AeroMAPS

Avancées et perspectives vers un IAM modulaire pour l'aviation

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Workshop ISA

13/12/2024

AeroMAPS

INSTITUTE FOR SUSTAINABLE AVIATION

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Introduction

The AeroMAPS Project

AeroMAPS

What future for aviation?

Multidisciplinary

Engineering

Sociology

Environment

Economics

Regulations

Academic...

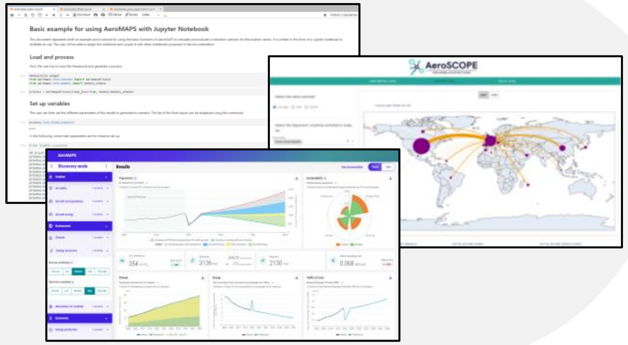
Publications and validation

Modular open-source code

...and collaborative

Close to industry stakeholders

Tools



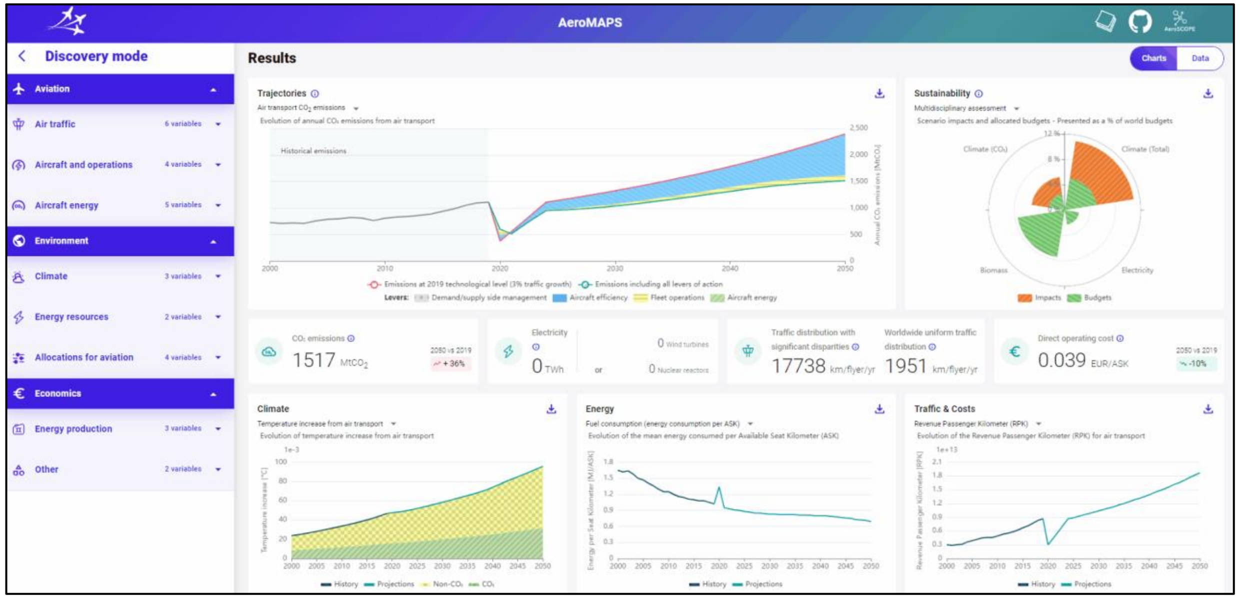
Two tools – AeroMAPS and AeroSCOPE

AeroMAPS

Objective: simulate air transport prospective scenarios
→ Build a sectoral integrated assessment model

An **open-source framework** for performing multidisciplinary assessment of prospective scenarios for air transport

Use of open-source Python frameworks (GEMSEO…) and development of a dedicated user interface with Sopra Steria

