Sustainable aviation methods and tools

An overview perspective

Prof. Joseph Morlier

Thanks for inviting me !!!

Calculate your plane travel footprint

I want to calculate emissions for a 1 passenger one-way flight in economy class between Toulouse-Blagn... and Soekarno-Hatta with a connection in Doha.

Calculate

You calculated an emission of:
1.9t

Estimation of the carbon dioxide emissions budget for one person, based on the Paris Agreement objective of maintaining global temperature warming "well below" 2°C.

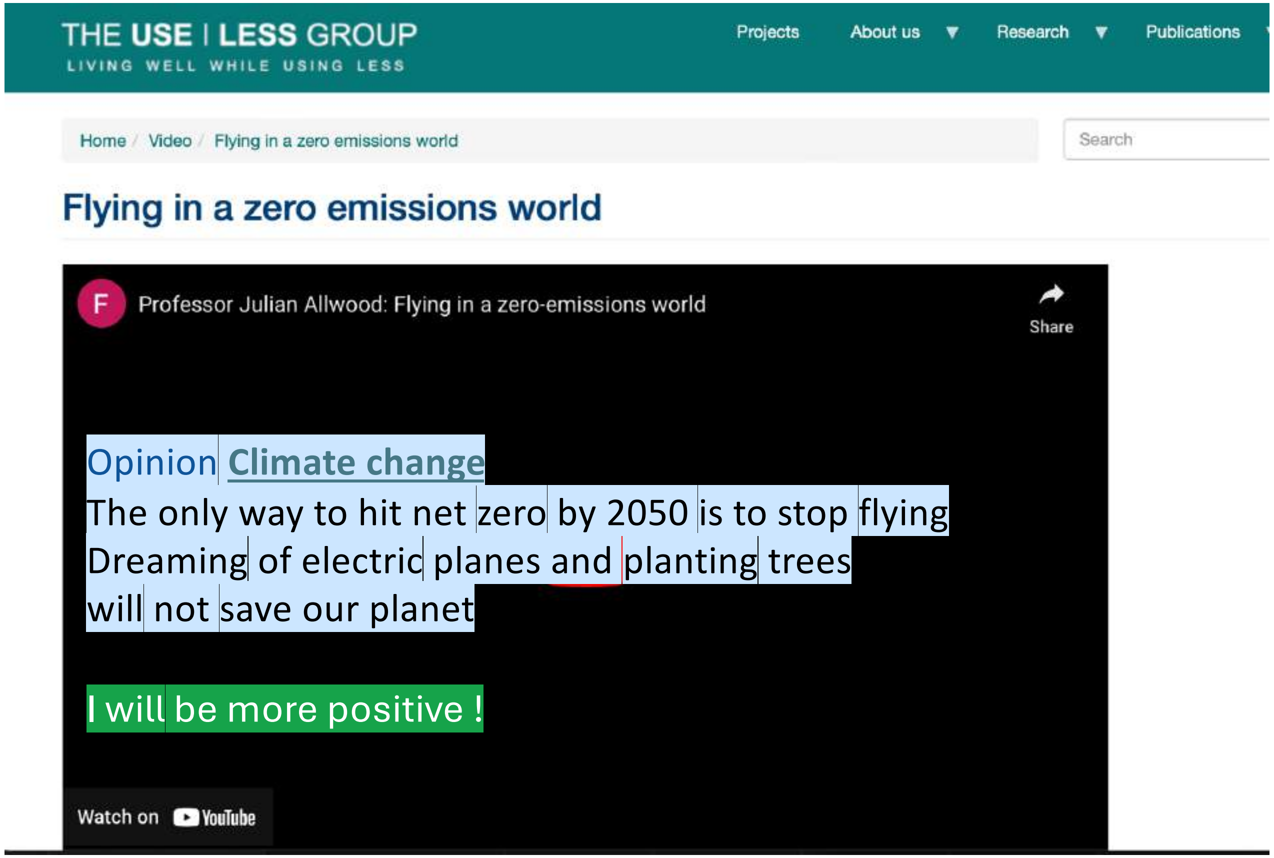
https://curb6.com/calculators/plane

Let’s make a pause on my flight

My round trip Flight « costs » me 1.9tCO2eq

But I’m here for research and education to promote Sustainable aviation !

