Life Cycle Assessment of Air Transport Systems

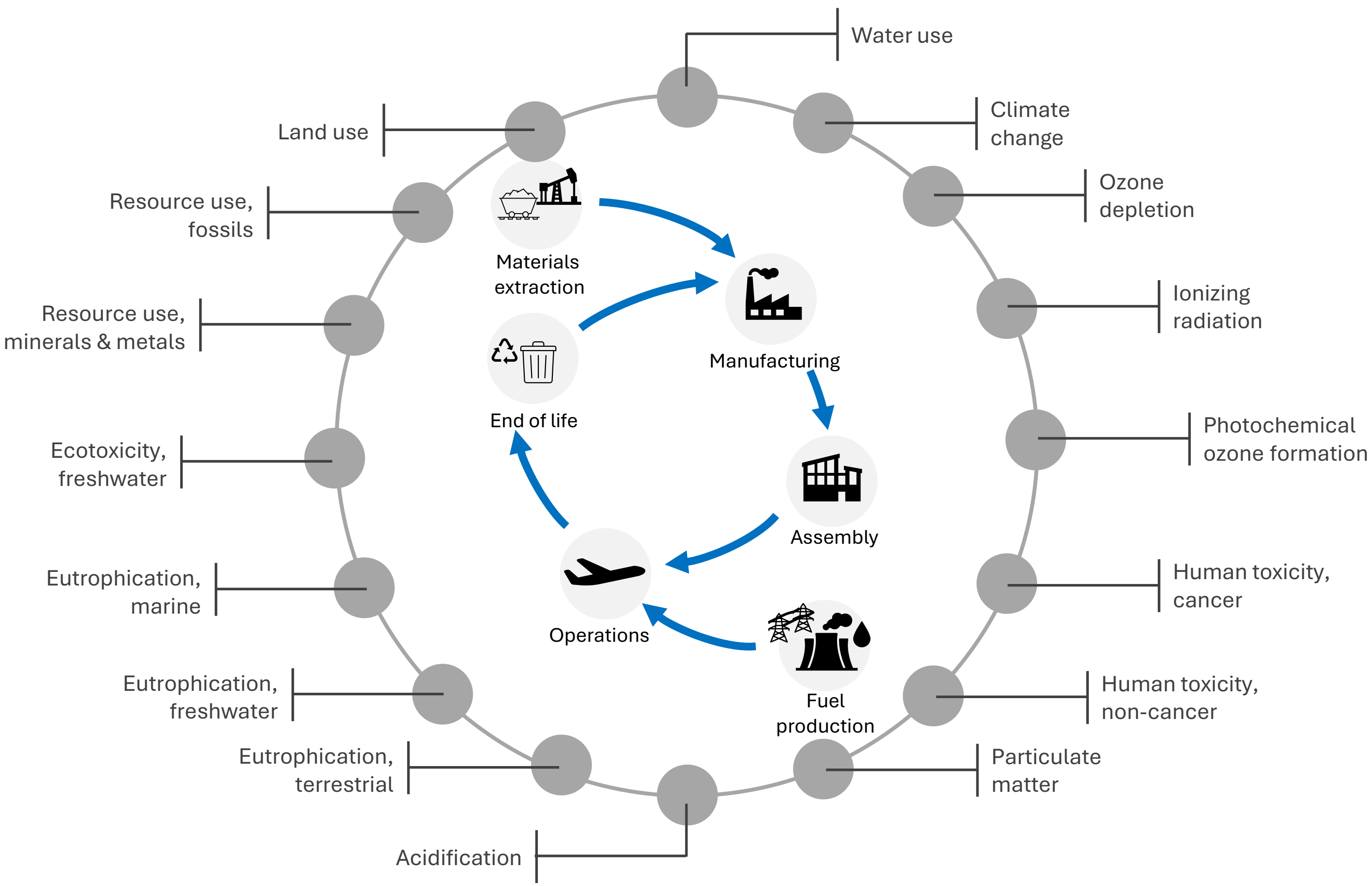
From aircraft design to the evaluation of transition scenarios for the aviation sector.

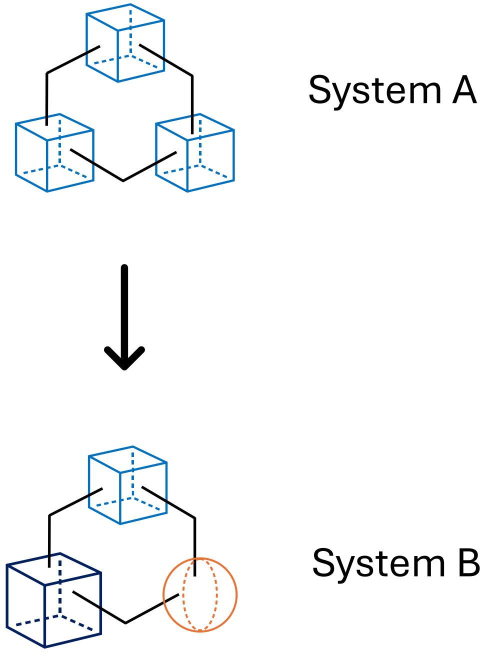
Félix POLLET - Postdoctoral researcher at ISA