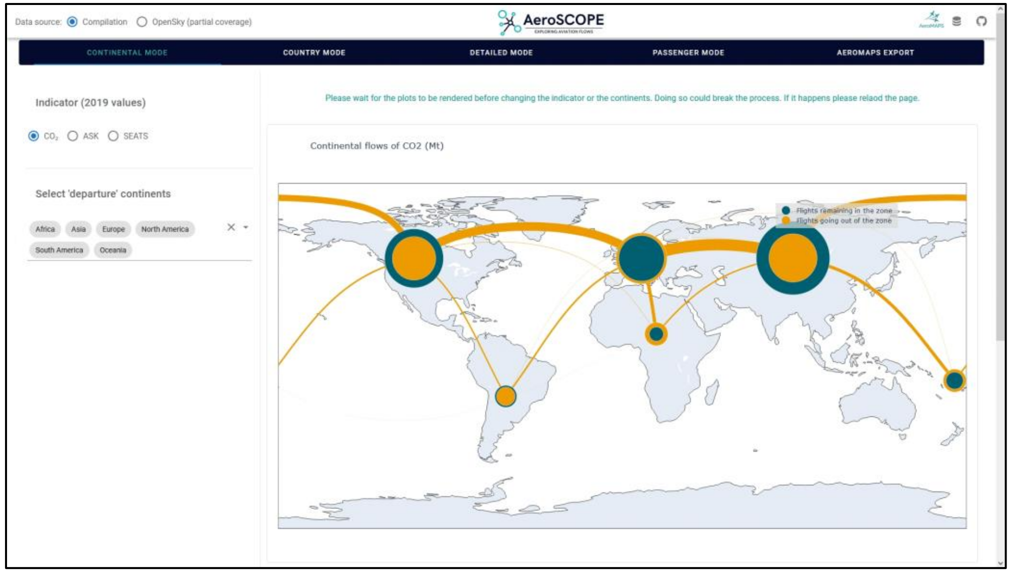


AeroSCOPE

Objective: regionalising AeroMAPS

Compilation of an **open-source** traffic and emissions **dataset**

Development of a dedicated user interface for dataset exploration



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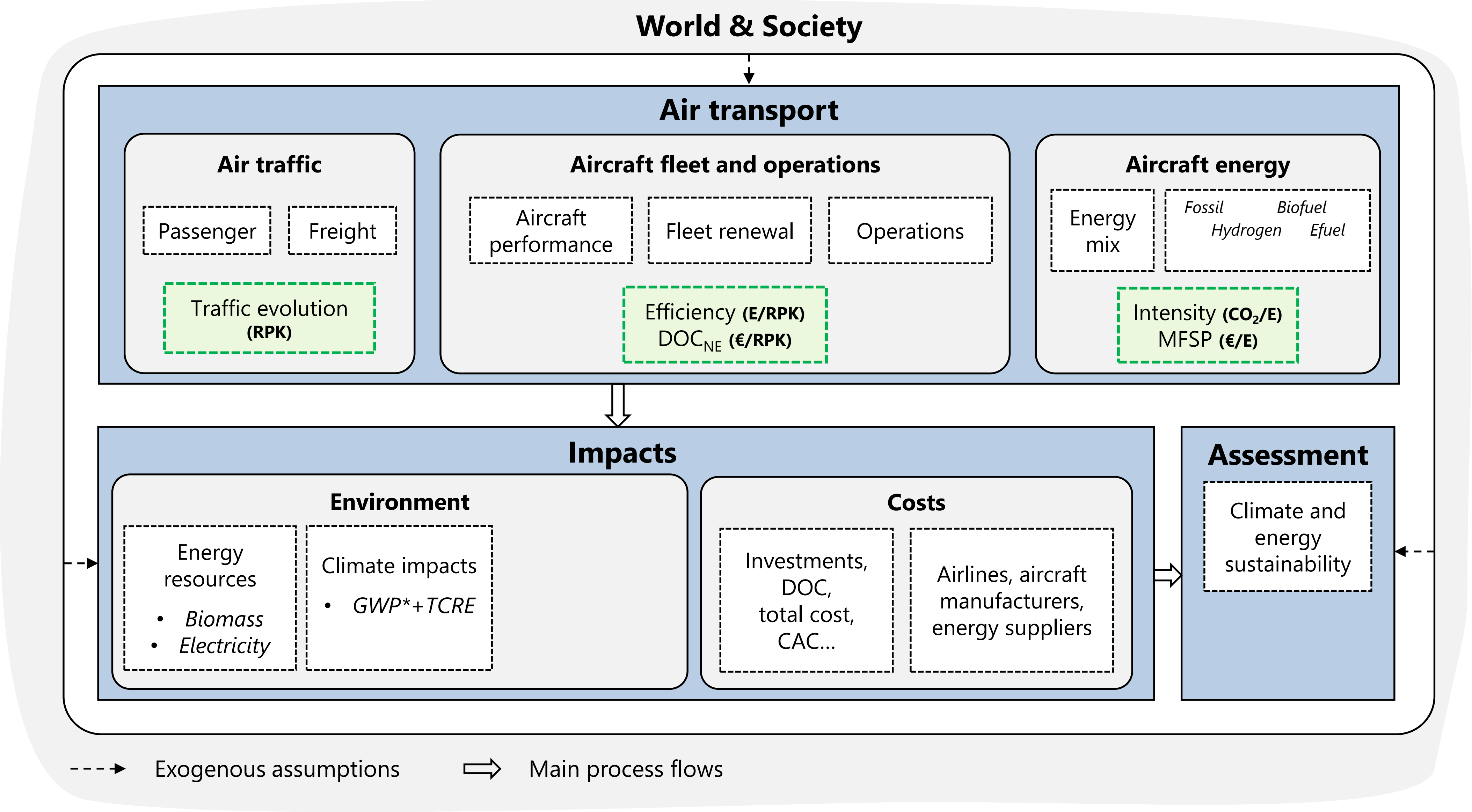
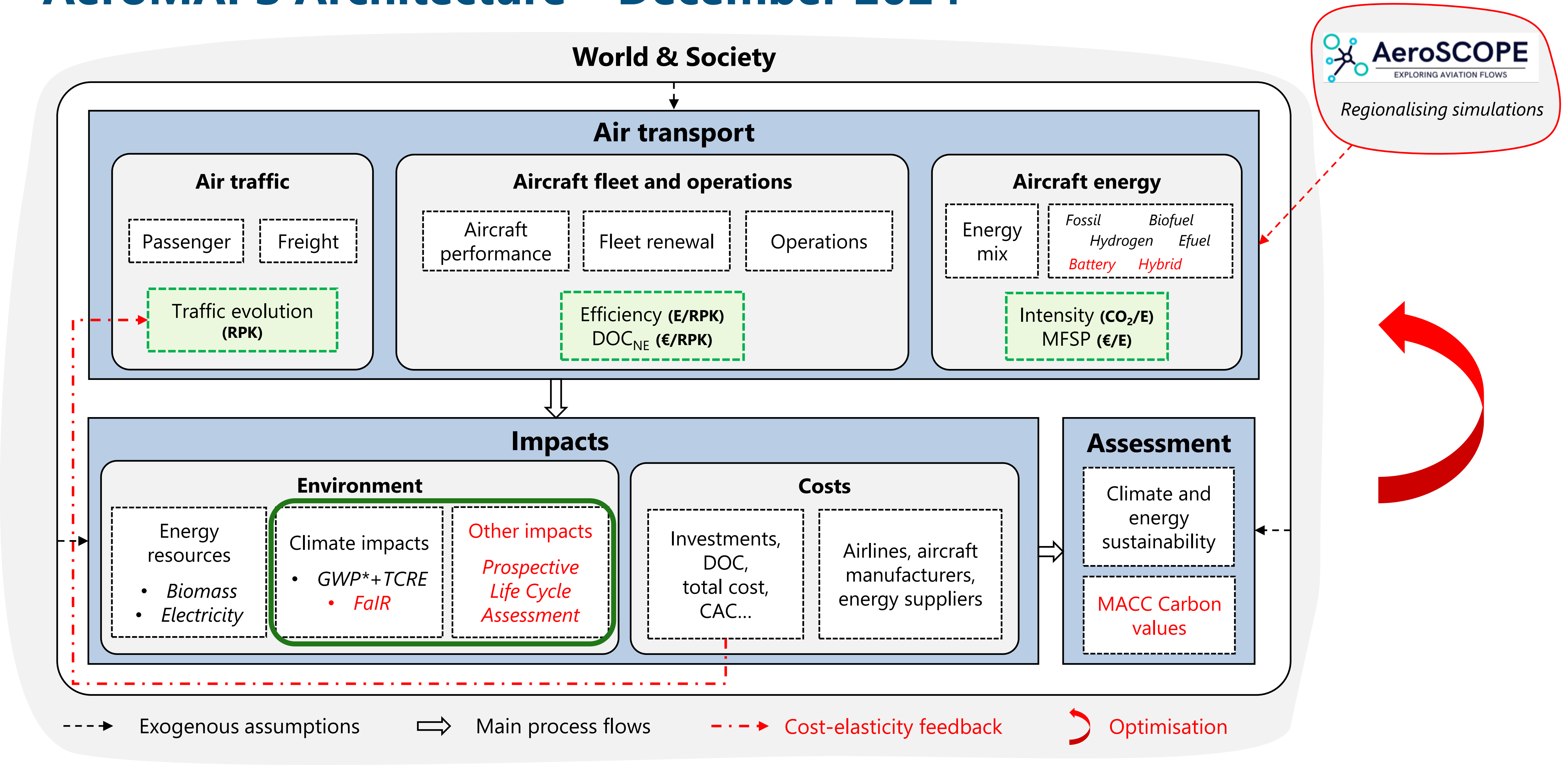
AeroMAPS Architecture – July 2023