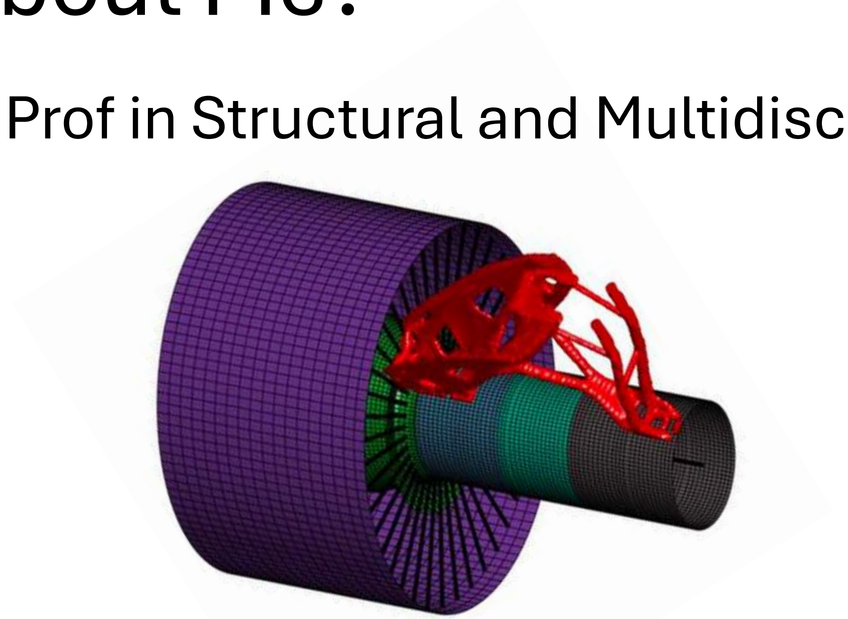
“The Most Intelligent Photo Ever Taken”: The 1927 Solvay Council Conference, Featuring Einstein, Bohr, Curie, Heisenberg, Schrödinger & More

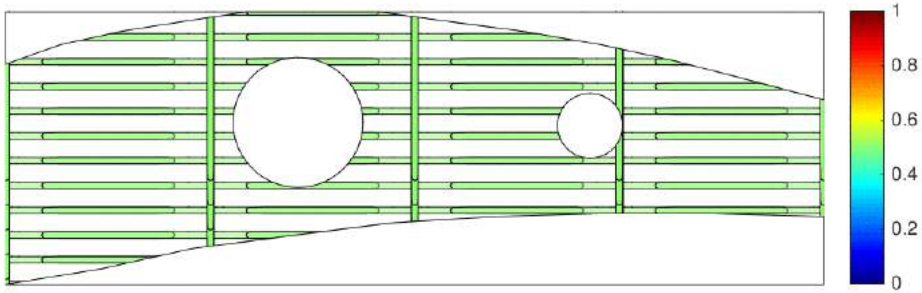


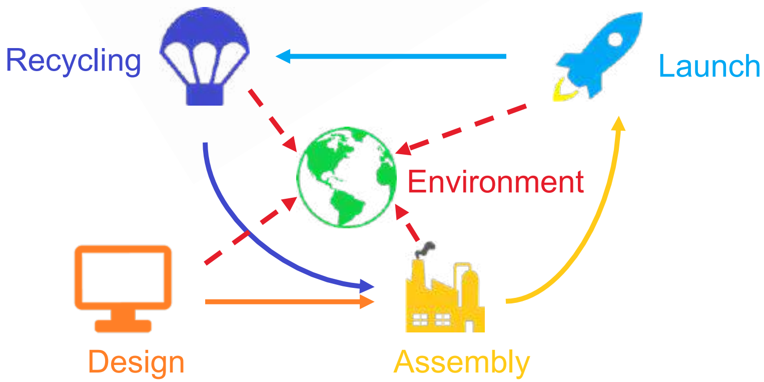
https://www.uselessgroup.org/publications/video/flying-zero-emissions-world

About Me?