Workshop ISA

1st July 2024

Principles of Life Cycle Assessment





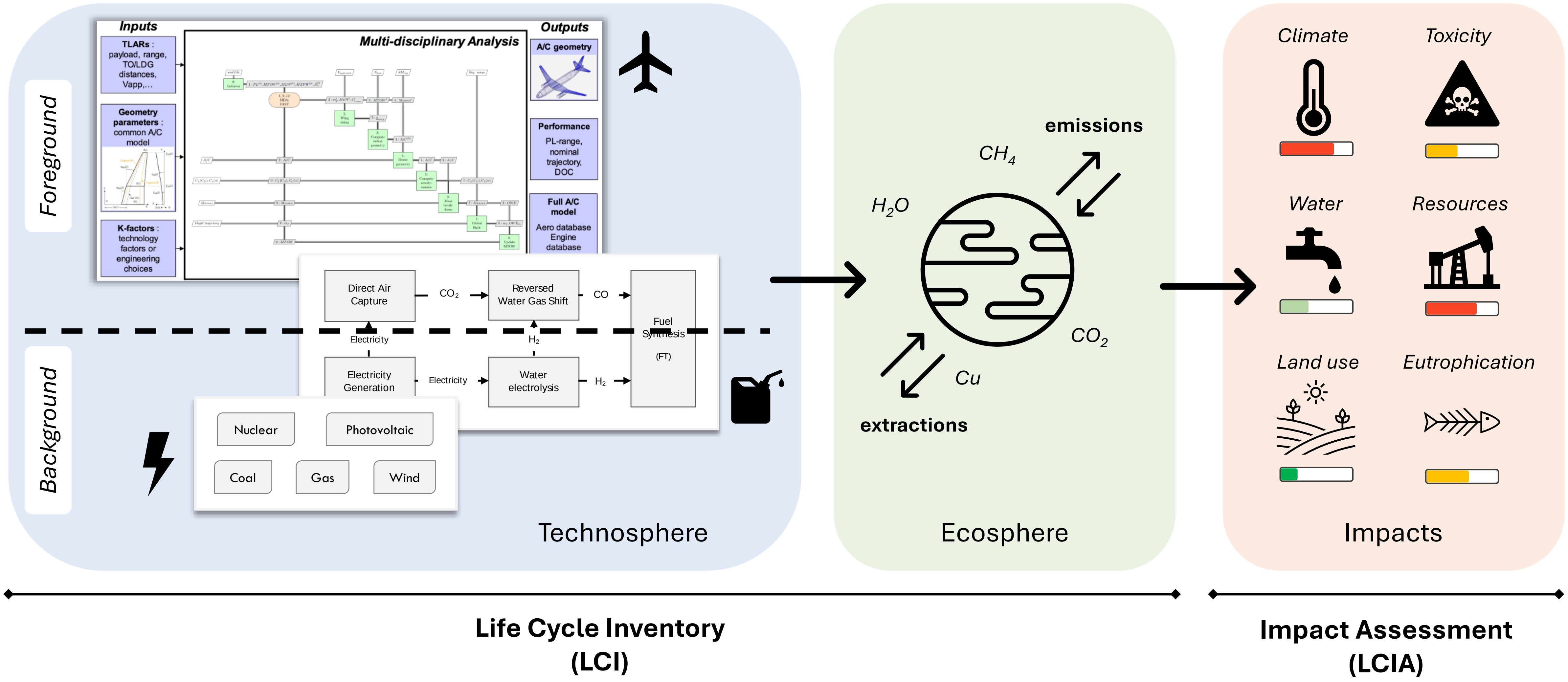
Introduction

Aircraft Design

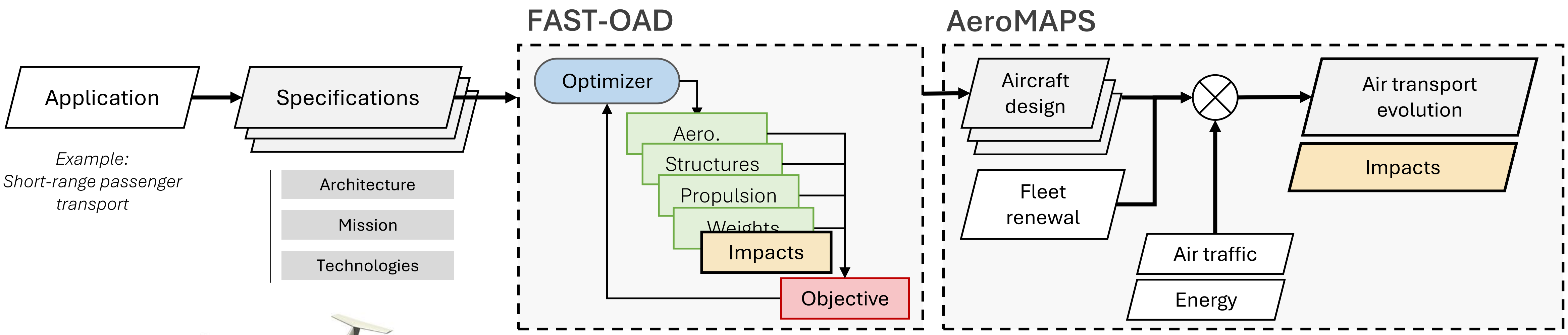
Transition Scenarios

Perspectives

Key steps of LCA

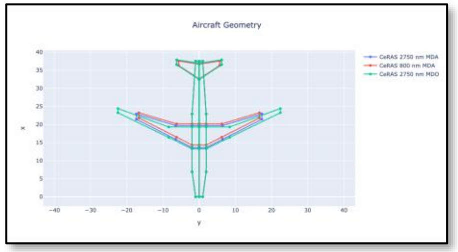


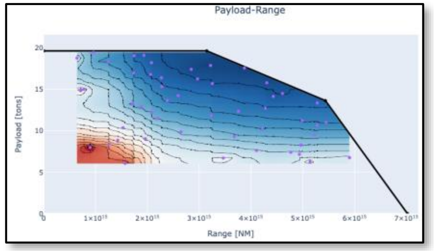
Aviation modelling tools

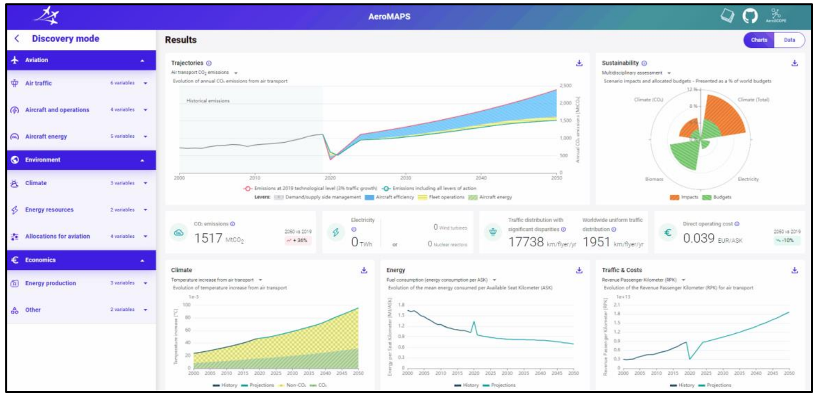


Example: Short-range passenger transport

- Architecture
- Mission
- Technologies







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1. Introduction
2. LCA for aircraft design
3. LCA for transition scenarios
4. Conclusion & perspectives

Eco-design of UAVs

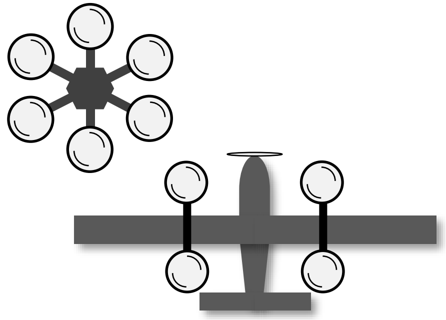
Application → Specifications → Sizing methodology → Environmental assessment → Optimal sizing

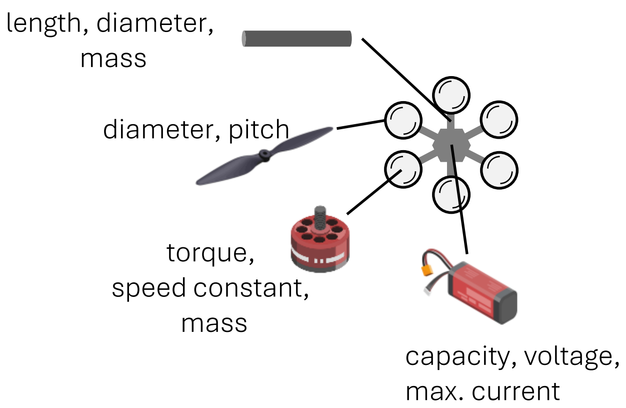
Example: Urban delivery

Specifications:
- Architecture
- Mission
- Technologies

FAST UAV
Multirotor | Fixed-Wing | Quadplanes
Design Optimization

Optimal sizing:
- Component masses
- Electro-mechanical parameters
- Dimensions
- ...





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Environmental module

LCA of background

Propeller [1 kg]	83.2 kg CO2-eq 2.5 x 10^{-4} kg Sb-eq …
Battery [1 kg]	14.8 kg CO2-eq 2.1 x 10^{-3} kg Sb-eq …
…	
Electricity [1 kWh]	0.55 kg CO2-eq …

Parametric LCA model

$$f_{climate}(P_i) = 83.2 \times m_{propellers} + \ldots + 0.55 \times E_{missions}$$

16 impact categories [1]

+ **Partial derivatives** for improved numerical resolutions

$$\frac{\partial f_{climate}}{\partial m_{propellers}}(P_i) = 83.2$$

…

$$\frac{\partial f_{climate}}{\partial E_{mission}}(P_i) = 0.55$$

UAV design (sizing methodology)

Component masses, mission energy

$m_{propellers} = 0.08\ kg$
$m_{batteries} = 1.69\ kg$
…

Impacts evaluation

Optimization
objective or constraints

Software tools

ecoinvent — LCI database version 3.9.0

Brightway — Open-source software for LCA calculation

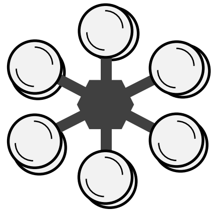
MINES ParisTech — LCA Algebraic — Python package for LCA parameterization

FAST UAV — Multirotor | Fixed-Wing | Quadplanes Design Optimization

[1] European Commission, Product Environmental Footprint methods, 2021

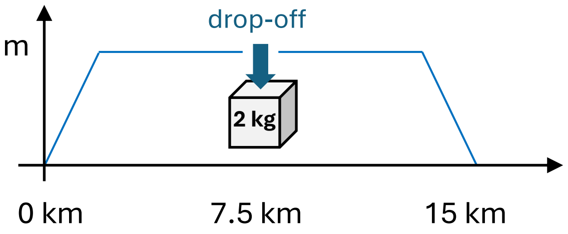
Case study

Architecture



Hexacopter with coaxial rotors

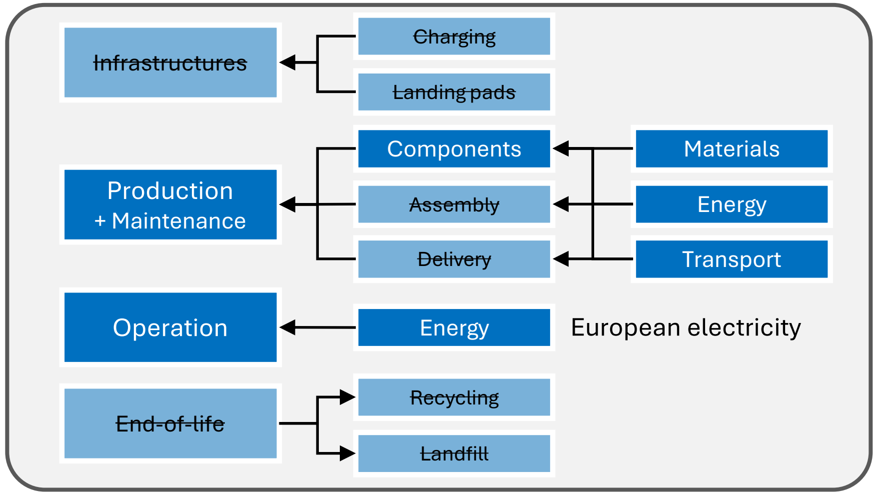
Mission
& usage



5 deliveries/day
260 days/year
2 years

2600 missions

Boundaries
of LCA study

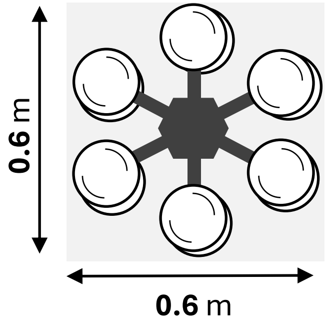


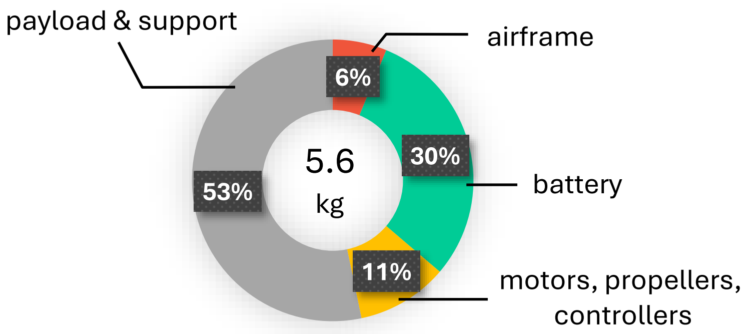
Research questions

1. Critical environmental impacts and main contributors?
2. Design implications of mitigating these environmental impacts?

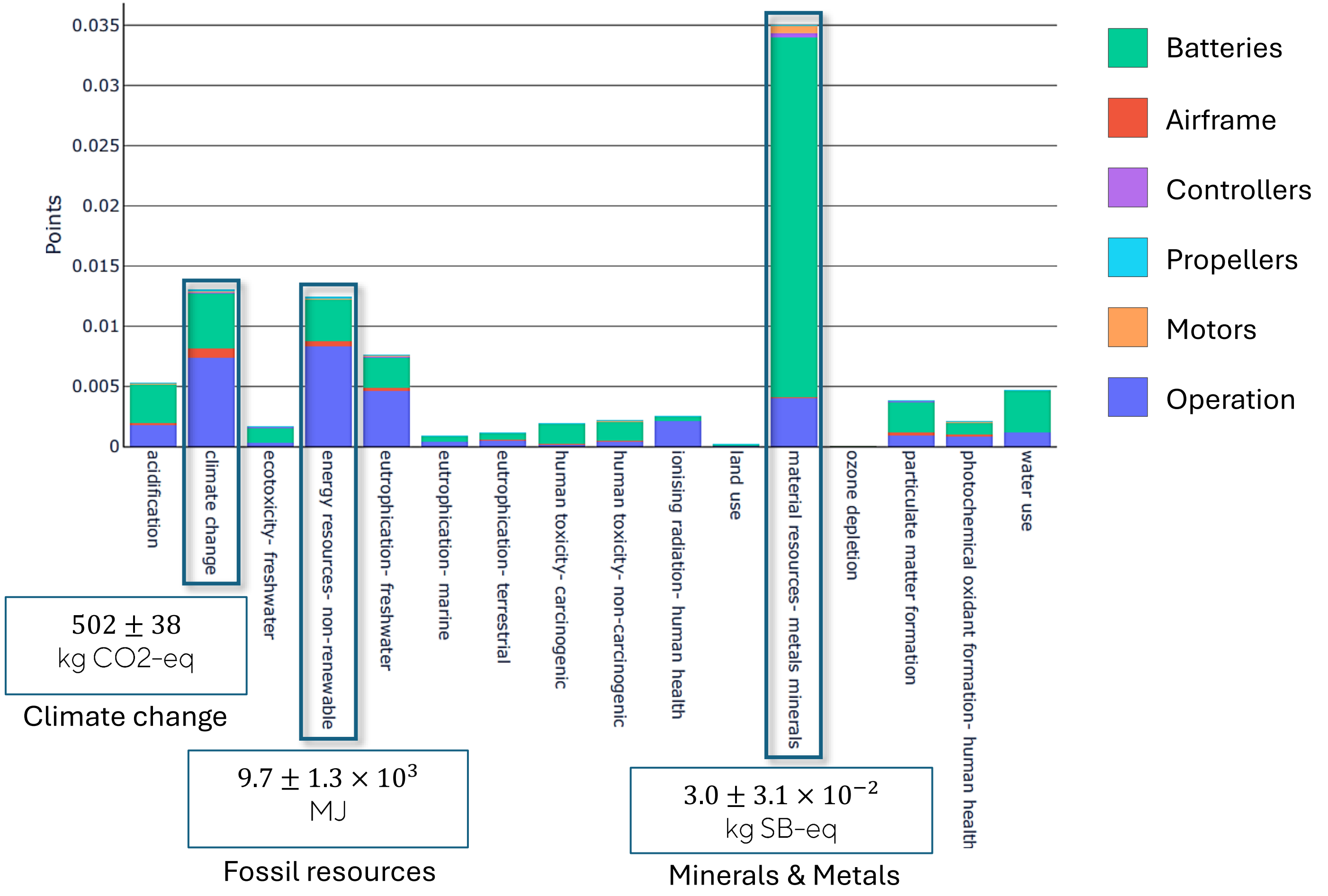
Critical impacts

Sizing results
(reference design)