AeroMAPS Architecture – December 2024



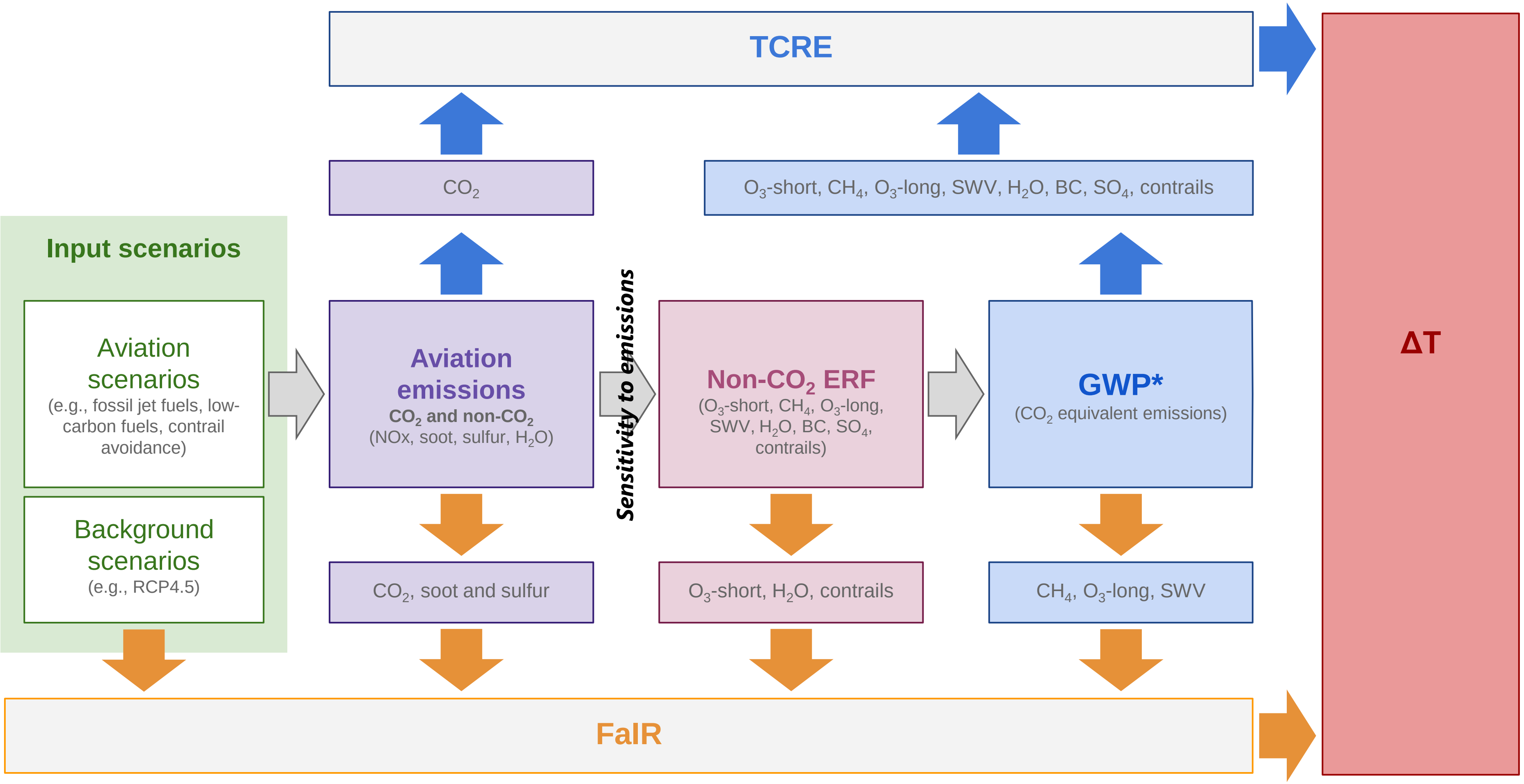
Modelling the aviation climate impacts

Two approaches

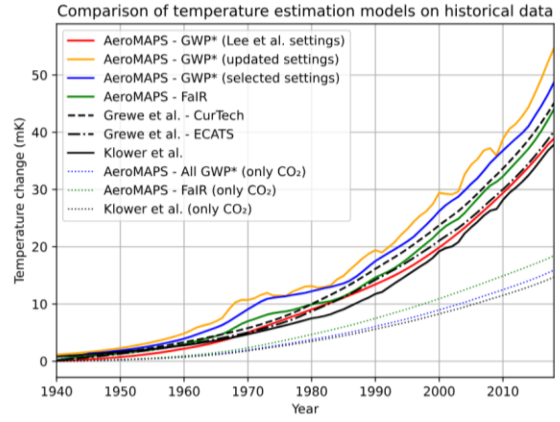
Warming-equivalent emissions → GWP*+TCRE

Climate emulator → FaIR

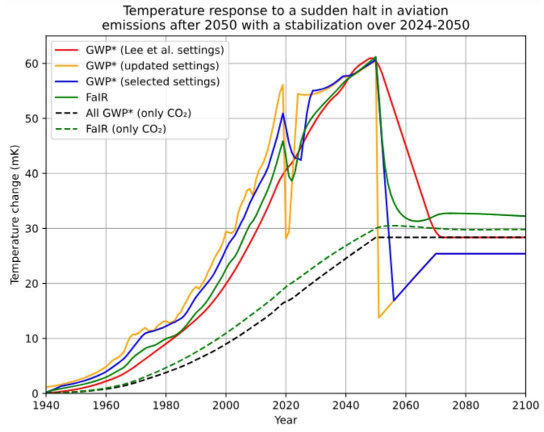
Validation



Historical data



Test cases

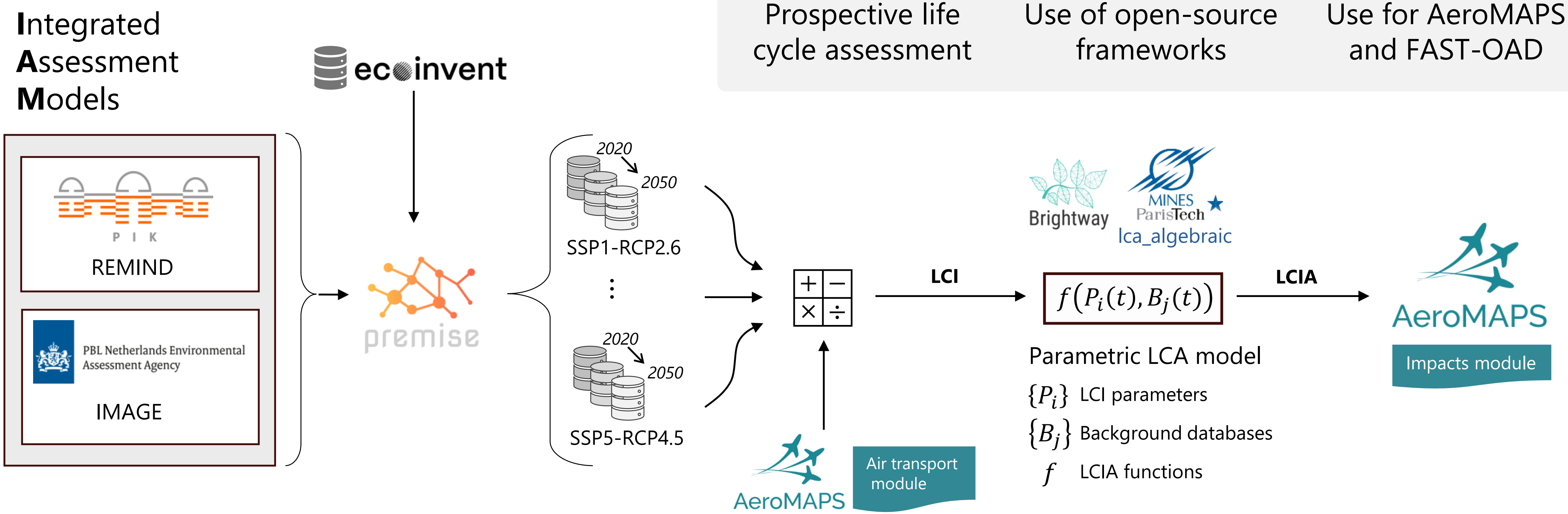


Modelling the other environmental impacts

Method
Prospective life cycle assessment

Tools
Use of open-source frameworks

Generic
Use for AeroMAPS and FAST-OAD



Background
(solar panels, steel production…)

Foreground
(aviation-related)

LCA model

Impact assessment

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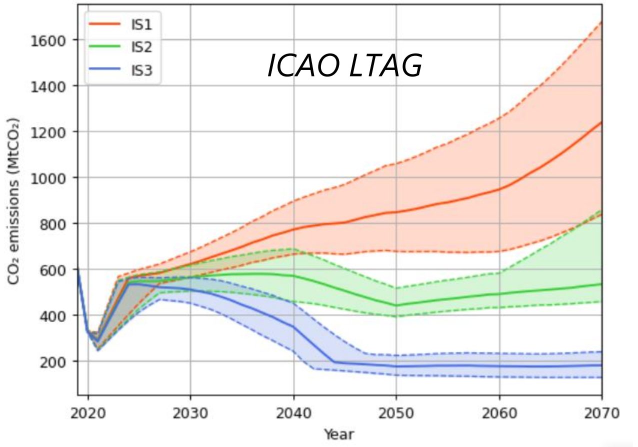
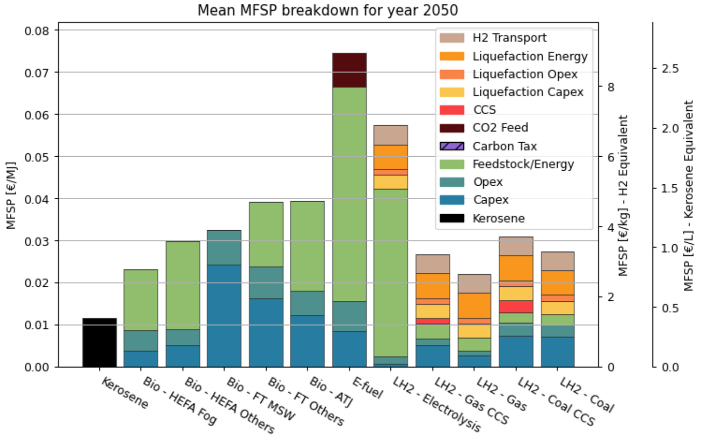
A wide range of applications