- Prof in Structural and Multidisciplinary Optimization

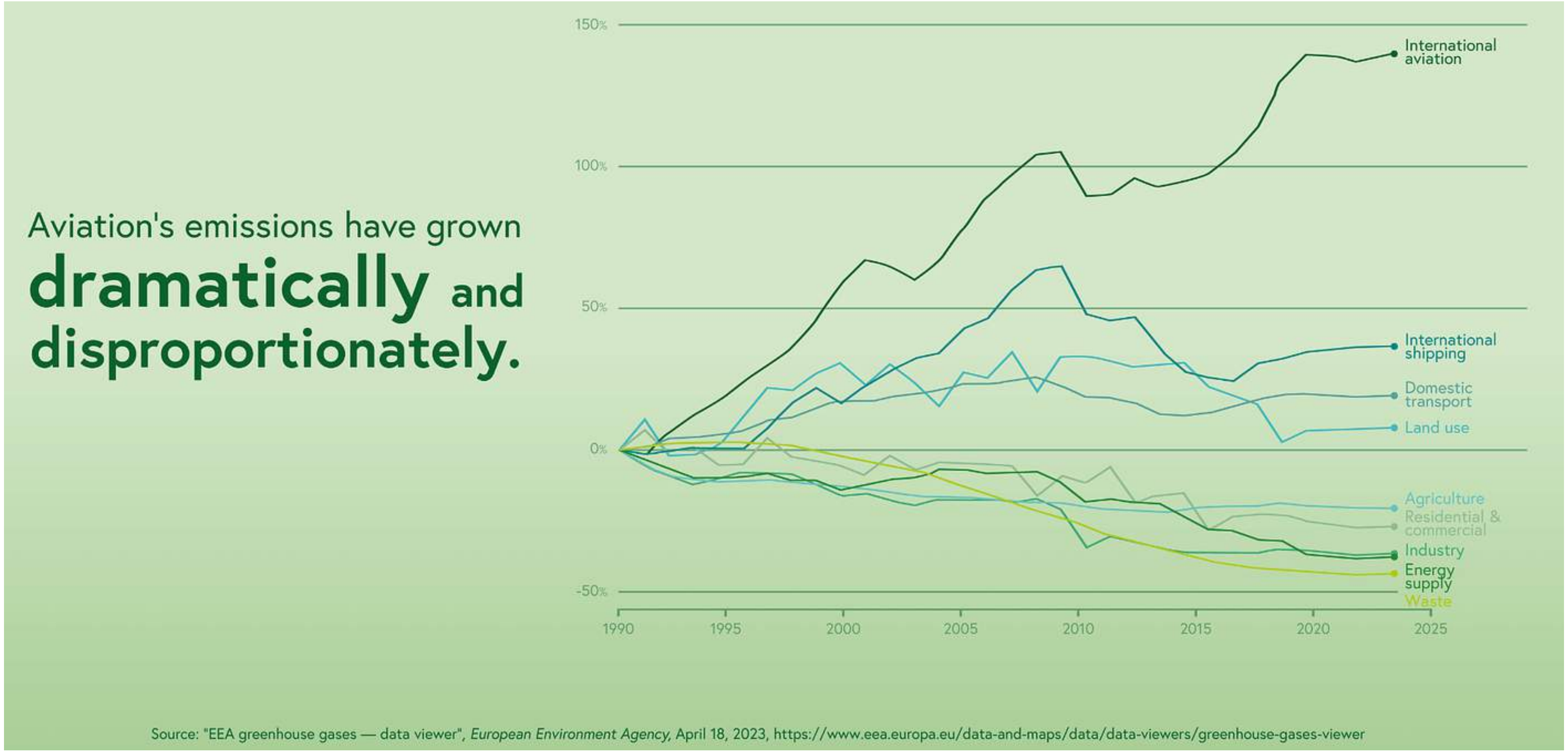