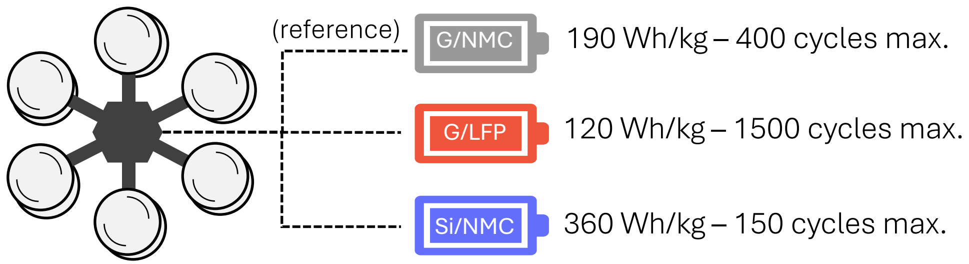


Environmental impacts
Normalized and weighted scores



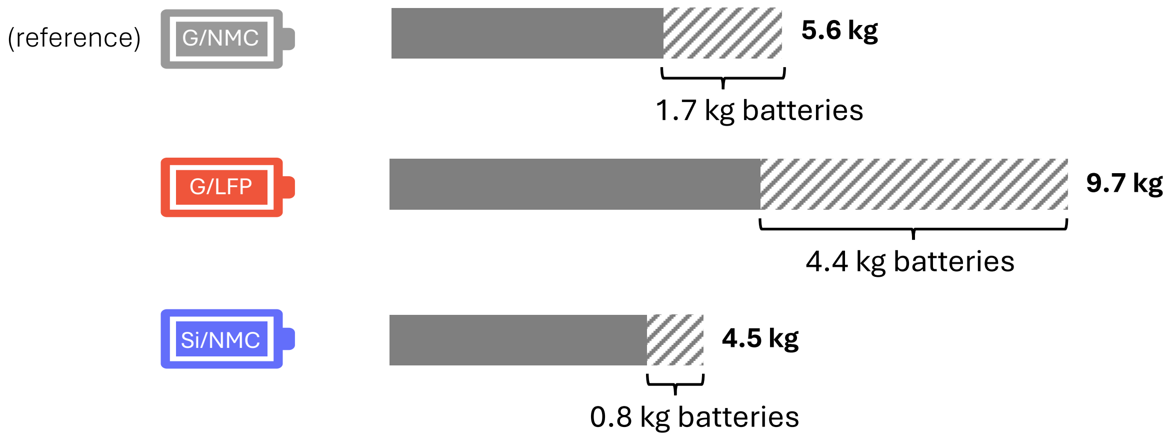
Sensitivity to technology

Technology assumptions

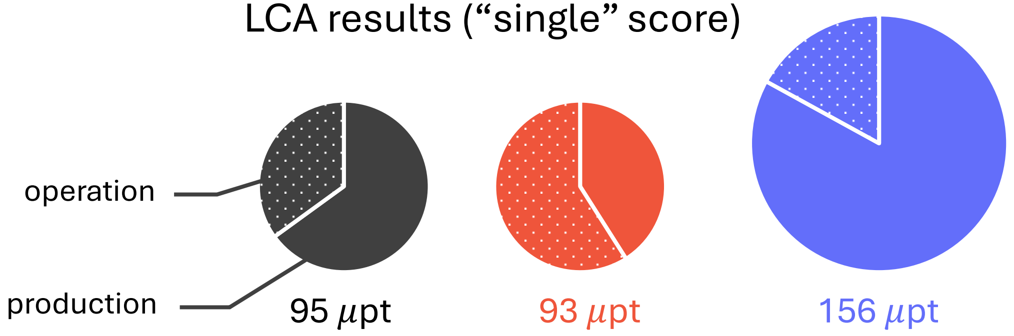


Sizing results

Total Mass



LCA results (“single” score)



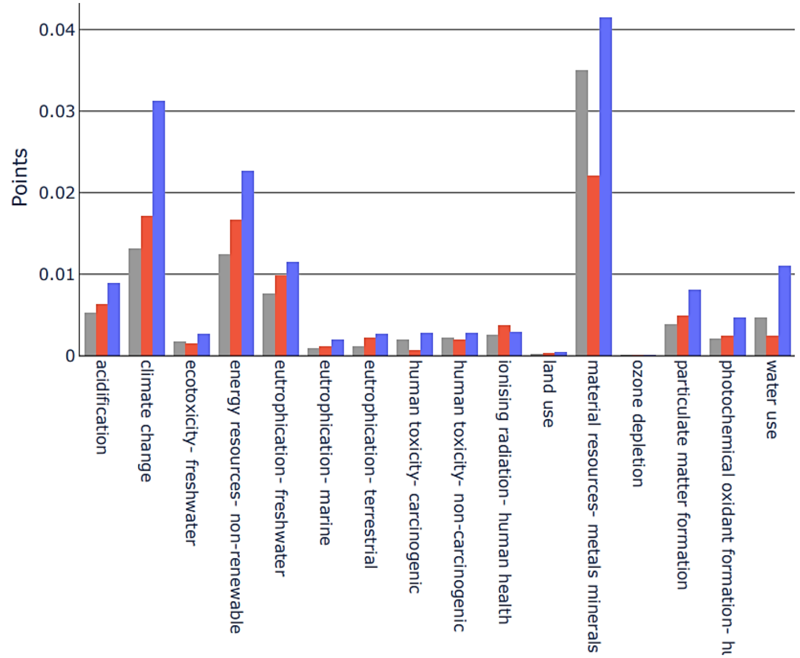
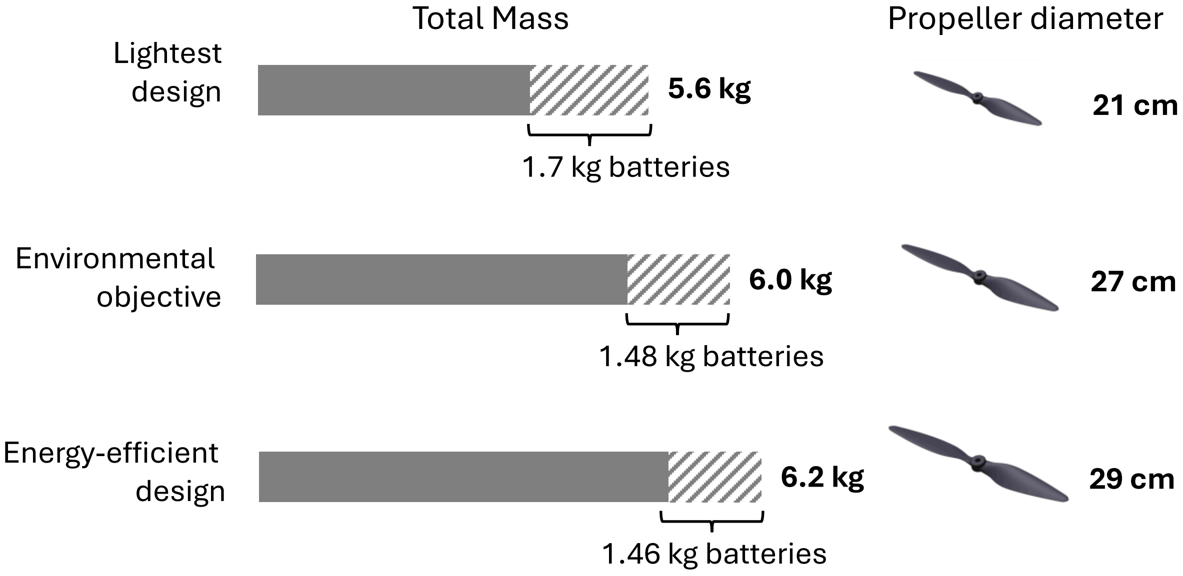


Fig.: Comparison of the environmental impacts for the three UAV designs

Sensitivity to sizing objective

Sizing results



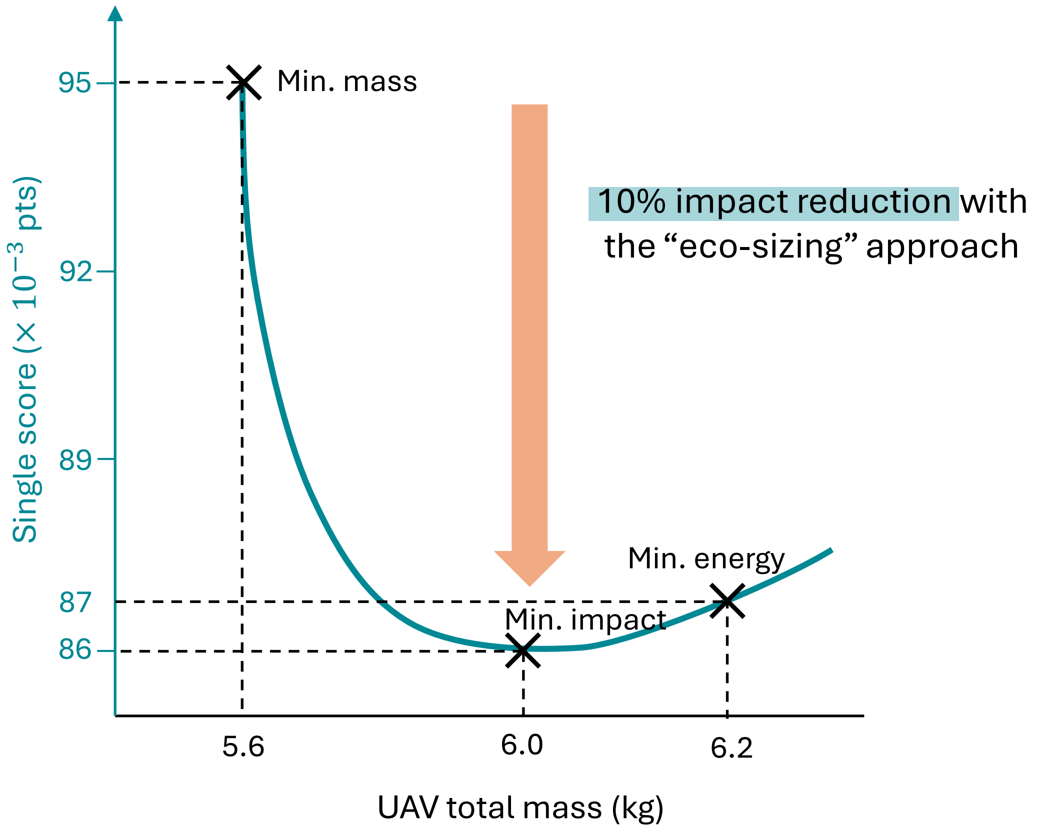


Fig.: Environmental score for different sizing objectives as a function of UAV mass