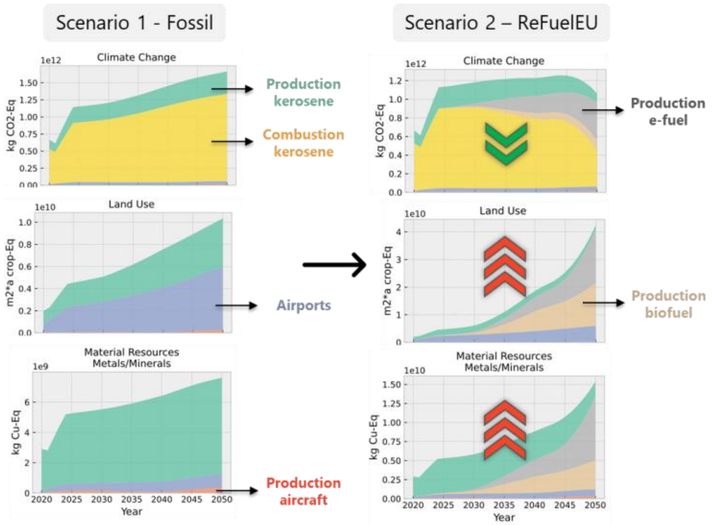
Scenario simulations

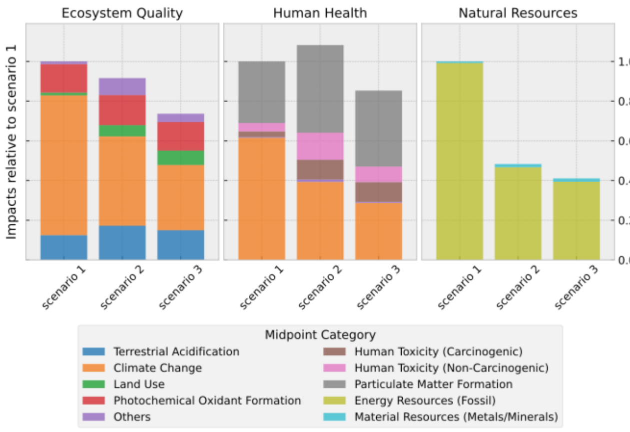


Cost analyses

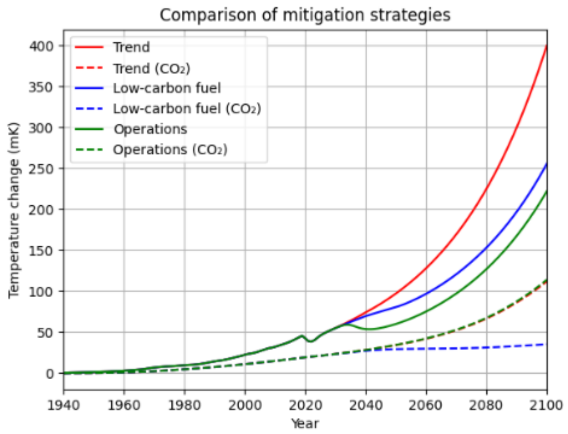


Environmental impacts



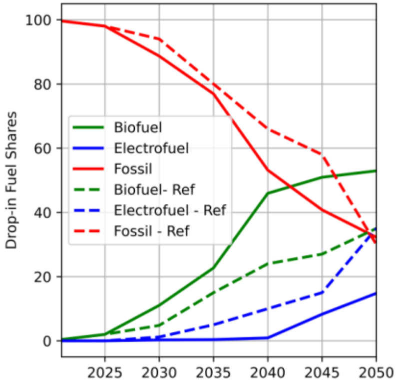


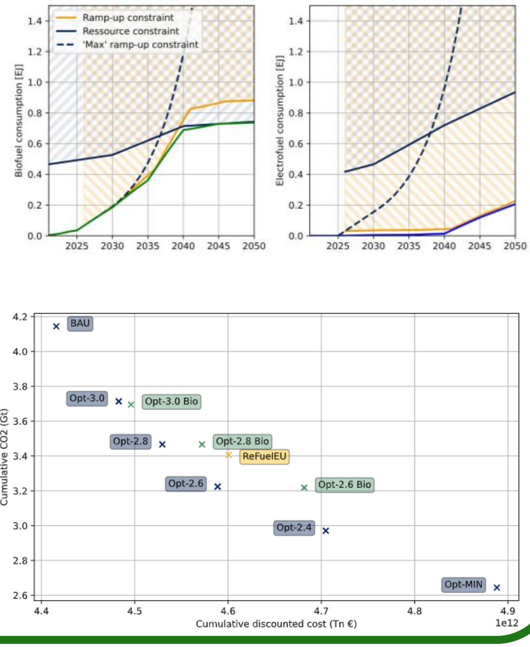
Climate impacts



Optimisations

Techno-economic and environmental

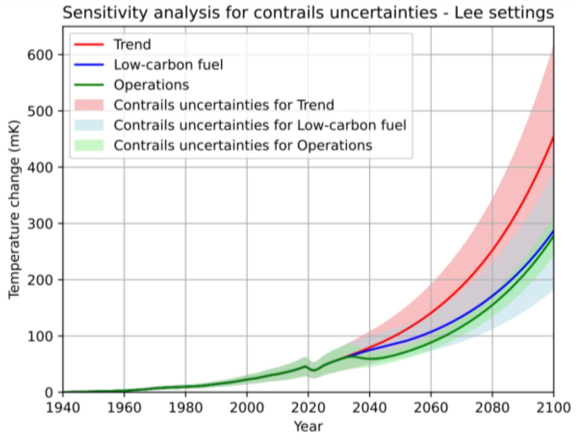


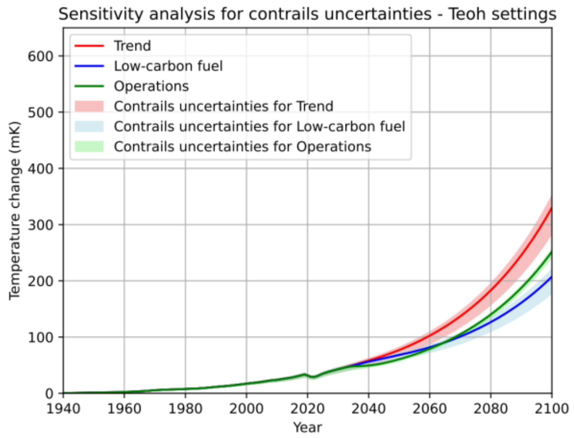


A. Climate impacts and metrics

Comparison of mitigation scenarios

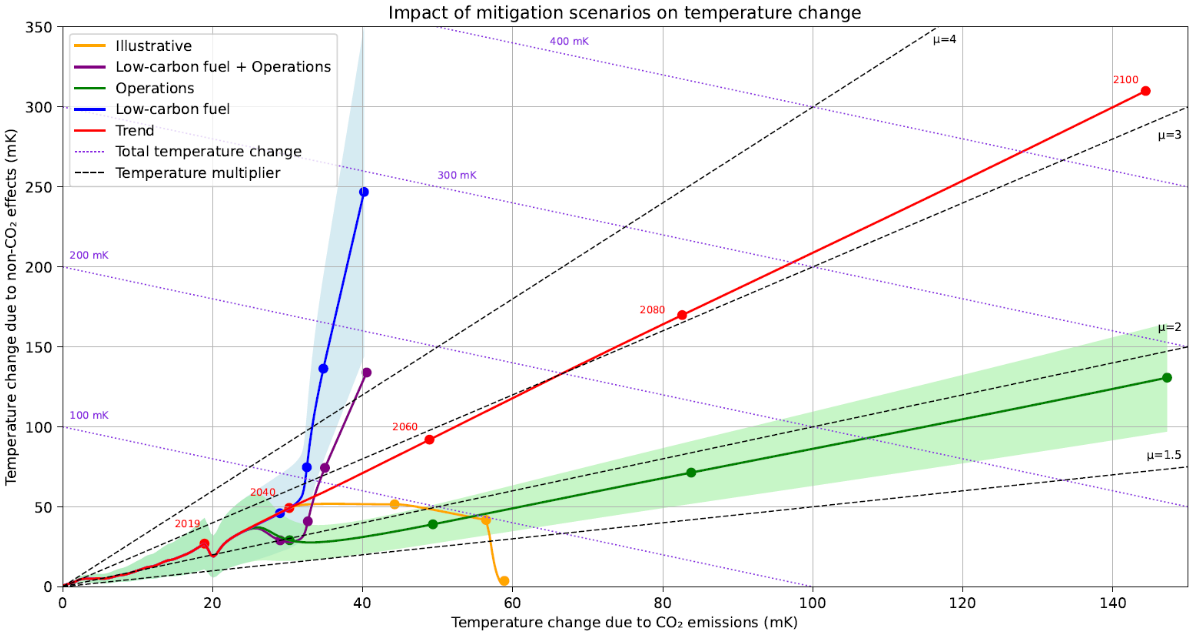
- Three scenarios:
  - ➢ Trend
  - ➢ Low-carbon fuels → ↘↘ CO_2, ↘ contrails
  - ➢ Contrail avoidance → ↘↘ contrails, ~ CO_2
- Temperature increase estimated with FaIR, integration of uncertainties, and comparison of CO_2 and non-CO_2 effects





Towards a discussion on climate metrics

- Difference between temperature multiplier and CO_2-equivalence metrics
- Lightweight climate models could be useful for assessing aviation mitigation strategies
- Conventional metrics (GWP, GTP, ATR…) remain important for some applications (OAD, pricing…)
- Metric choice for consistency with ΔT depends on traffic evolution rather than technology



B. Cost-efficient scenario design

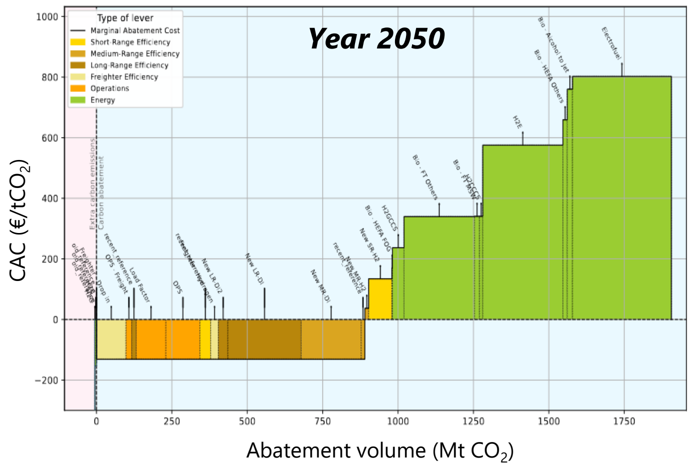
First economic works
→ Antoine Salgas PhD

AeroMAPS initially built for energy and climate analyses and scenario design
➔ Cost as an *observation* only

Cost-centered scenario design

MAC Curves

