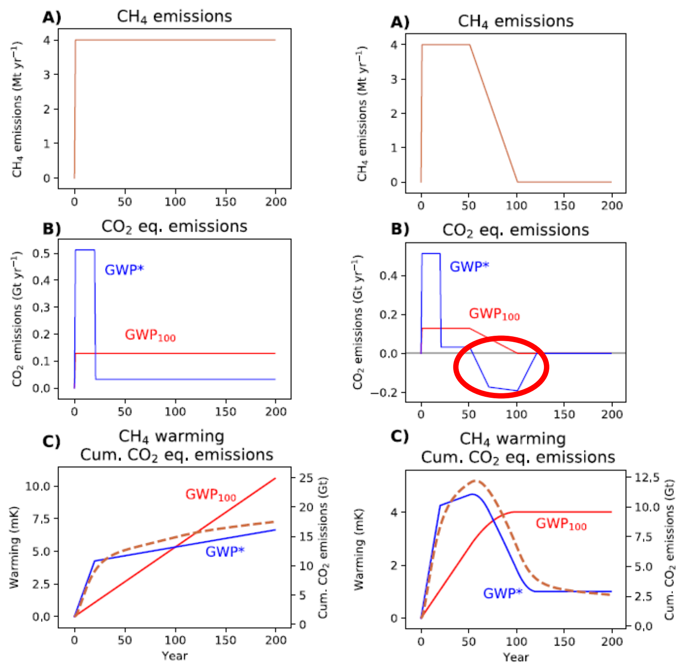
Comparison of short- and long-lived GHGs



$$\text{GWP} \rightarrow GWP(H) = \frac{\int_0^H RF_G(t)dt}{\int_0^H RF_{CO_2}(t)dt} \Rightarrow E_{CO_2eq}(H) = E_G.GWP(H)$$

$$\text{GWP*} \rightarrow E_{CO_2eq*}(H) = \frac{\Delta E}{\Delta t}.GWP(H).H = \frac{\Delta F}{\Delta t}.\frac{H}{\int_0^H RF_{CO_2}(t)dt}$$

GWP/GWP* for short-lived GHGs



Reference : Lynch et al. (2020)

Aviation and climate

Climate effects of aviation

Aviation commitments

CO_2 emissions from air transport

Methodological framework

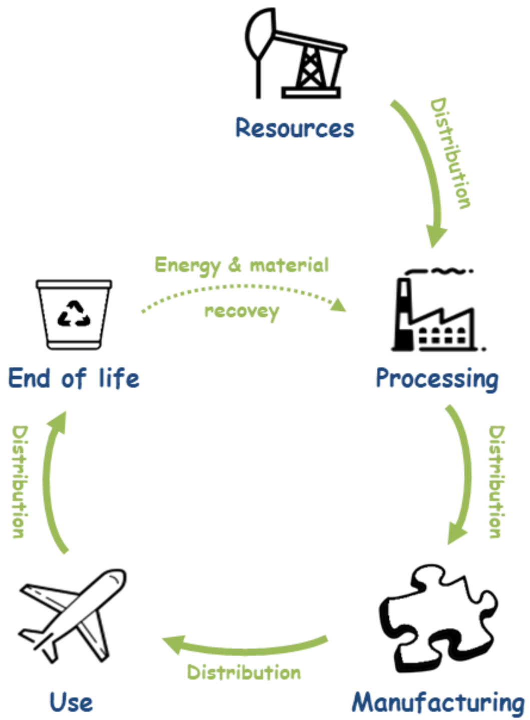
- Perimeter considered for kerosene consumption (IEA)
  → Only commercial aviation, excluding military (8%) and private (4%)

- Direct emissions → Kerosene combustion
- Global emissions → Kerosene combustion (81%) + Kerosene production (17%) + Rest of the life cycle (2%)

CO_2 emissions	Direct	Global
Values in 2019	921 Mt	1134 Mt
Error with ATAG	0,6 %	-

The different sources can be found directly on CAST, the tool that will be presented in the following