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Future work

FAST-OAD
Open-source framework
for overall aircraft design

→

FAST-OAD-CS25
Regional, SMR, (LR)

→

FAST-OAD-CS23
General aviation (+ Commuter)

←

Environmental module

FAST-UAV
Multirotor, Fixed-wing and Hybrid UAVs

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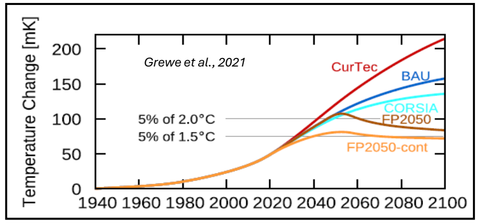
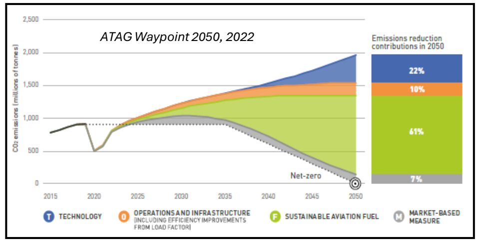
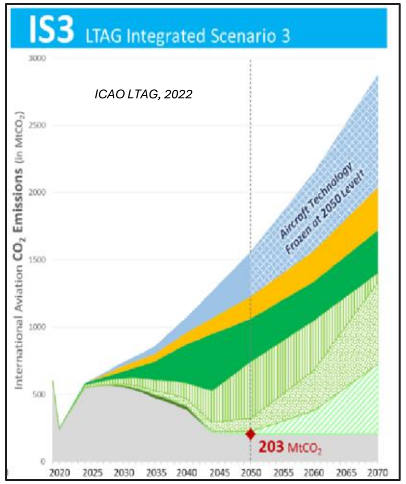
AeroMAPS

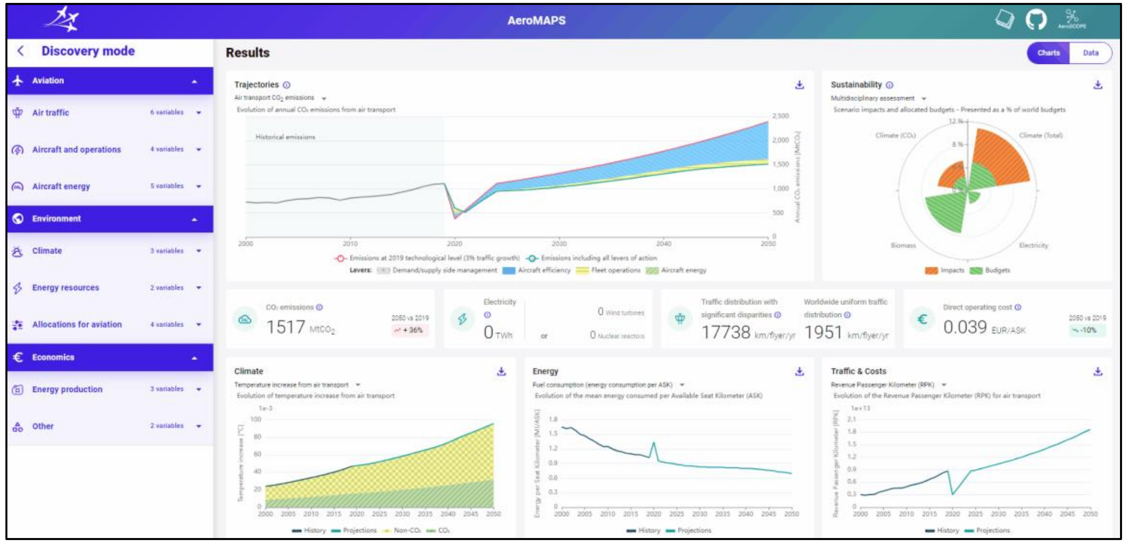
Numerous publications of air transport prospective scenarios…



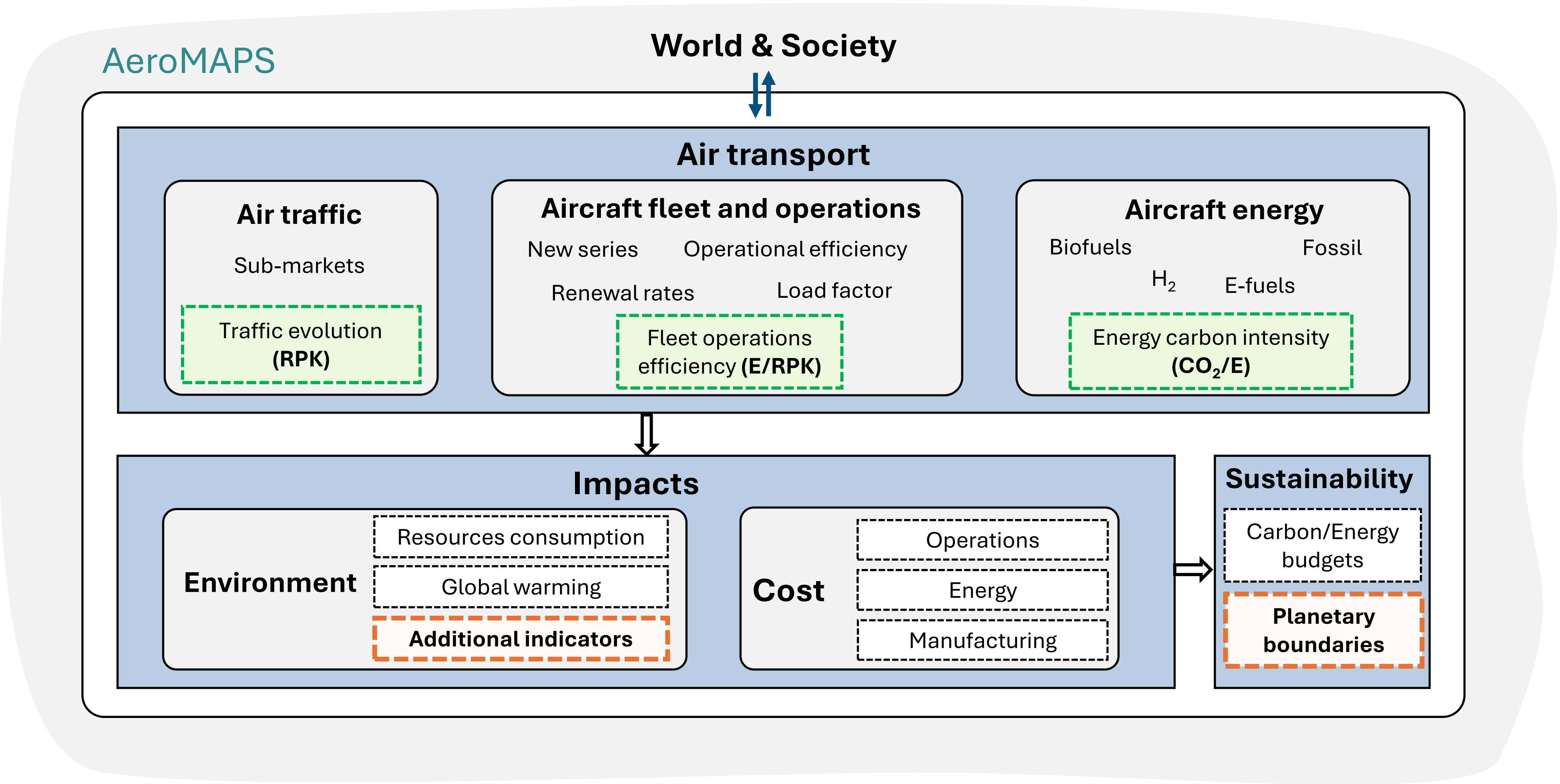




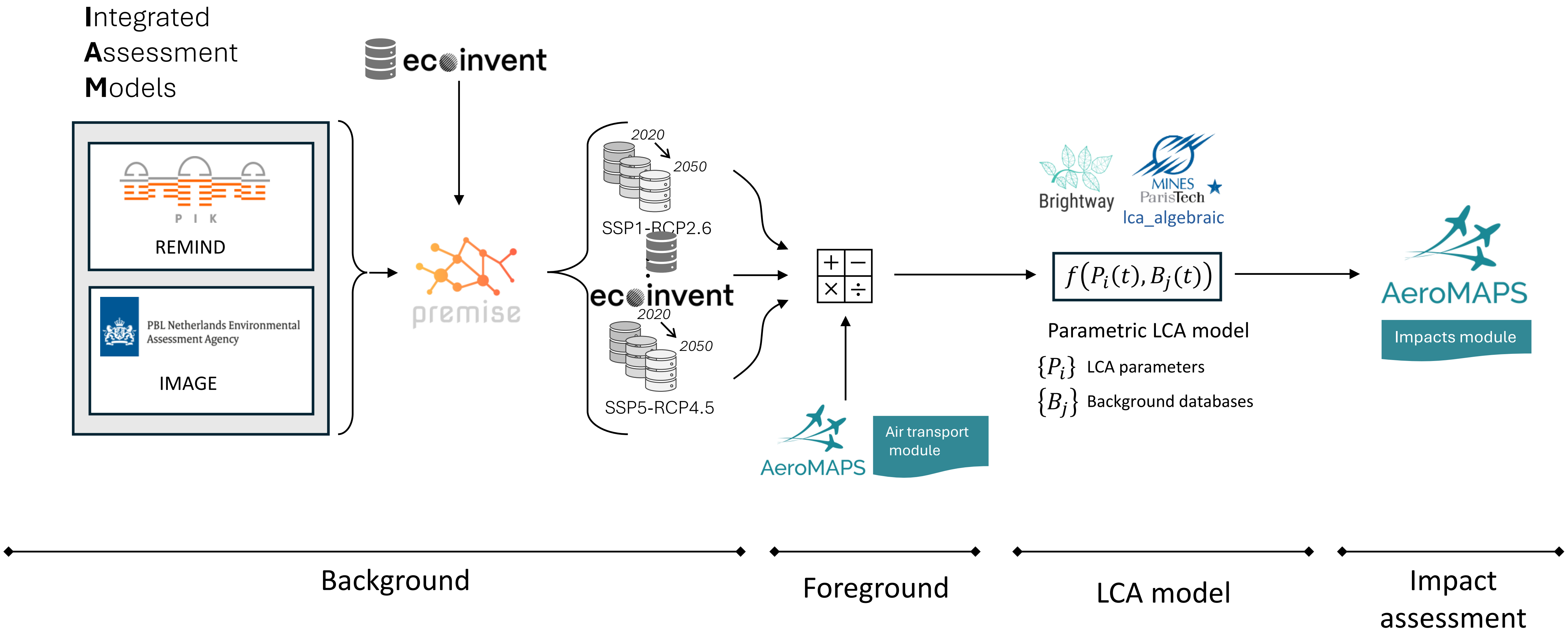
AeroMAPS: An open-source framework for performing multidisciplinary assessments of prospective scenarios for air transport.