- Evaluation of cost vs emissions of each option
- Users = optimisers
- Simple but inherent limits
- Audience: policymaking



Two main approaches to "cost-optimal" decarbonisation scenarios

➔ *Cost-benefit* approach

1. Evaluate the cost of the future damages caused by aviation
2. Implement decarbonisation options that are less expensive than those damages

⚠ Damages uncertainty / intertemporal arbitration / sectoral declination ⚠

➔ *Cost-effectiveness* approach

1. Set a carbon budget/temperature target to respect
2. Find the least-cost pathway to respect it

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MAC Curves

- Evaluation of cost vs emissions of each option
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- Audience: policymaking

Optimisation

- Cost minimisation
- Less explicit
- More complex interactions handled
- Audience: experts

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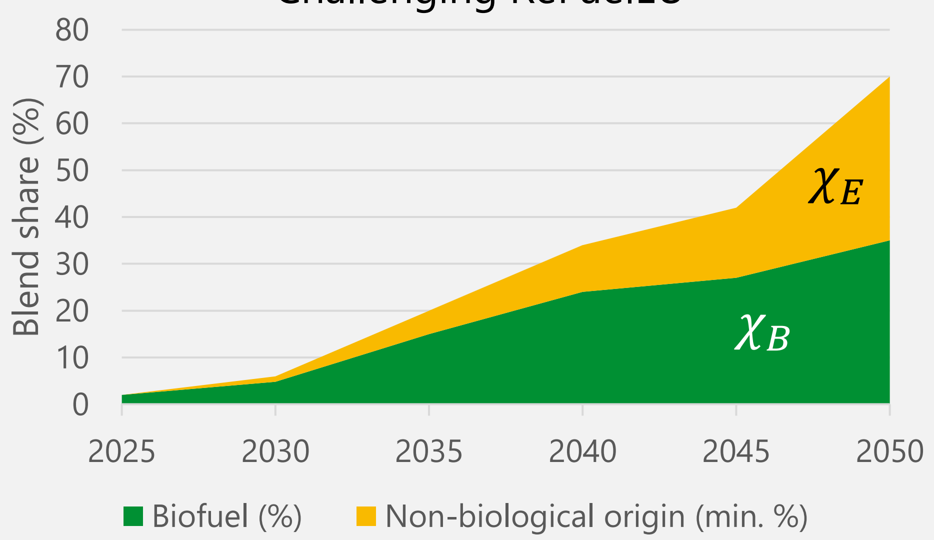
B. Scenario optimisation

Use case

Challenging ReFuelEU



Original ReFuelEU Mandate

NB: no exact share of biofuel are defined: ReFuelEU specifies a total SAF share and a min non-biofuel share

Using AeroMAPS to challenge this mandate: Implementation of a constrained cost-effectiveness optimisation approach

Optimisation problem

From a baseline regionalised European aviation scenario

Minimise TC → Total airline cost

with respect to $\chi_{B,t_{ref}} \in [0,1], t_{ref} \in \{2030, 2035, \ldots, 2050\}$