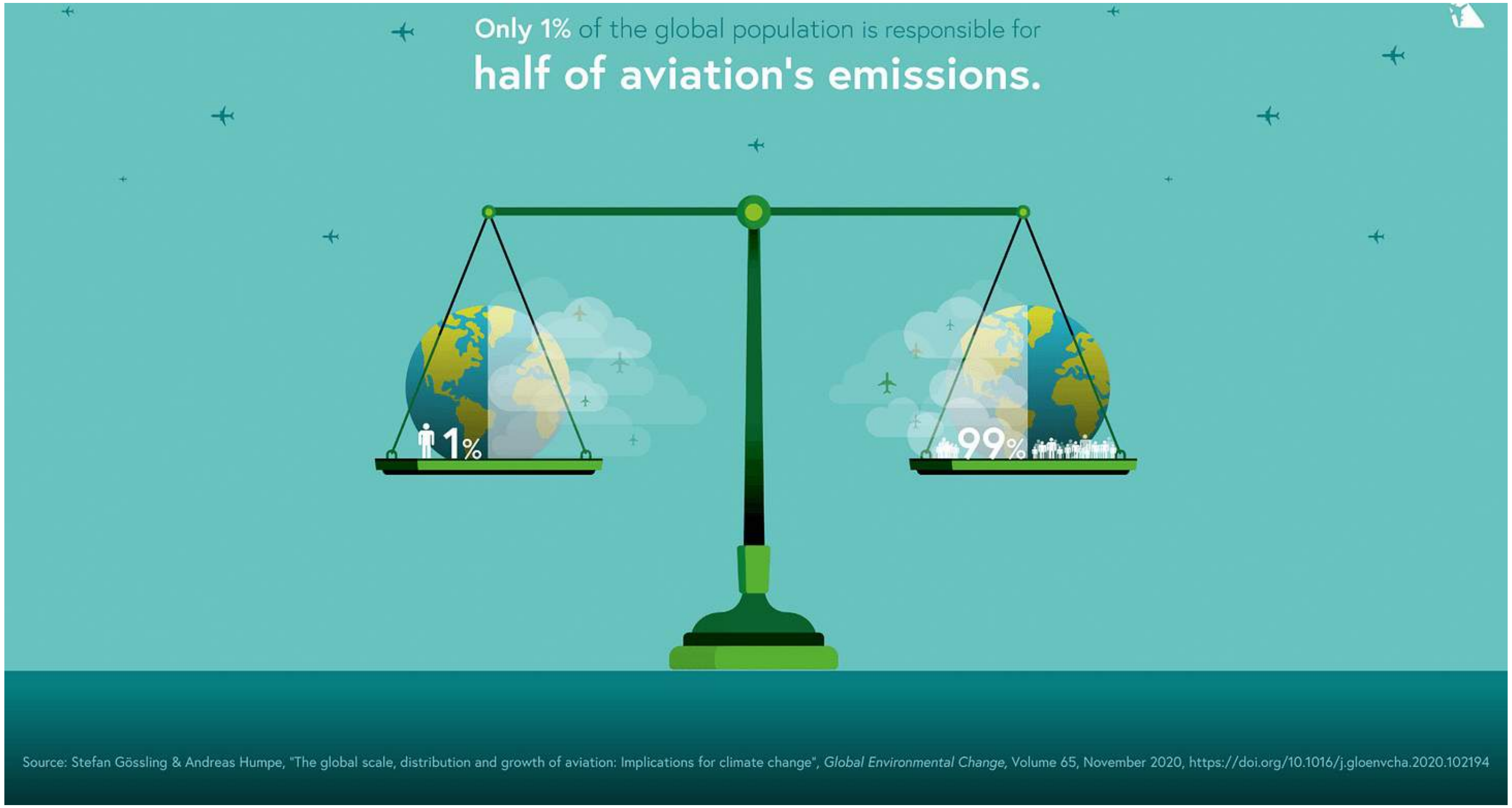


Sustainable aviation?