Architecture of AeroMAPS



Environmental module



Case study

Air traffic

+3% per year

Aircraft fleet & operations

- New architectures with 20% efficiency gains in 2035
- 6.1% operational gains 2020 → 2050
- 82.4 → 85% load factor increase in 2050

Global socio-economic pathway

SSP2 « Middle of the road » (historical trends)
Without climate policy
Modelled with REMIND IAM

Environmental indicators

ReCiPe methods [1]
21 impact indicators

Energy mix

Scenario 1 - Fossil

100% fossil kerosene

Scenario 2 - ReFuelEU

	2030	2035	2040	2045	2050	
Fossil	94%	80%	66%	58%	30%	
Biofuels	4.8%	15%	24%	27%	35%	[forest residues]
E-fuels	1.2%	5%	10%	15%	35%	[**grid** electricity]

Scenario 3 – ReFuelEU Solar

ReFuelEU with e-fuels produced from **photovoltaic** electricity

[1] Huijbregts et al., ReCiPe2016: a harmonised life cycle impact assessment method at midpoint and endpoint level, 2017

Midpoint impacts

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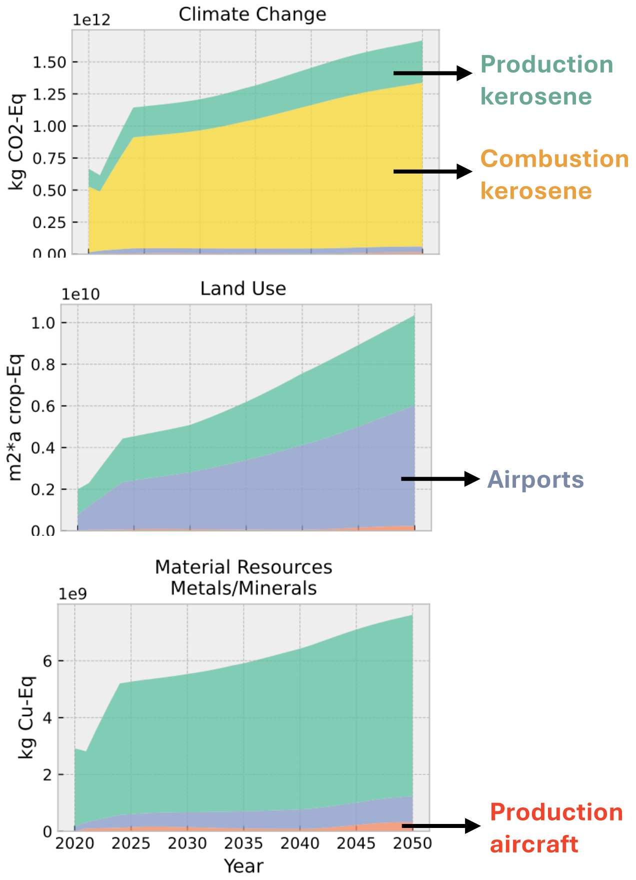
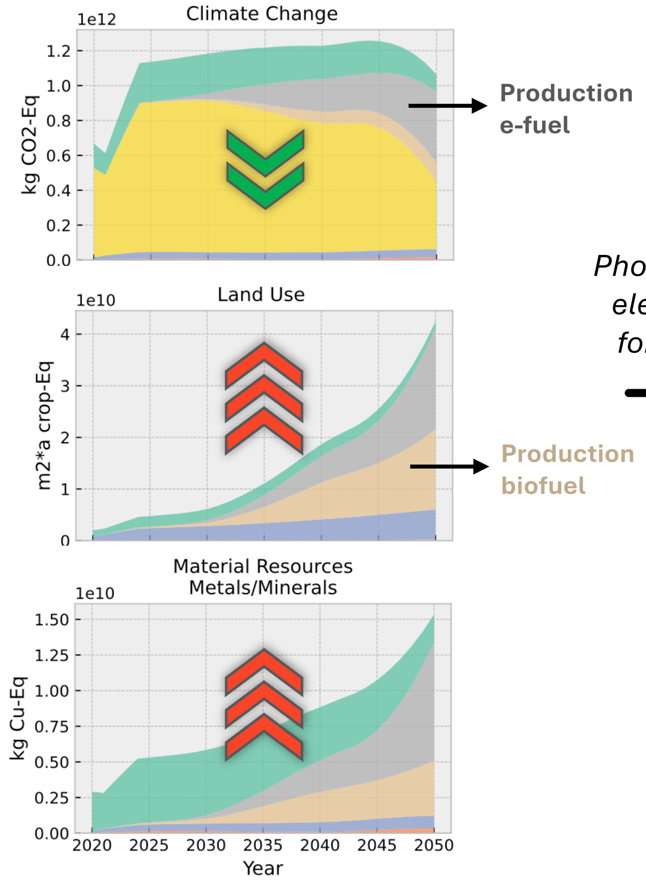
Scenario 1 - Fossil