Aircraft life cycle



Historical evolution : Kaya equation for aviation

Adaptation of the Kaya equation to aviation

$$CO_2 = RPK \times \frac{ASK}{RPK} \times \frac{E}{ASK} \times \frac{CO_2}{E}$$

Revenue Passenger Kilometer

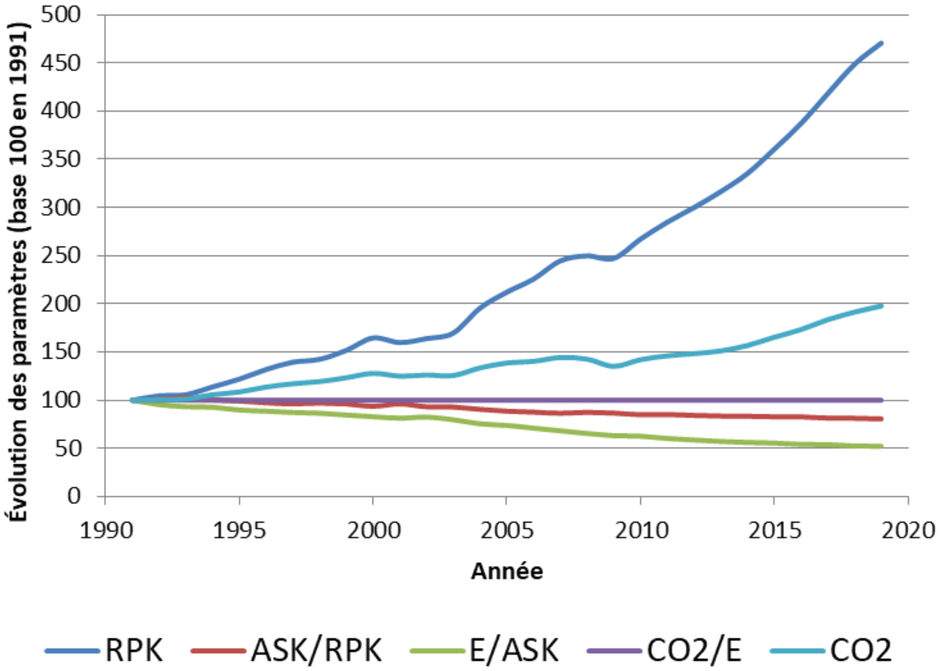
Reverse of the load factor

Energy by Seat.km

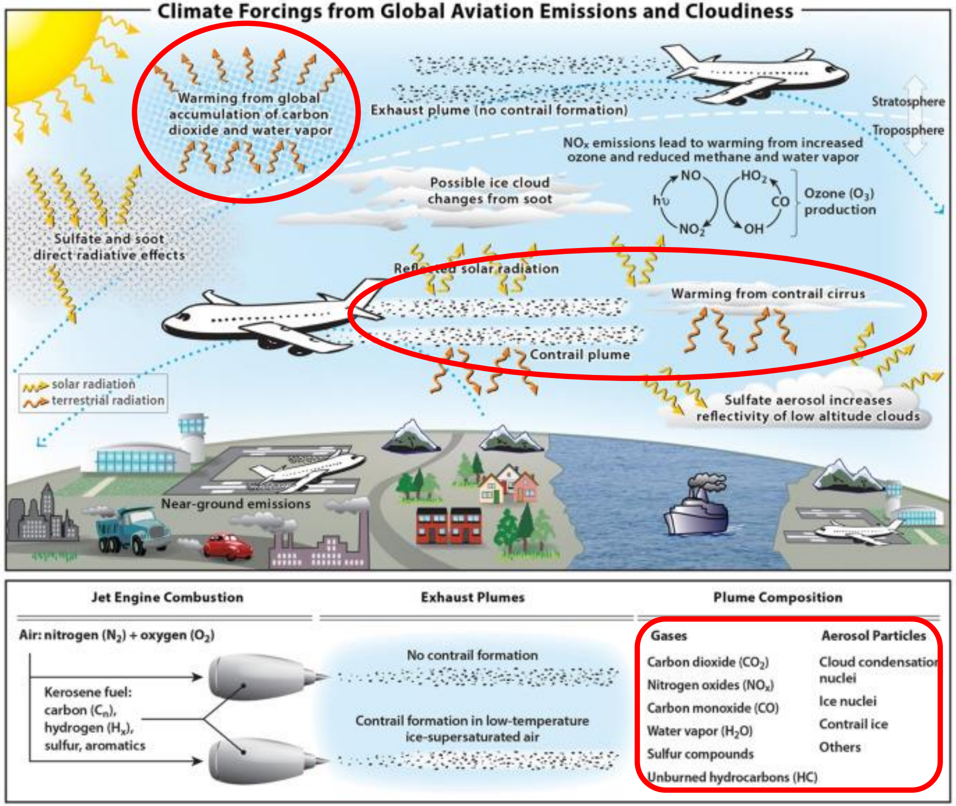
CO_2 content of energy

Historical of Kaya equation for aviation

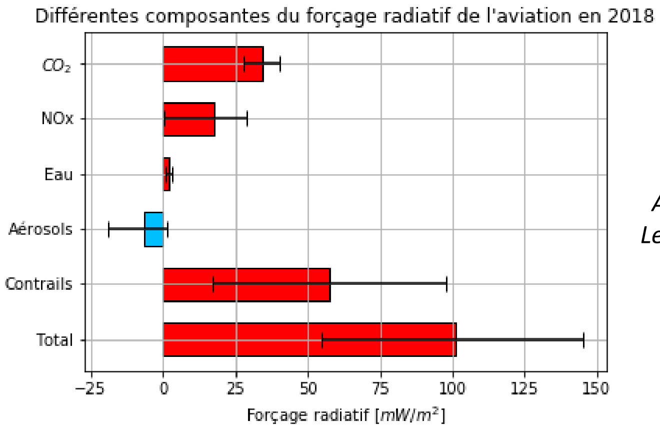
References: IEA, ICAO



Climate impacts of aviation



Reference: Lee et al. (2020)



Adapted from Lee et al. (2020)

1/3 CO_2 effect (long-term)

2/3 non-CO_2 effect (short-term)

The climate impact of aviation in figures

Several figures that coexist