https://green.simpliflying.com/p/understanding-sustainable-aviation

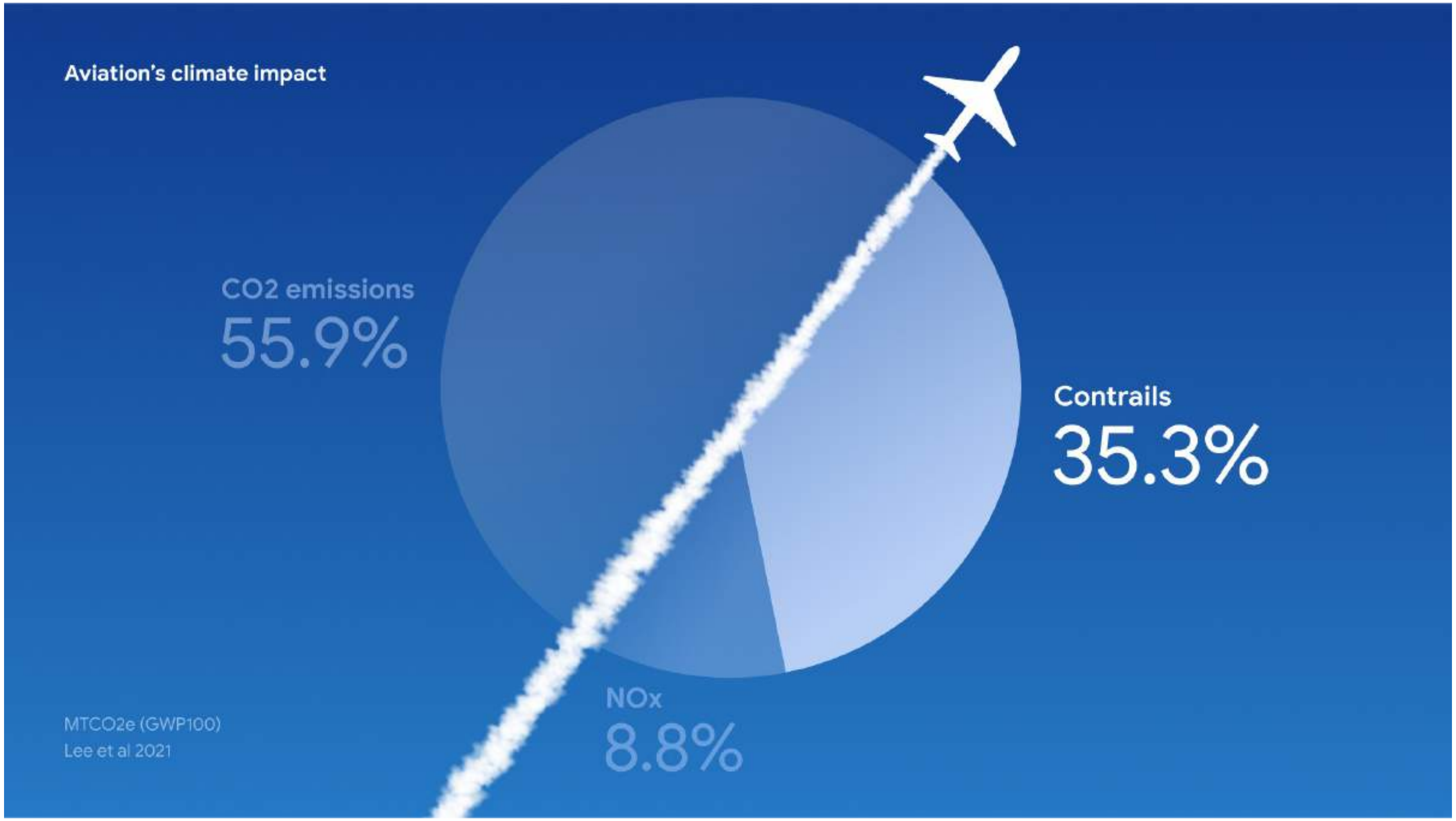


Sustainable aviation?



Sustainable aviation?

Sustainable aviation?



SA?

Sustainable Aviation (SA) is a multi-disciplinary field that seeks solutions to improve the environmental and societal impacts of air transportation. It aims to reduce aviation's contribution to climate change through new practices and radical innovation

https://aero.engin.umich.edu/research/research-areas/sustainable-aviation/

Agenda for today

1. Sustainable Aviation (SA) With one eye open / With two eyes open
2. Design Optimization (DO)
3. Combining SA+DO for my research
4. Conclusions

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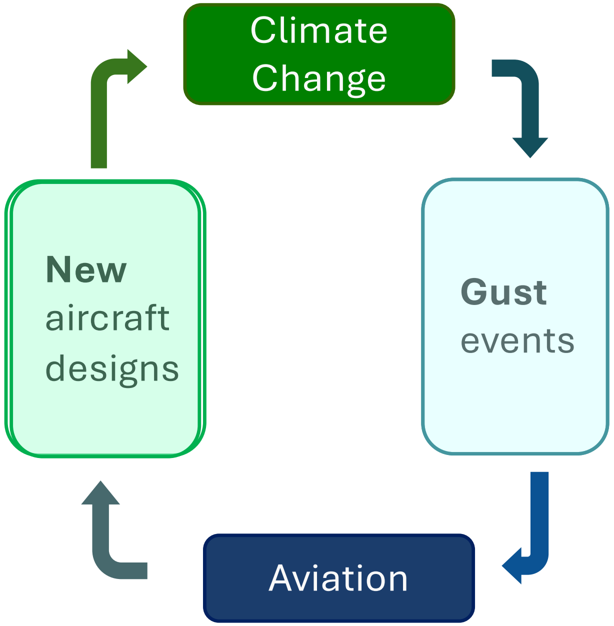
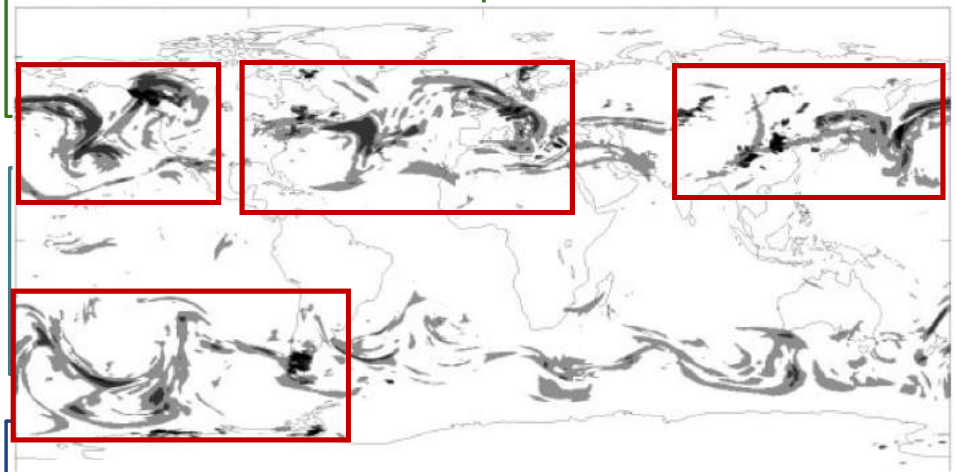
Current situation