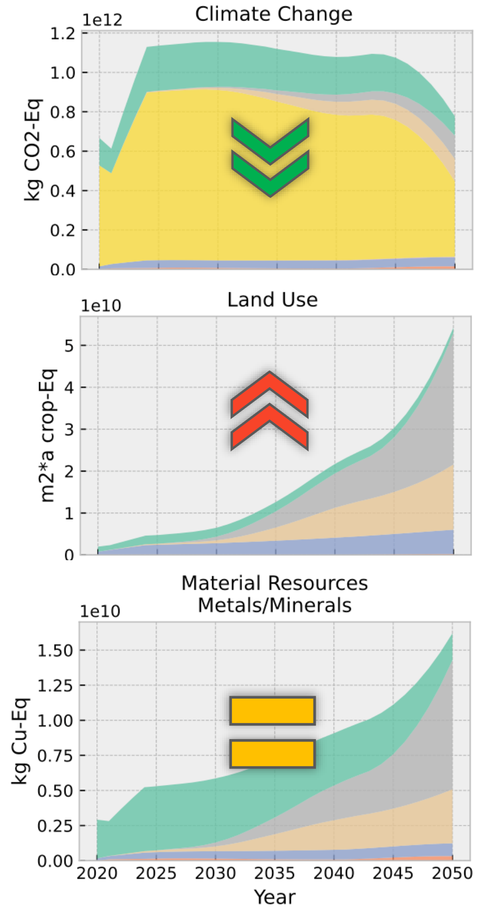
+ Biofuel
+ E-fuel

Scenario 2 – ReFuelEU



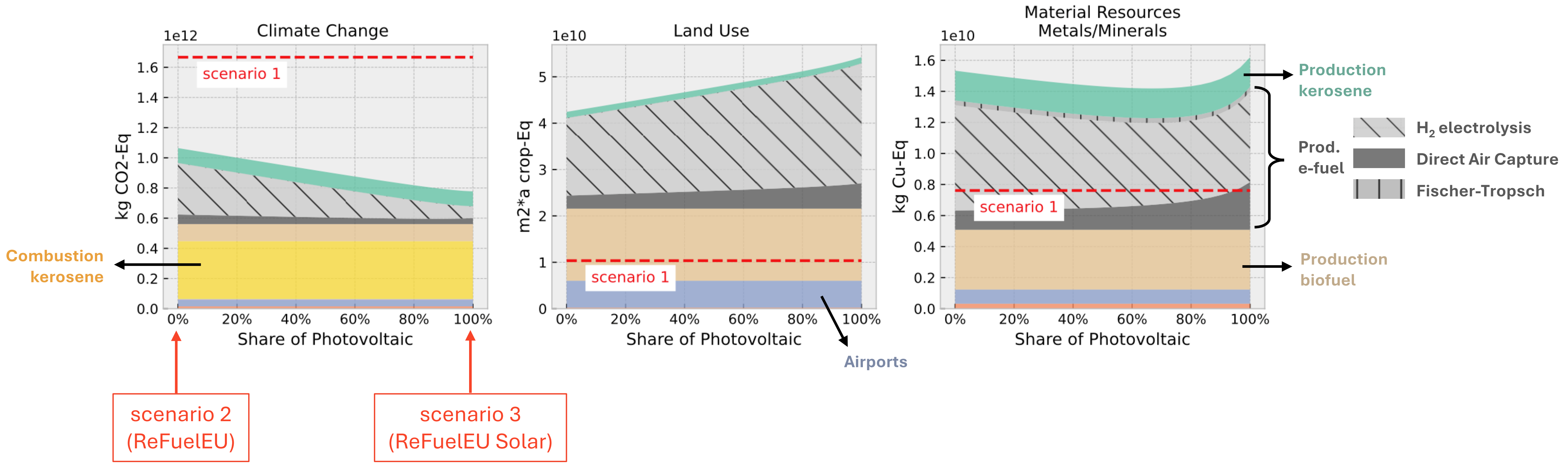
Photovoltaic electricity for e-fuel

Scenario 3 – ReFuelEU Solar

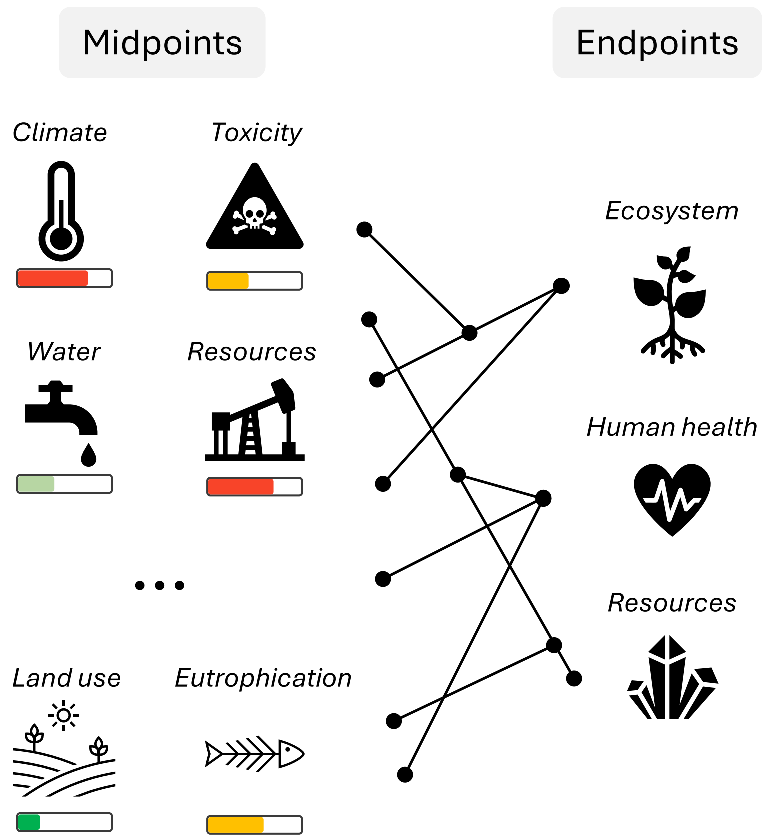


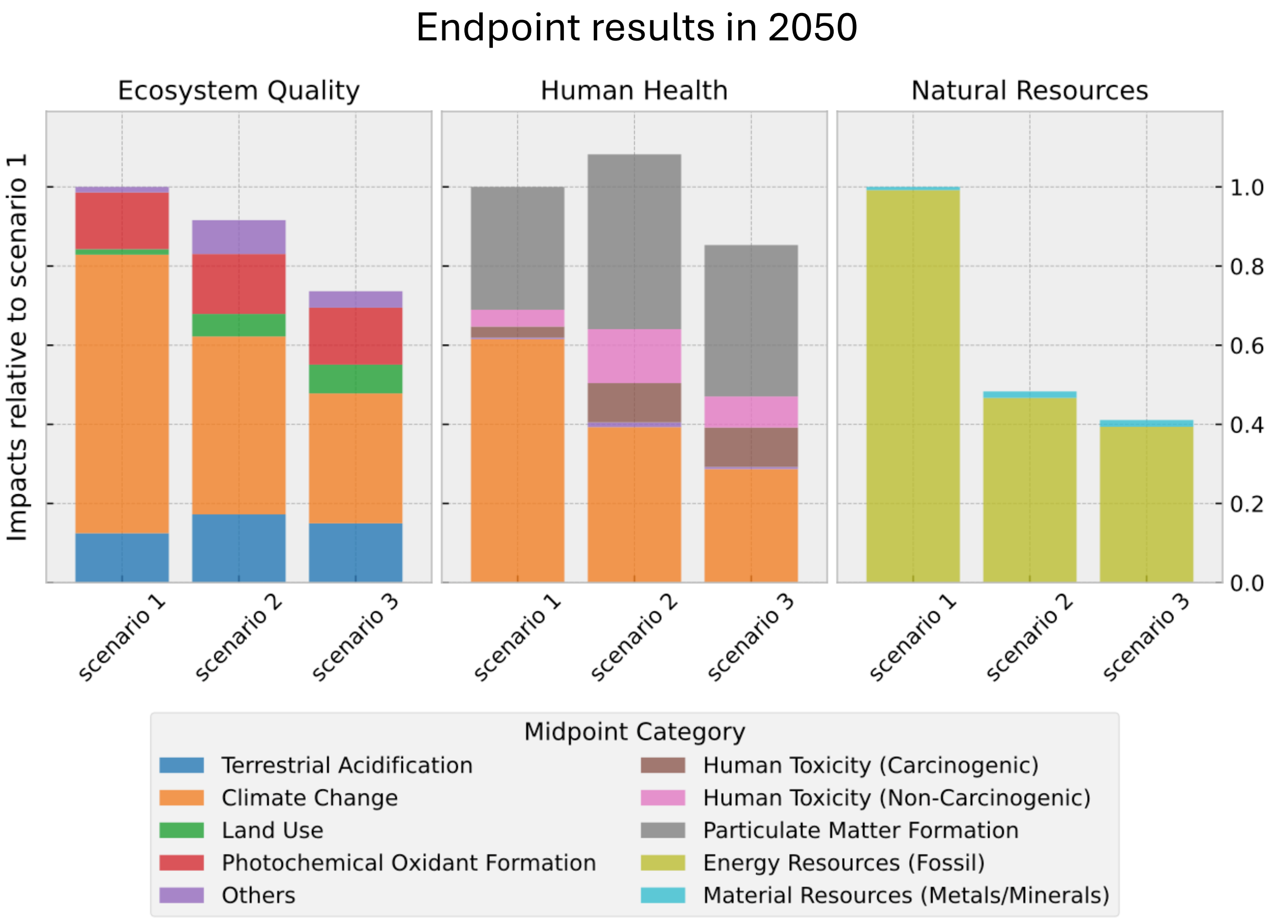
Sensitivity analysis

Sensitivity to electricity mix (in 2050)



Endpoint impacts





Influence of socio-economics & climate policy

	SSP 1 - Sustainable development less inequalities, less resource-intensive lifestyles…	**SSP 2 - Historical trends** for social, economic, and technology
No climate policy		
RCP 2.6 Paris Agreement +2°C		

→ *Socio-economic pathway*

← *Climate policy*

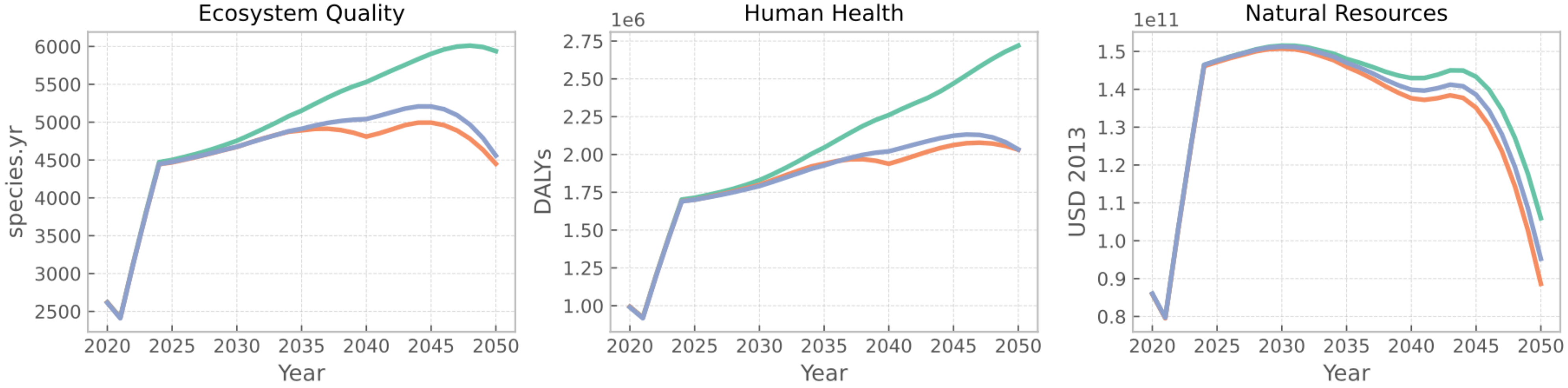
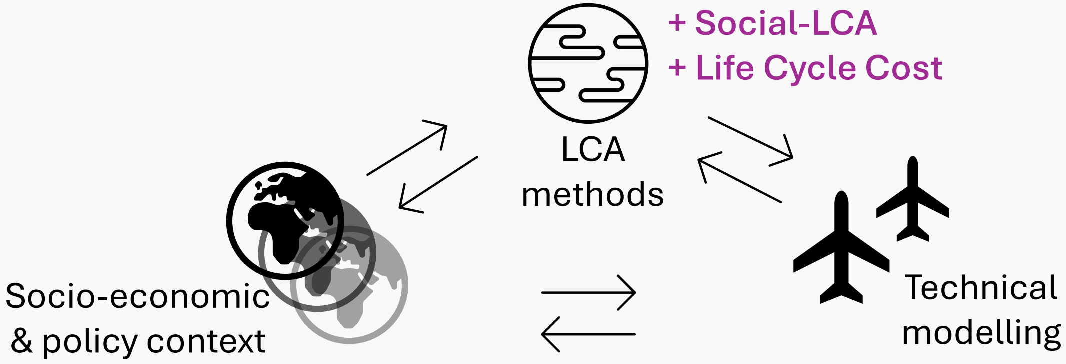


Fig.: Endpoint results for Scenario 2 (ReFuelEU) and different SSP/climate policies (modelled by the *REMIND* IAM)

Conclusion & perspectives

Conclusions & perspectives

Pillars of environmental assessment



S-LCA
LCA ↔ Aircraft design
LCC

LCA is a key enabler for **integrated eco-design** approaches.