Perimeter

→ Direct/Global: Only global emissions here

Physical phenomena

- CO_2 emissions
- ERF (including non-CO_2 effects)

Temporality

- "Historical " impact: we count the emissions since the beginning of human industrial activities (1750)
- "Recent" impact: emissions are counted over a recent period
  - Reference year for CO_2: 2019
  - Reference period for the ERF: 2000-2018

Key figures in the world

World CO_2 emissions in 2019: $43{,}1\ Gt$
Reference: Global Carbon Project

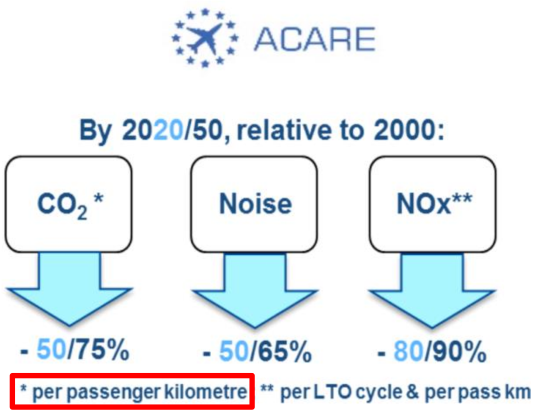
Anthropogenic ERF in 2011: $2{,}29\ W/m^2$
Reference: IPCC, AR5 (2013)

Summary table

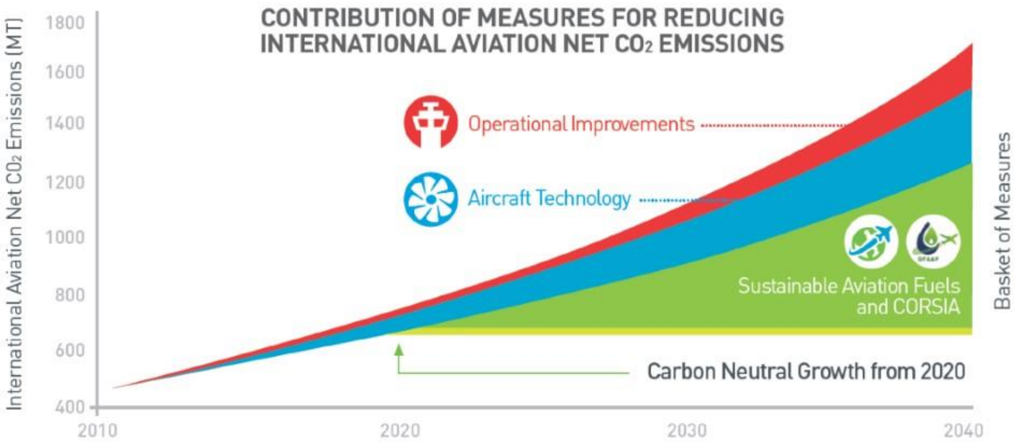
Physical phenomena	Historical	Recent
CO_2	1.5%	2.6%
ERF	3.8%	5.1%