- Fuel consumption per passenger per km is comparable to that of a modern car
- The **large distances** and **massive number of passengers** cause significant climate impact
- Aviation currently accounts for **2.5%** of the global CO_2 emission
- This percentage will rise if we do not act
- Furthermore, **non-CO_2 effects** ($NO_x \rightarrow O_3$, contrails) more than double the climate impact

But what are the effect on aviation?

Aviation currently accounts for **2.5%** of the global CO_2 emission





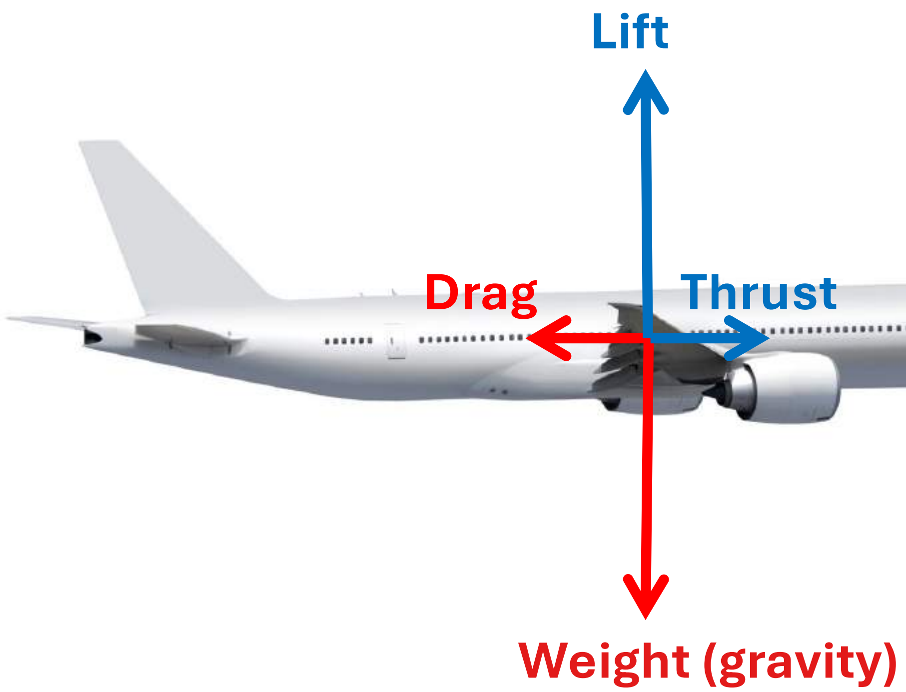
Source:
Gill, Meteorology Applications, 2014.

loads for new **high Aspect Ratio** wings.

Source: Airbus ©

Energy-efficient planes are the key

And weight is a determining factor…



Why?

$$\text{"The rate of aircraft weight reduction"} = \text{"The rate of fuel weight burned"}$$

$$\text{Range} = Vt_f = V \times \underbrace{\left(\frac{L}{D}\right)}_{\text{aircraft designer}} \times \underbrace{I_{sp}}_{\text{propulsion system designer}} \times \underbrace{\ln\left(\frac{W_i}{W_f}\right)}_{\text{structural designer}} .$$

Since the endurance/range is defined by *cruise* conditions, the equilibrium steady flight conditions of T=D and L=W