- ✓ Conclusive study on electric UAVs
- ◷ Extension to commercial aircraft

S-LCA
LCA ↔ Air transport
LCC

Systematic assessment of **transition scenarios.**

- ✓ Integration of LCA into AeroMAPS
  Release Q4 2024
- ◷ Sensitivity & uncertainty analyses
- ◷ Finer modelling of fuel pathways
  & improved impact assessment methods
- ◷ Comparison with environmental budgets for "absolute" impact assessment (sustainability)
- ◷ Consistency between air transport scenarios and socio-economic pathways / climate policies modelled by IAMs

Thank you

Publications

- Pollet, F., Budinger, M., Delbecq, S., Moschetta, J.-M., & Planès, T. (2023). **Environmental Life Cycle Assessments for the Design Exploration of Electric UAVs.** Proceedings of the Aerospace Europe 2023 Conference

- Pollet, F., Planès, T., & Delbecq, S. (2024). **A comprehensive methodology for performing prospective Life Cycle Assessments of future air transport scenarios.** Submitted to the 34th Congress of the International Council of the Aeronautical Sciences

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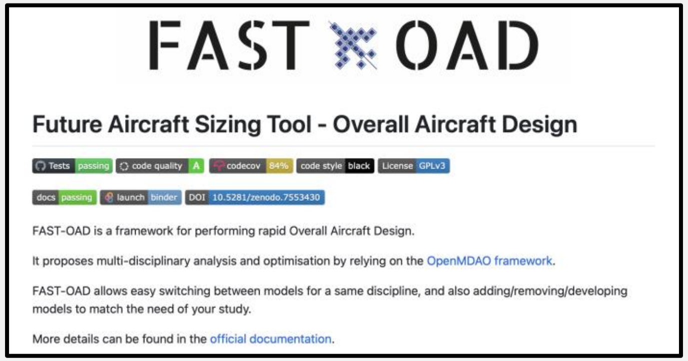
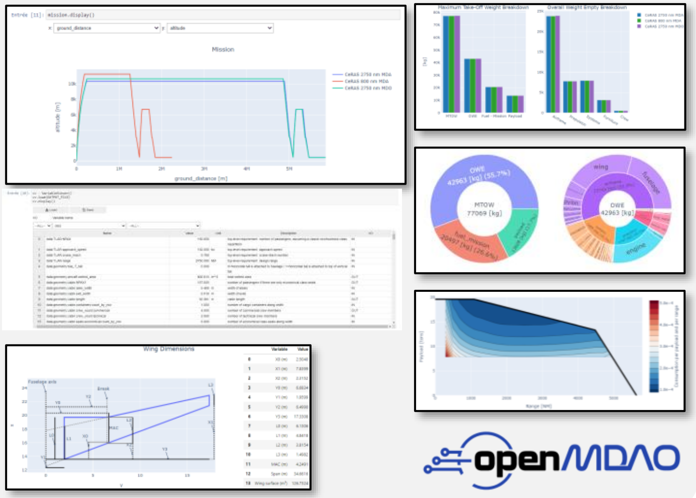
Aircraft design tools

FAST-OAD: an open-source framework for overall aircraft design



https://github.com/fast-aircraft-design/FAST-OAD



openMDAO

FAST-OAD-CS25: Regional, SMR, (LR)

ONERA ATR AIRBUS CEDAR

C. David et al. "From FAST to FAST-OAD: An open source framework for rapid Overall Aircraft Design." 2021.

FAST-OAD-CS23: General aviation (+ Commuter)

ONERA DAHER

F. Lutz et al. "FAST-OAD-GA: an open-source extension for Overall Aircraft Design of General Aviation aircraft." 2022.

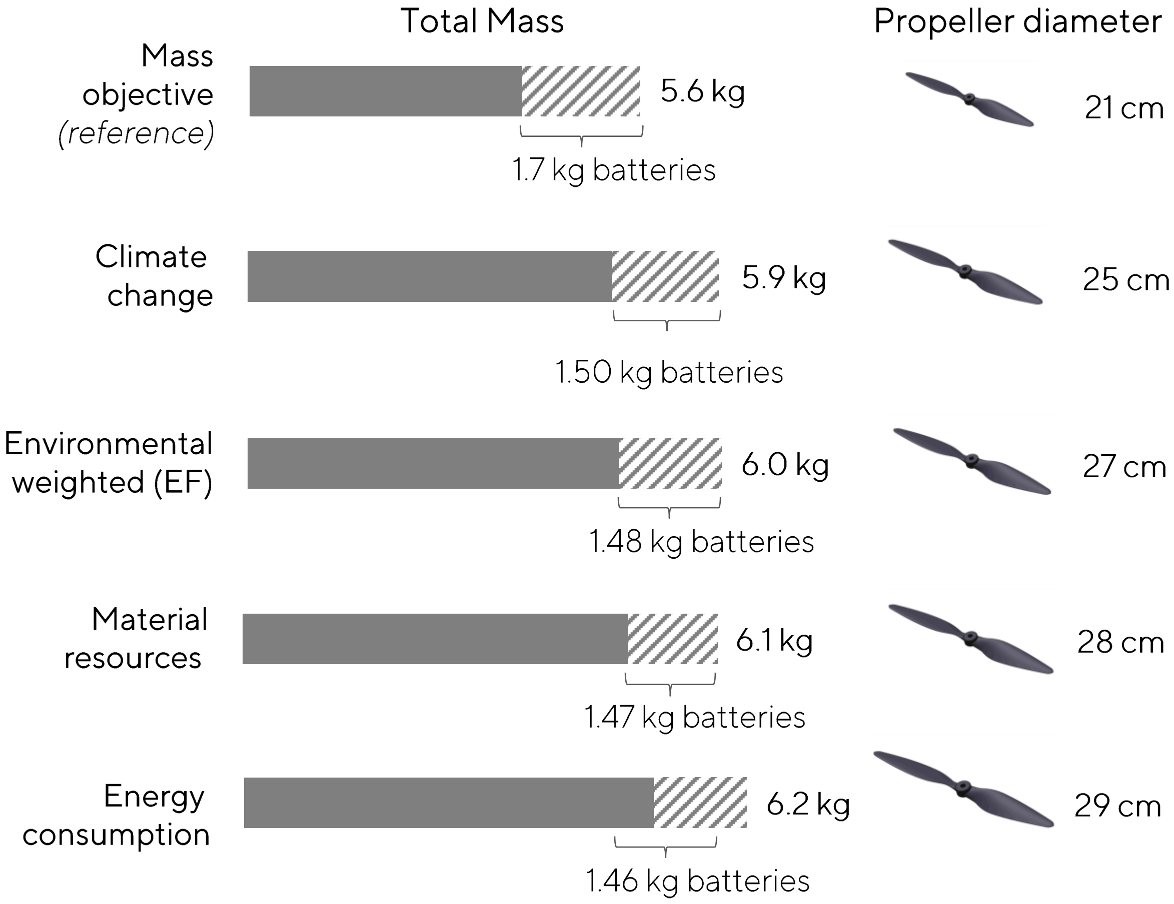
FAST-UAV: Multirotor, Fixed-wing and Hybrid UAVs

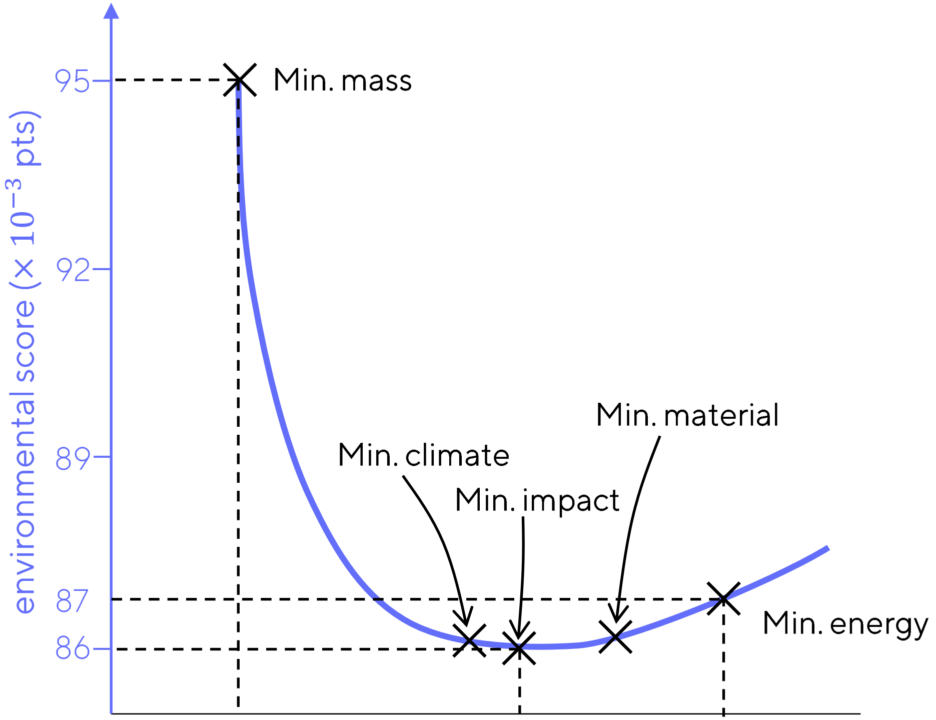
INSA Toulouse Concordia University

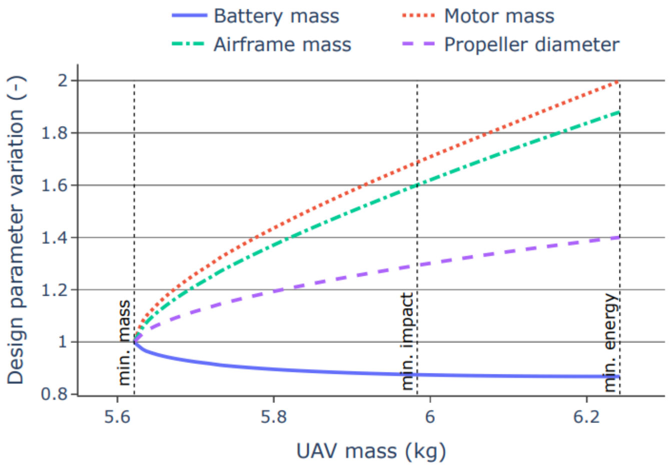
F. Pollet et al. "A common framework for the design optimization of fixed-wing, multicopter and VTOL UAV configurations." 2022.