Commitments to reduce aviation emissions

Commitments from ACARE
Advisory Council for Aviation Research and innovation in Europe



Commitments from ICAO
International Civil Aviation Organization



Other mechanisms exist

- In Europe: Emissions Trading Scheme (EU ETS)
- ATAG (*Air Transport Action Group*) : -50% less CO_2 emissions in 2050 than in 2005

Use of the CAST tool

Presentation of the tool

CAST methodology

Illustrative scenarios

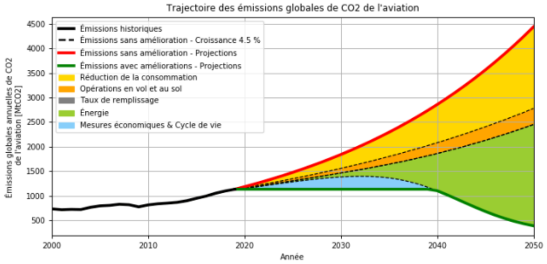
Development of a specific tool

CAST (*Climate and Aviation – Sustainable Trajectories*)

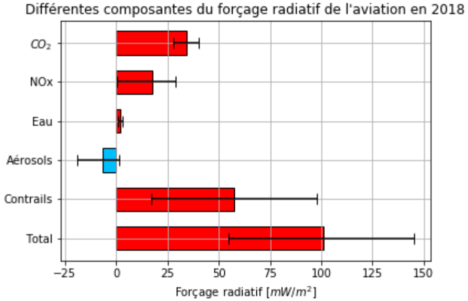
https://cast.isae-supaero.fr

Defining aviation trajectories that respect the Paris Agreement
Developed at ISAE-SUPAERO in Python programming language
Interactive, educational and freely accessible

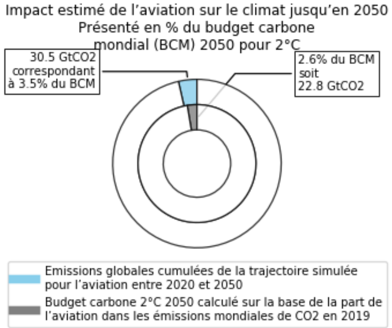
1 Simulation of different trajectories for aviation



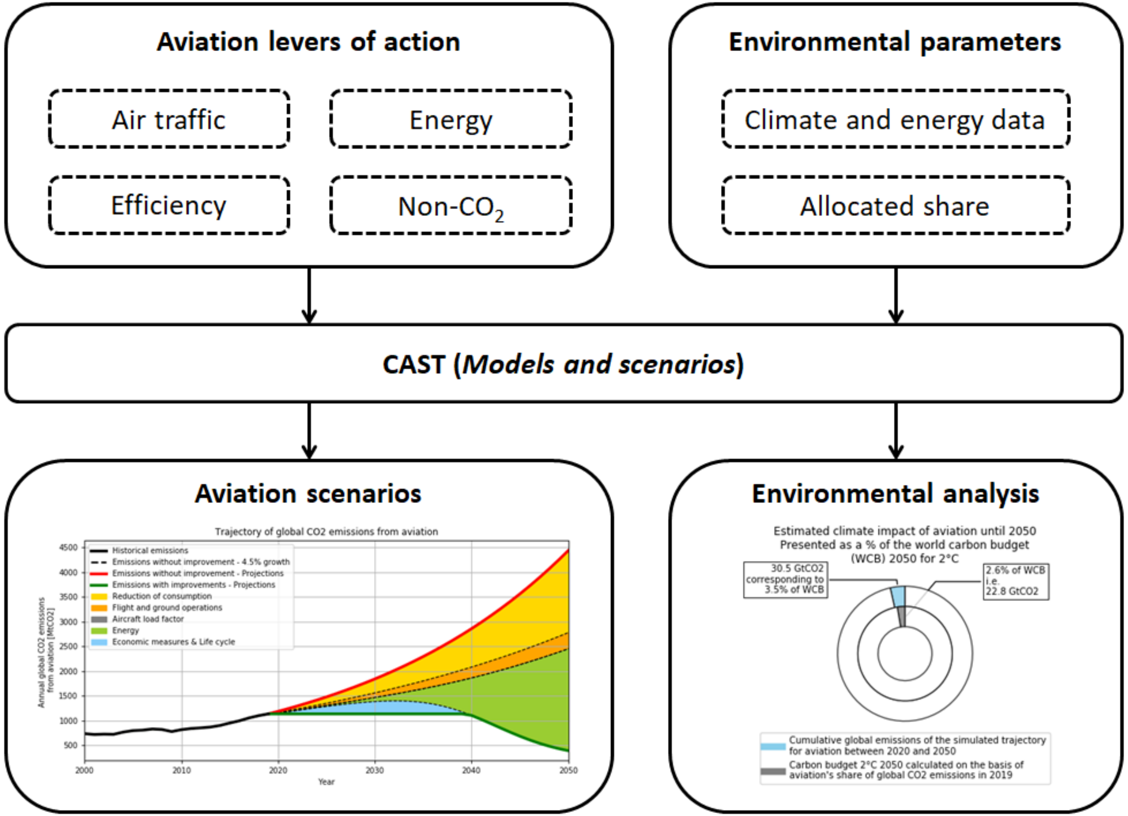
2 Assessment of environmental impacts of aviation