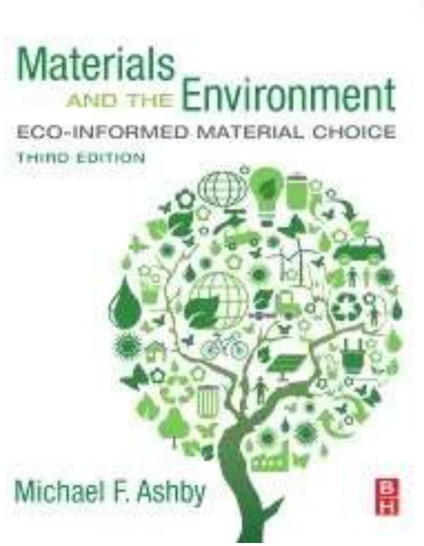
We have to use a holistic approach

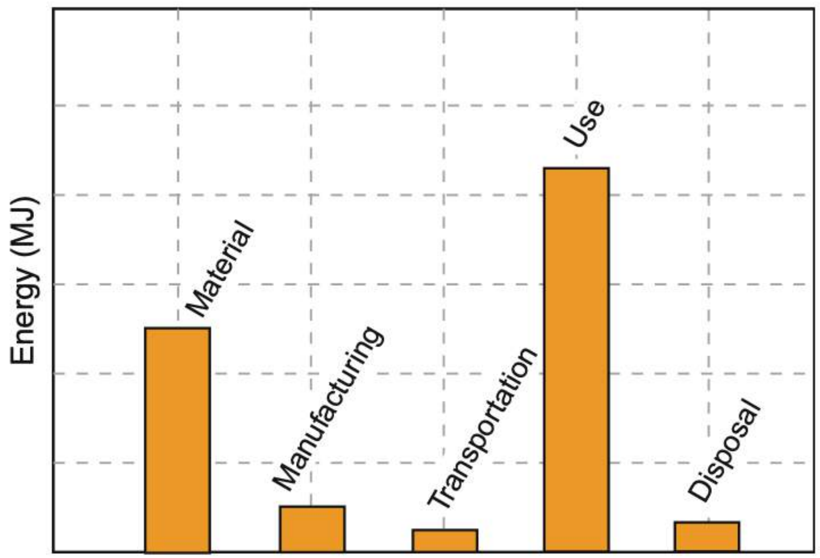
All knobs we may turn are interconnected

Reduce ***Emission*** by

- Replace fossil fuels
- Introduce extremely fuel-efficient aircraft (high L/D, **low mass**)
- Using energy efficient and cleaner propulsion systems
- Optimizing cruise altitude/speed (also for non-CO_2 effects!)
- Alternative/intermodality transport