Sensitivity to weighting of environmental objective

Sizing results







Fi ctives

Sustainability of last-mile delivery

4 kg/week (e.g., groceries) from a 10 km store

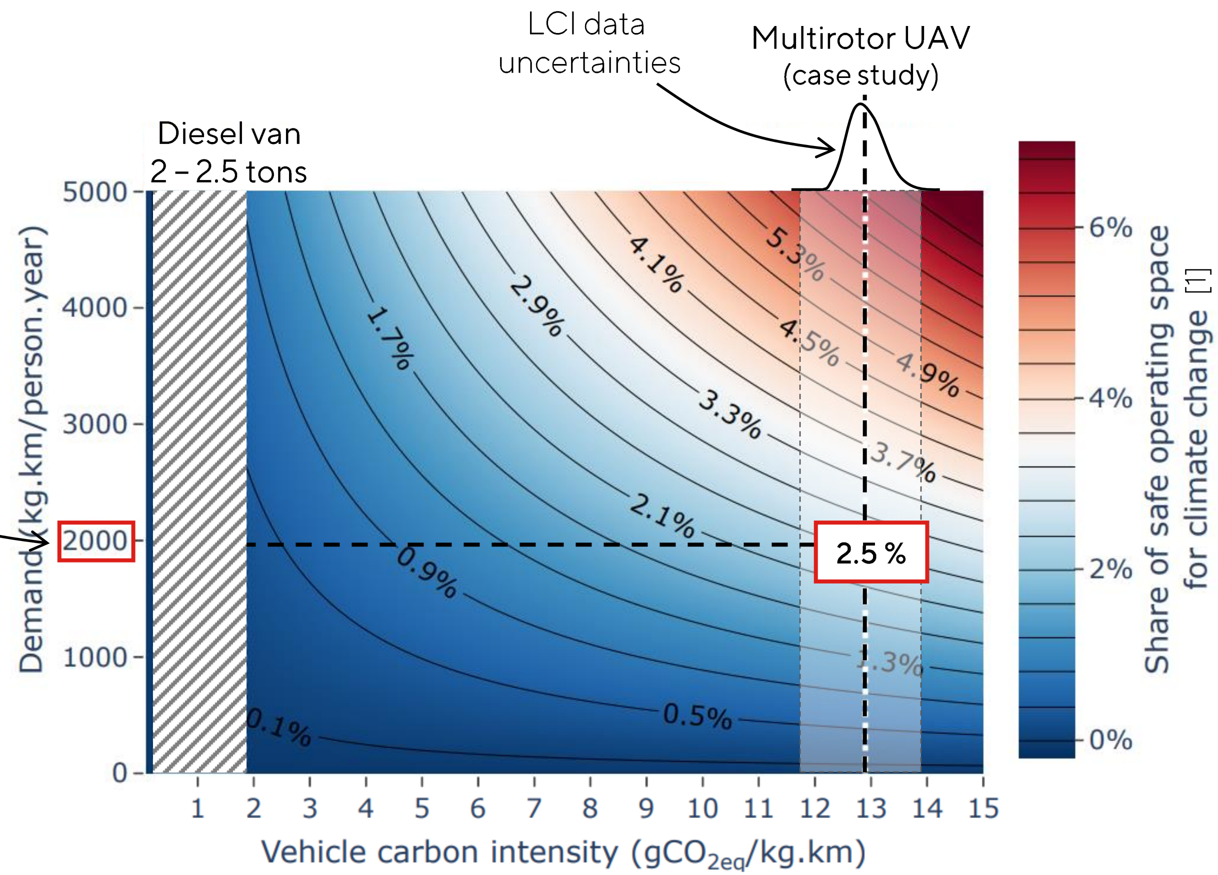
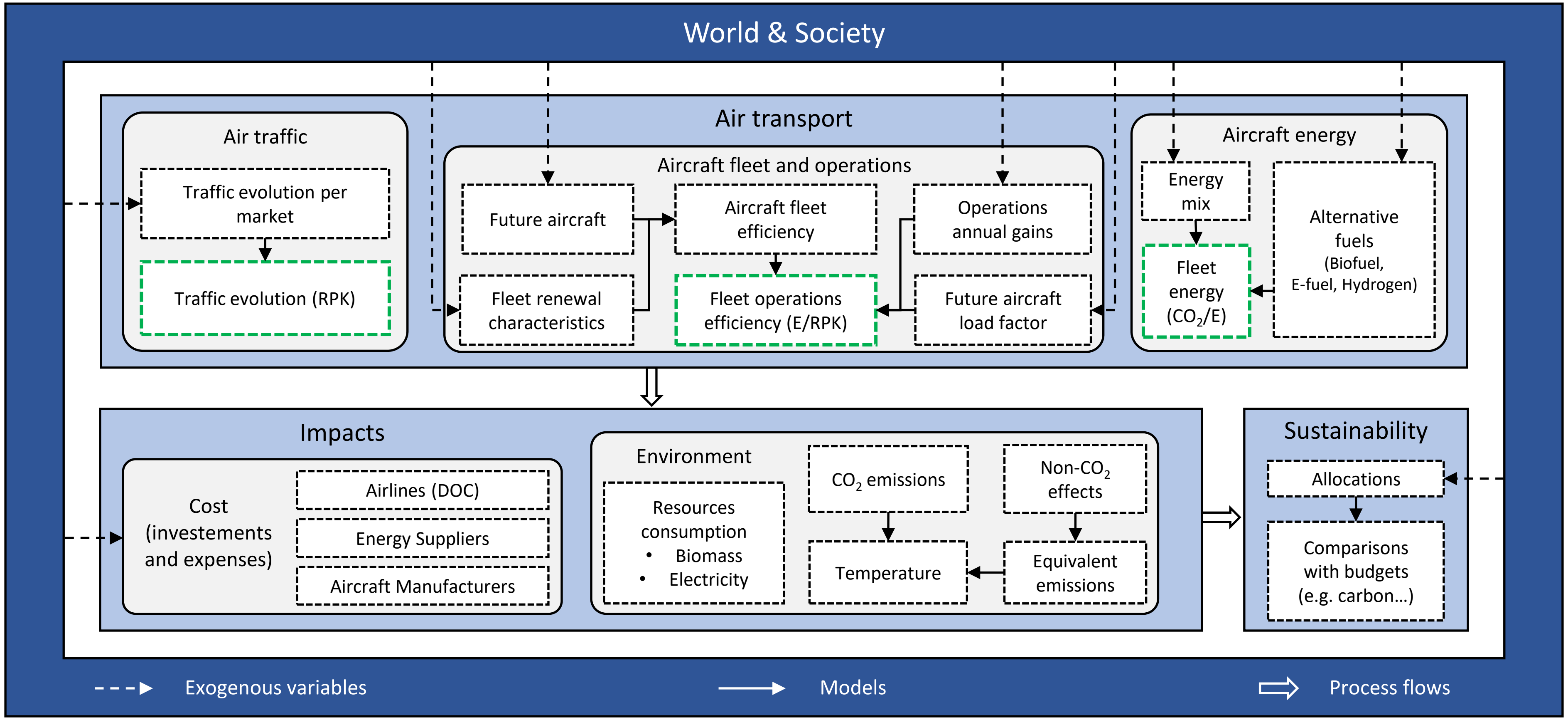


Fig.: Share of safe operation space consumed by last-mile delivery as a function of vehicle carbon intensity and usage intensity

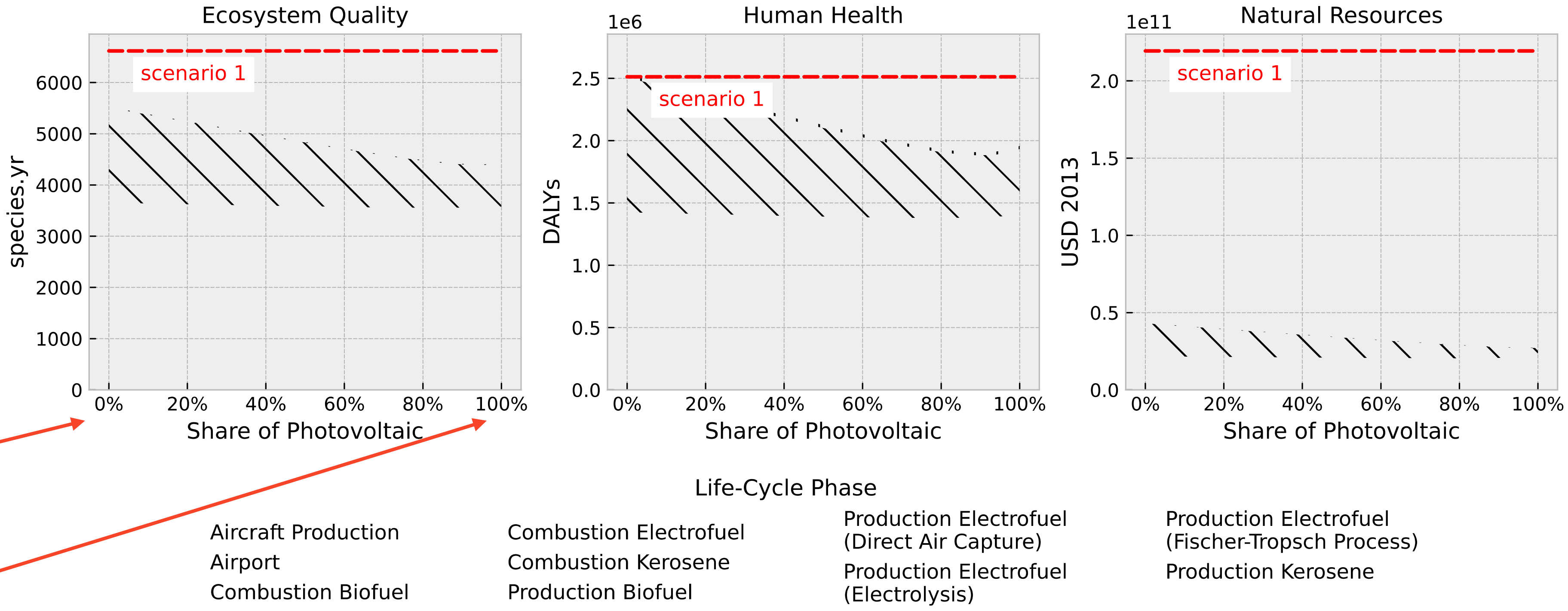
[1] Sala et al., Journal of Environmental Management, 2020

AeroMAPS


World & Society
Air transport
Air traffic
Traffic evolution per market
Traffic evolution (RPK)
Aircraft fleet and operations
Future aircraft
Aircraft fleet efficiency
Operations annual gains
Fleet renewal characteristics
Fleet operations efficiency (E/RPK)
Future aircraft load factor
Aircraft energy
Energy mix
Fleet energy (CO_2/E)
Alternative fuels (Biofuel, E-fuel, Hydrogen)
Impacts
Cost (investements and expenses)
Airlines (DOC)
Energy Suppliers
Aircraft Manufacturers
Environment
Resources consumption
• Biomass
• Electricity
CO_2 emissions
Non-CO_2 effects
Temperature
Equivalent emissions
Sustainability
Allocations
Comparisons with budgets (e.g. carbon…)
Exogenous variables
Models
Process flows

Sensitivity analysis

Sensitivity to electricity mix (in 2050)

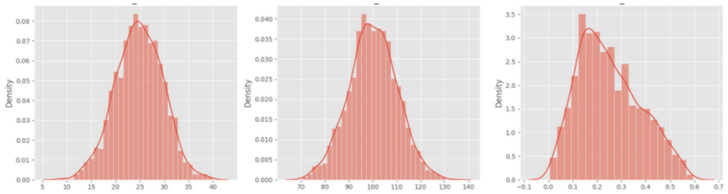


scenario 2

scenario 3

$$Impact_k = f(p_1, \dots p_n)$$

→ Monte Carlo sur paramètres incertains →



→ Validation modèle référence
ou estimation incertitudes futures

$$Impact_k = f(p_1, \dots p_n)$$

→ Identification des paramètres influents par analyse de sensibilité *(e.g., Sobol’)* →

Modèle simplifié

$$\widehat{Impact}_k = g(p_1, \dots p_m) \quad m < n$$

	Climate	Land use	Water use	...
p_1				
p_2				
p_n				