3 Analysis with regard to climate and energy issues



Architecture of CAST



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Tool presentation

CAST : *Climate and Aviation - Sustainable Trajectories*

Simulate your climate trajectories for aviation - Simulez vos trajectoires climatiques pour l'aviation

Beta

Français

Présentation | Tutoriel | Simulateur | Données | Documentation

Présentation de CAST

L'outil CAST (*Climate and Aviation - Sustainable Trajectories*) permet de générer des trajectoires pour l'aviation compatibles avec les accords de Paris sur le climat. Les objectifs généraux sont d'évaluer les impacts climatiques de l'aviation, de simuler des trajectoires pour l'aviation en jouant sur différents leviers d'action et d'analyser ces trajectoires au regard des enjeux climatiques.
L'outil se décompose en 5 onglets principaux :

- **Présentation** sensibilise au changement climatique et à l'impact de l'aviation
- **Tutoriel** permet de guider l'utilisateur dans sa manipulation du simulateur
- **Simulateur** permet de simuler des trajectoires climatiques pour l'aviation et de les évaluer
- **Données** fournit les données d'entrée et les résultats du simulateur
- **Documentation** détaille l'ensemble des notions, modélisations et scénarios du simulateur

Le défi climatique

Les activités humaines causent de multiples impacts environnementaux, un des plus connus étant le changement climatique. Ce dernier est majoritairement dû à nos émissions de gaz à effet de serre (GES), notamment le dioxyde de carbone (CO_2).
Pour évaluer l'impact sur le climat d'un phénomène physique, les climatologues utilisent la notion de forçage radiatif (en W/m^2). Un forçage radiatif positif induit un réchauffement, alors qu'un forçage radiatif négatif induit un refroidissement. Par exemple, émettre des GES dans l'atmosphère génère un forçage radiatif positif donc un réchauffement climatique. Plus on en émet, plus la planète se réchauffe.
Dans le cadre des accords de Paris sur le climat, les États se sont engagés à limiter le réchauffement climatique nettement en dessous de 2°C par rapport aux niveaux préindustriels et de poursuivre l'action menée pour limiter l'élévation des températures à 1,5°C. Pour cela, il faut réduire rapidement nos émissions de GES.
Un outil de mesure intéressant pour quantifier ces engagements est le budget carbone. Ce budget représente la quantité totale de CO_2 que l'on peut encore émettre pour limiter le réchauffement climatique à une certaine température (par exemple +2°C). Ce budget peut être calculé pour un pays ou un secteur d'activité et l'analyse de ce budget peut permettre d'élaborer des trajectoires de transition.