$\chi_{E,t_{ref}} \in [0,1], t_{ref} \in \{2030, 2035, \ldots, 2050\}$

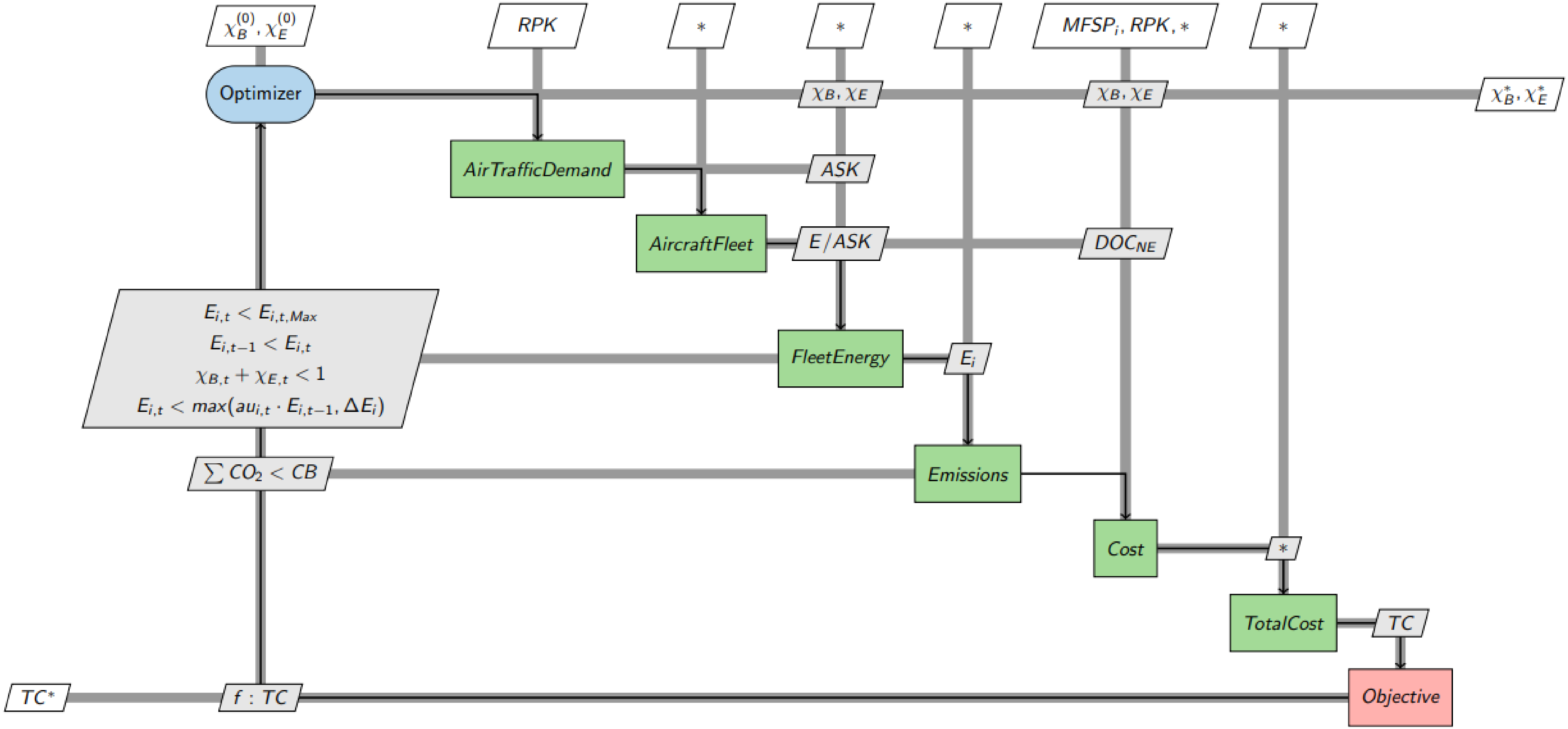
subject $\boldsymbol{G}_k(\boldsymbol{x}), k \in \{1, \ldots, 8\}$

Constraints $\boldsymbol{G}_k(\boldsymbol{x})$

- Share of world carbon budget
- <100% SAFs
- Share of resource available
- Ramp-up
- No ramp-down

One constraint per year → reduction

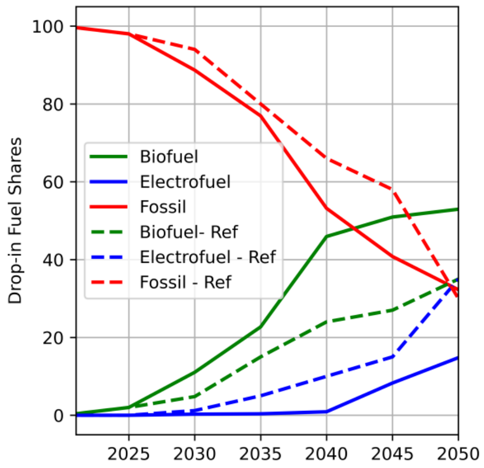
B. Optimisation problem XDSM diagram (fixed demand)



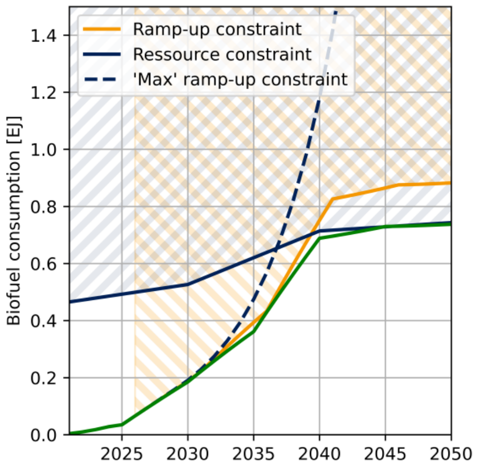
B. Results

Initial optimisation

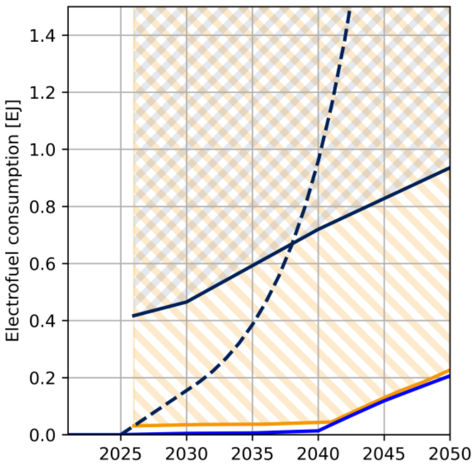
Overall blend



Biofuel



E-fuel

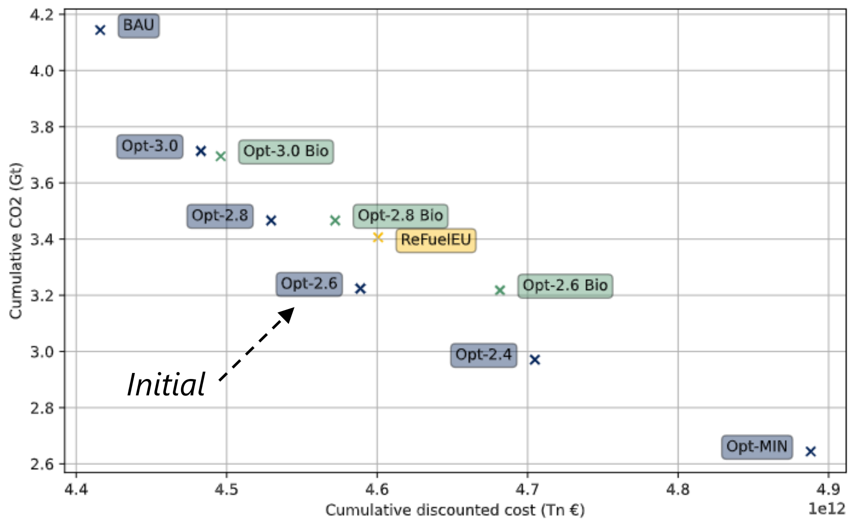


- Faster fossil kerosene reduction
- Shifted towards biofuel

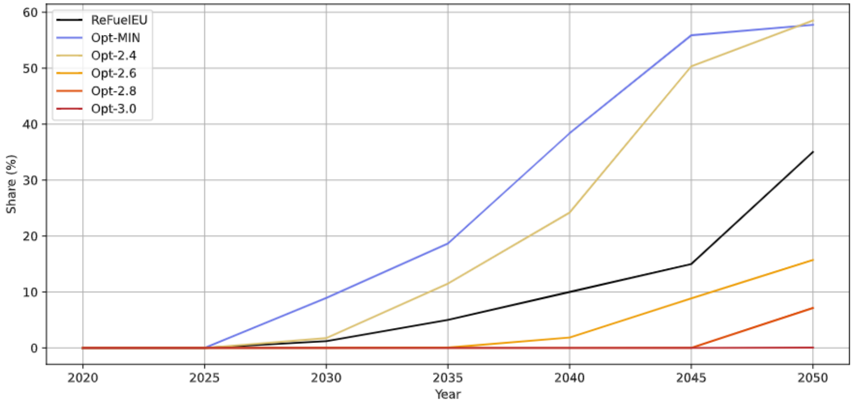
- Biofuel constraints are always active
- Ramp up → Resource

- Resource constraint inactive
- Late deployment

Pareto front



E-fuel shares



Sensitivity to constraints

- Carbon budget: grandfathering approach → others
- Biomass allocated: 10% of world biomass → 5%

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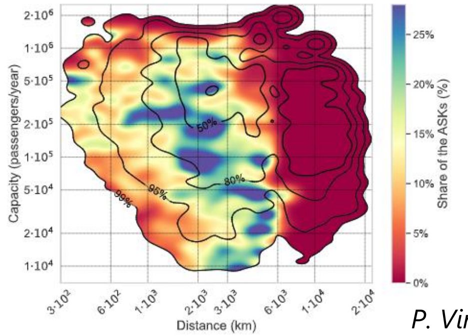
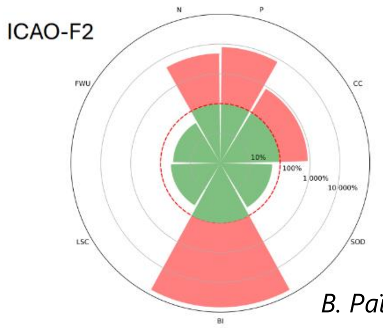
Current and future research works

- **Fleet renewal, operations and fuels (Paco Viry…)**
  - Production, retirement and productivity
  - Aircraft/route allocations
  - Overview of operations efficiency
  - Contrail avoidance and SAF effects
- **Climate, LCA and PB (Félix Pollet, Bastien Païs…)**
  - New climate models and climate metrics
  - LCI (fuels), LCIA (update for climate and others)
  - Planetary boundaries and downscaling
- **Demand (Ian Costa Alves, Paco Viry, Thomas Bétous…)**
  - Models based on GDP and logistic functions
  - Integration of quali-quantitative parameters
  - Sufficiency measures (e.g. quotas integrating sociological analyses)
- **Cost and economy (Antoine Salgas…)**
  - Market equilibrium (airfare, fuels)
  - Scheme modelling: CORSIA, EU-ETS
- **Features (Antoine Salgas, Ian Costa Alves…)**
  - Interactions between regions and stakeholders
  - Coupling, optimisation, uncertainties
  - AeroSCOPE → Emission monitoring

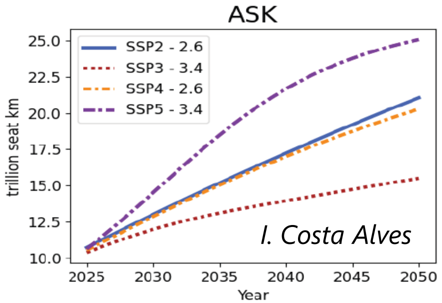
THALES
TU Delft
DTU AIRBUS
INSA TOULOUSE
Université de Lille
tbs Business School
SAINT EXUPÉRY

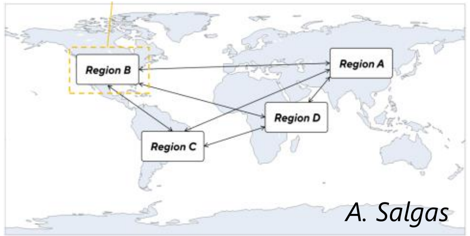


P. Viry



B. Païs





Development of "AeroMetrics"

Calculation of climate and environmental metrics for several applications

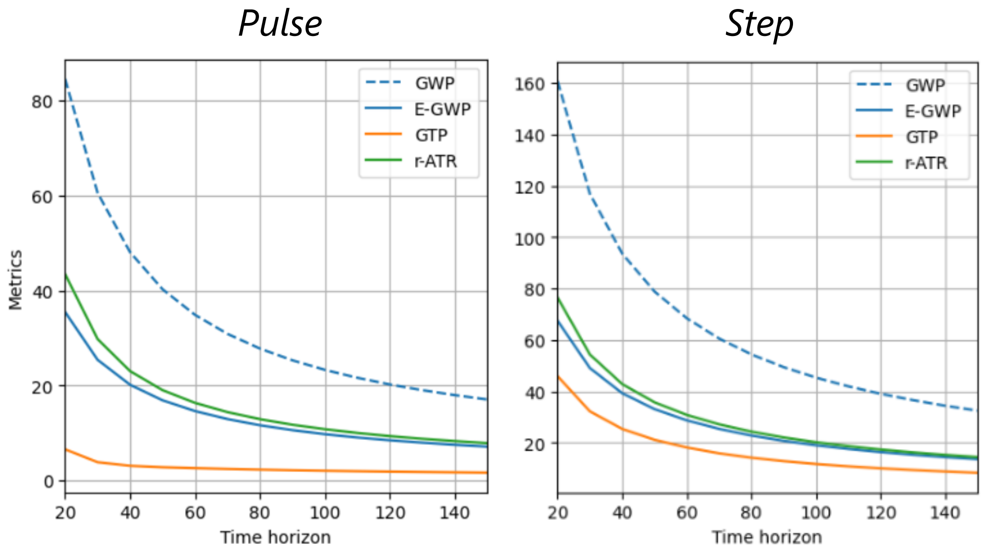
Overall aircraft design, flight path, LCIA, pricing…

Updating climate LCIA methods

Parametrisable estimates of CO_2-equivalence metrics

- **Conventional metrics**: $AGWP = \int_{t_0}^{t_0+H} RF(t)dt \qquad ATR = \frac{1}{H}\int_{t_0}^{t_0+H} \Delta T(t)dt$
- **Parametrisation**: pulse/step, species quantity, sensitivity, efficacy…
- **Calculation**: use of the climate models available in AeroMAPS
- **Applications**: overall aircraft design, flight path, LCIA, pricing…

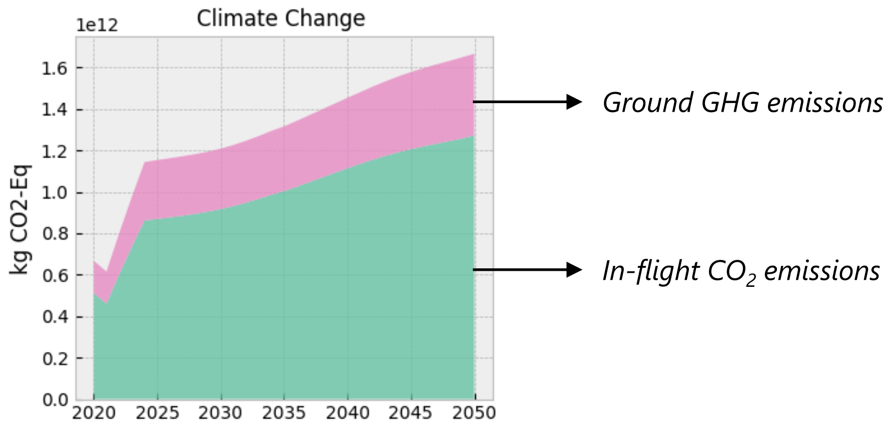
Calculation for contrails



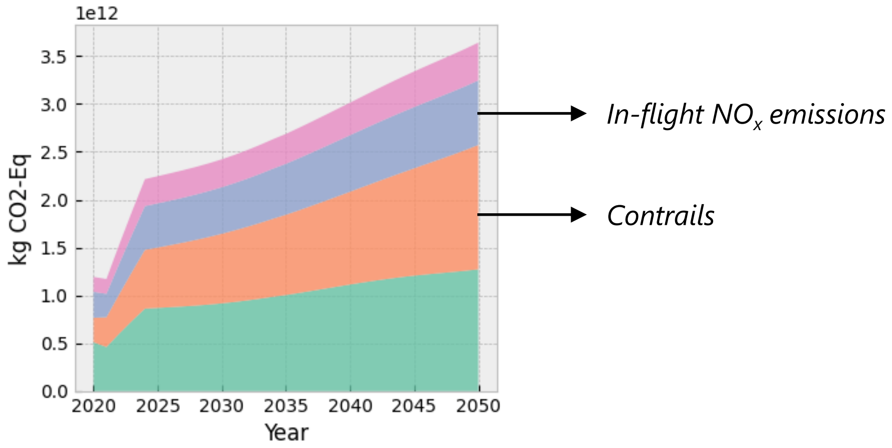
Application: integration in LCA

- Application on a trend scenario with kerosene
- GWP100 from Lee *et al.* (2021) for contrails and NO_x