L'impact de l'aviation

Les impacts environnementaux de l'aviation peuvent être directs (lors de la phase de vol d'un avion) ou indirects (lors de l'ensemble du cycle de vie, hors phases de vol). Les impacts globaux représentent l'ensemble des impacts directs et indirects. D'un point de vue climatique, l'aviation génère de multiples effets :

- Des émissions de CO_2 (GES) directes (combustion du carburant) ou indirectes (production du carburant, infrastructures...)
- Des émissions de NOx en altitude qui interagissent avec d'autres gaz atmosphériques
- Des émissions de vapeur d'eau (GES) en altitude
- Des aérosols issus de particules fines et d'oxydes de soufre (SOx) des moteurs
- Des traînées de condensation ou *contrails* qui sont les traces blanches visibles dans certaines conditions dans le sillage des avions en vol

La figure ci-dessous, adaptée des travaux de Lee et al., récapitule ces différents impacts en utilisant la notion de forçage radiatif. Les phénomènes au forçage radiatif positif (en rouge) réchauffent la planète au contraire des autres (en bleu) qui la refroidissent. Au global, le secteur aérien génère un forçage positif et donc un réchauffement climatique. La responsabilité de l'aviation dans le changement climatique est estimée entre 3 et 4%.

Sustainable carbon trajectories

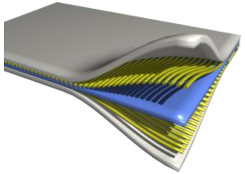
Balancing cumulative CO_2 emissions determined by levers of action...

1. Air traffic → *Level of air traffic (de)growth*
2. Energy efficiency → *See box*
3. Alternative fuels → *Biofuels, electrofuels, hydrogen*
4. Carbon offsetting → *Complex and hybrid*

... with a carbon budget allocated to aviation

Choice of an objective and an allocation rule

By default: 2.6%



Materials

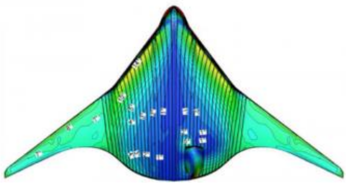
Subsystems electrification

Routes

Airports

Motorization

Hybridization/Electrification



New architectures

Load factor

Sustainable climate trajectories

Balancing cumulative "equivalent" emissions via GWP*...

Different levers of action that can be used

1. Level of air traffic
2. Energy efficieny
3. Alternative fuels
4. Offsetting (hybrid)
5. Strategies for non-CO_2 effects

Contrails :
Reduce the size and number of particles

Contrails :
Change altitude locally

NOx :
Reduce emissions

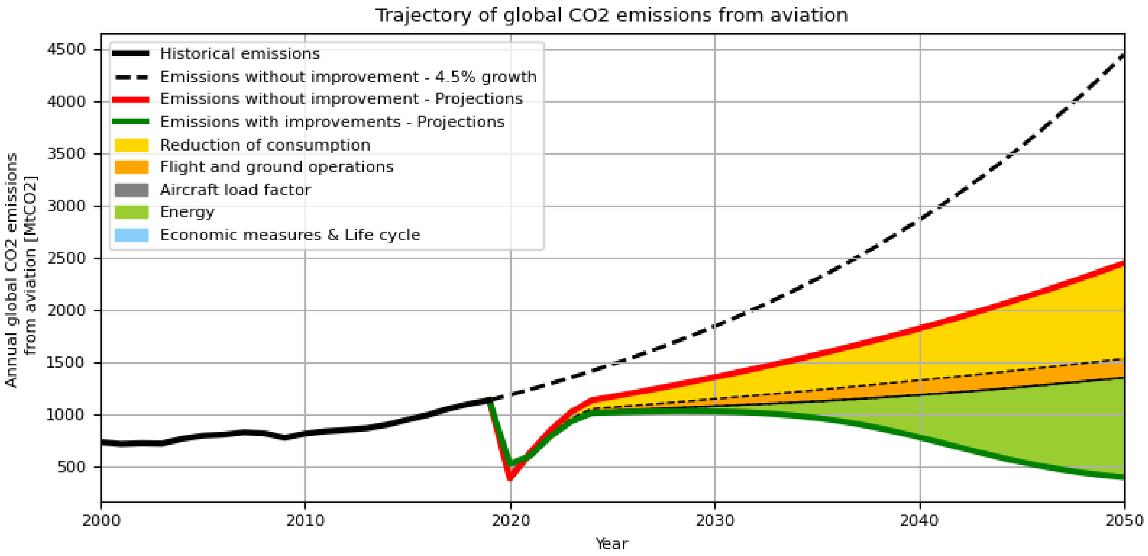
... with an equivalent carbon budget allocated to aviation