Without non-CO_2



With non-CO_2



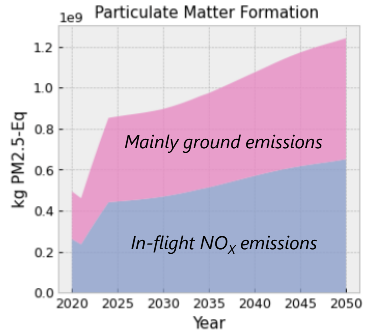
Updating other LCIA methods

Most LCIA characterisation factors (CFs) are provided for ground-level emissions

Most aviation emissions occur during flight in the lower stratosphere

→ **Develop CFs for aviation**

PMF results using ground CFs



Examples of CFs to update (or not) for aviation

Midpoints	CO_2	NO_x	SO_x	BC	H_2O	Contrails	Others (HC, NMVOC...)
CC		x	x	x	x	x	Previous slide
PMF		x	x	x			
POF		x					x
TA		x	x				
LU							
MRS							

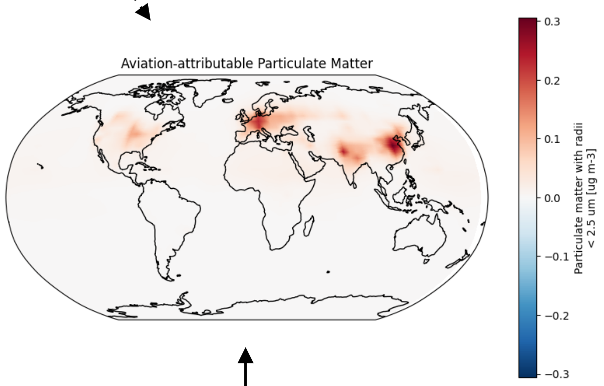
CC: climate change / PMF: fine particulate matter formation / POF: photochemical ozone formation / TA: terrestrial acidification / LU: land use / MRS: mineral resource scarcity

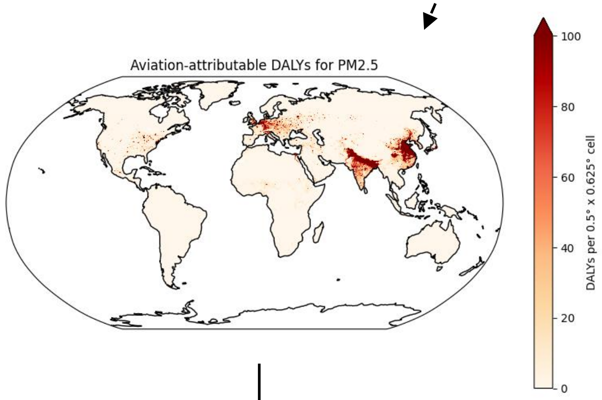
Methodology for estimating aviation CFs (human health case)

Aviation emissions → Pollutants at ground level → Human exposure → Disability-adjusted life years (DALYs)

Chemical-Transport Model · *Population grids* · *Concentration-Response Functions*

Application for NO_x impacts on PMF





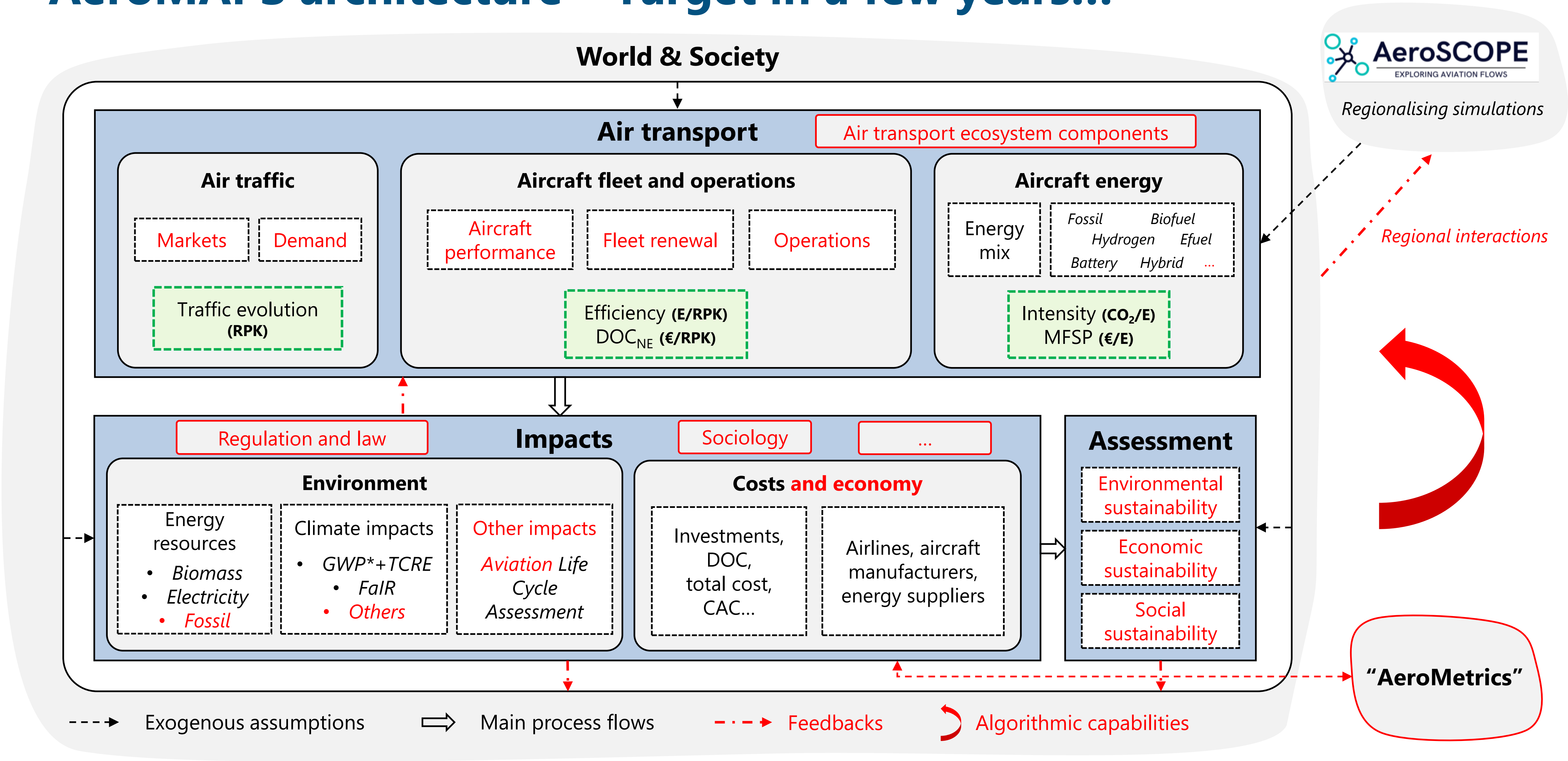
Ground-level pollutants data from Quadros et al. (2020)

→ Own data in the future?

Aggregated coefficient (DALY/kgNO_X)

Ground factor	Aviation factor
6.92×10^{-5}	1.24×10^{-4}

AeroMAPS architecture – Target in a few years…



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Conclusions

AeroMAPS

- Project: exploring future air transport by developing a family of software
- Academic research: open-source, modular and collaborative
- Broader objective: decision support and policymaking

Tools

- AeroMAPS: air transport prospective scenario simulator → aviation IAM
- AeroSCOPE: dataset for exploring aviation traffic and emissions
- "AeroMetrics": calculator of climate and environmental metrics for aviation

Roadmap

- Short-term: full integration of fleet renewal, LCA and optimisation in AeroMAPS, with dedicated publications + release of "AeroMetrics"
- Medium-term: integration of current and future research works on demand, operations, planetary boundaries... + development of new features (regional interactions, uncertainties...) and other tools
- Long-term: integration of other disciplinary fields towards a sectoral integrated assessment model

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Thanks for listening

AeroMAPS