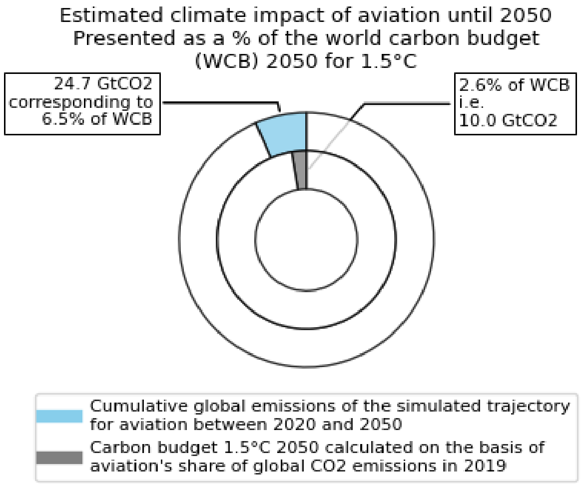
Choice of an objective and an allocation rule
By default: 5.1%

Remark

Cumulative "equivalent" emissions may become negative with traffic regulation and/or mitigation strategies
Aviation could reduce its impact compared to 2019

Example: Scenario ATAG Waypoint





Aviation should be allocated between **2.9% (+2°C) and 6.5% (+1.5°C)** of the world carbon budget to meet the Paris Agreement

The most recent ATAG commitments do not meet the Paris Agreement with a non-differentiated allocation of the world carbon budget

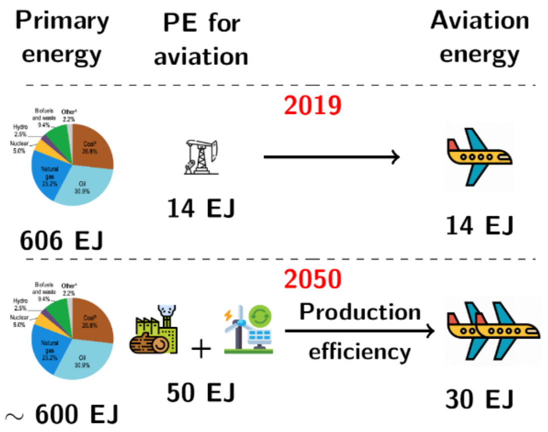
Towards a displacement of the environmental problem?

Availability of energy resources

The alternative fuels envisaged (biofuels, electrofuels, hydrogen) will have to be produced for use by aviation, but also by all sectors of activity. Their production will also have to respect various constraints (for example: available biomass without competition with agricultural land)

How much energy resources will then be available for aviation?

Illustrative example



Example on ATAG Waypoint

- Assumptions considered:
  - ➢ Use of biofuels only
  - ➢ World biomass available in 2050: 100 EJ
  - ➢ Production yield: 50%

- Scenario ATAG Waypoint → 15 EJ of biofuels in 2050, or 30% of available biomass

Conclusion

What can we learn from all this?

Climate emergency
Quickly reduce our CO_2 emissions
The cumulative emissions are important

Carbon budget
Relevant tool to evaluate scenarios
Choice of allocation rules (policy)

Climate impacts of aviation
1/3 CO_2 (long-term)
2/3 non-CO_2 (short-term and uncertain)

Aviation and climate in figures
2.6% of world CO_2 emissions (2019)
5.1% of recent world ERF (2000-2018)

Levers of action
1. Level of air traffic
2. Share of carbon budget allocated (↗ ou ↘)
3. Technology (efficiency, low-carbon fuels)

Sustainable scenarios
Currently → Need to allocate more
Allocated share/traffic level trade-off
Beware of problem shifting

Application on the CAST tool

Objectives of the session

- Handling the CAST tool
- Analyze scenarios, both for CO_2 emissions and for non-CO_2 effects
- Understand the concept of environmental problem shifting

Organization of the session

1. Go to rooms 61.001-002-009-010, you must use the computers in the rooms

2. You will have a paper version of the subject and you will have to write to 2-page report per pair

3. Open CAST on the computer (via Linux) following the instructions provided on LMS
   Do not connect to the classic CAST website for this session! You won't have all the features up to date and we risk breaking the server ☹

Thanks for listenning !

Questions ?