Environnemental Footprint

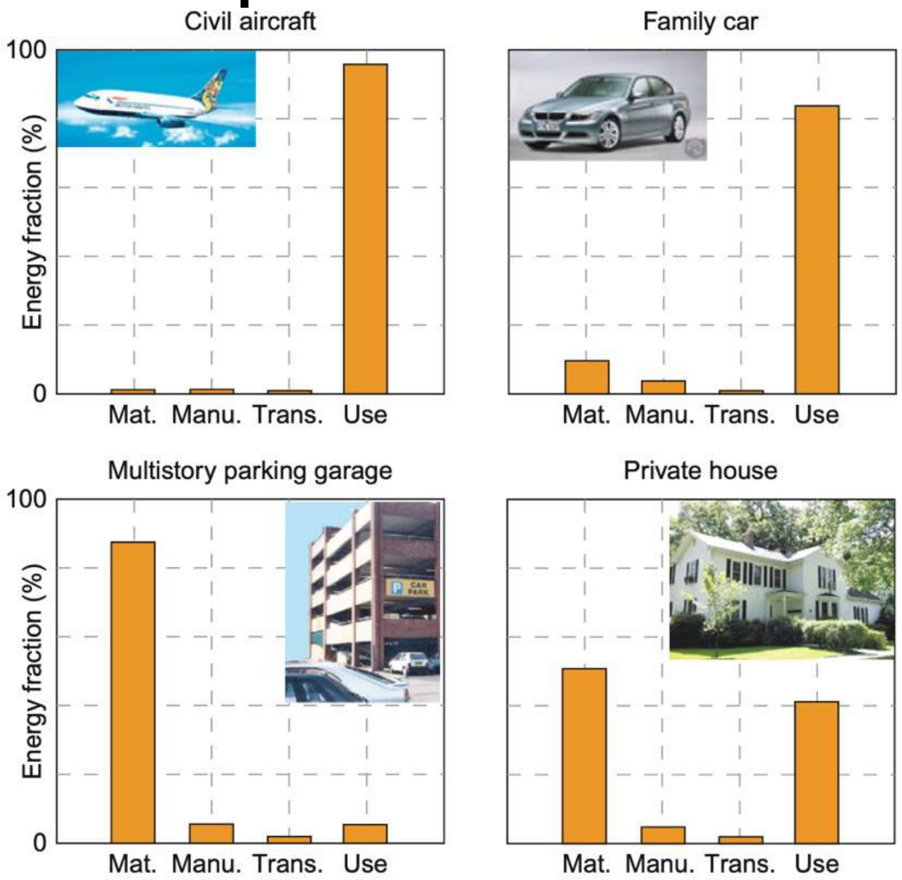




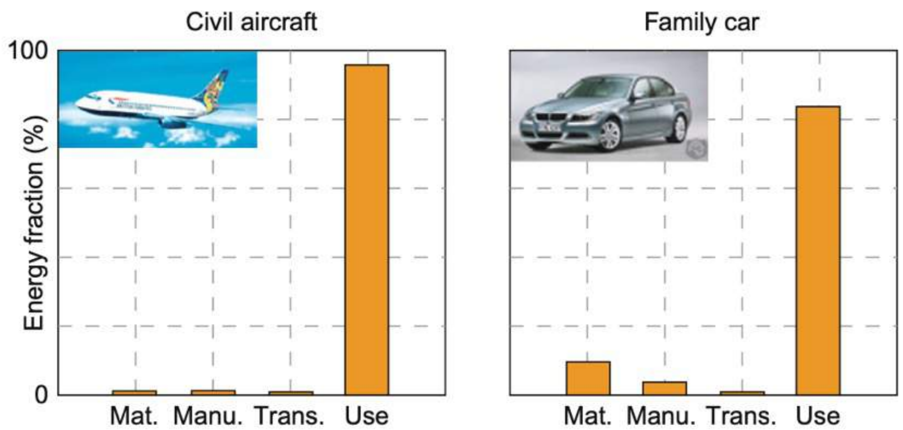
$\propto CO_2$

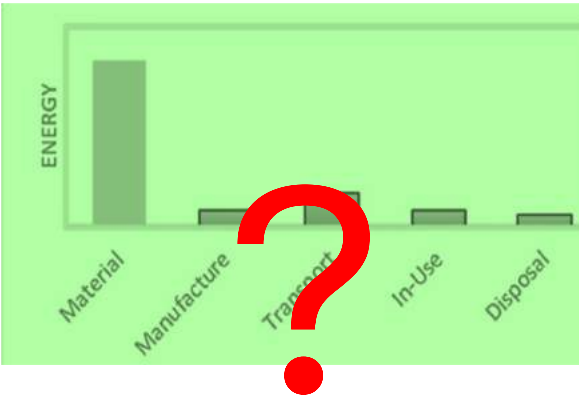
Breakdown of energy into that associated with each life phase

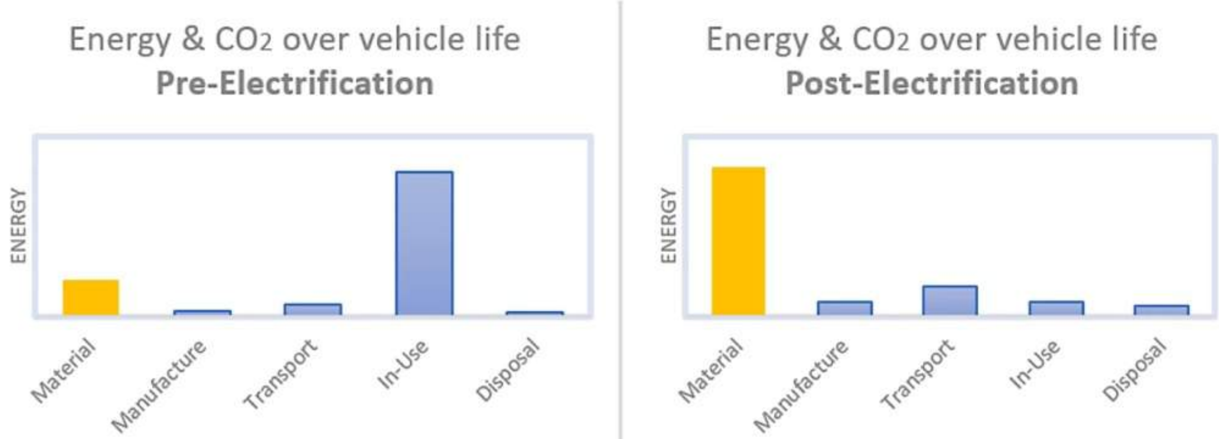
Different products … different impacts



Electrification example (from automotive)

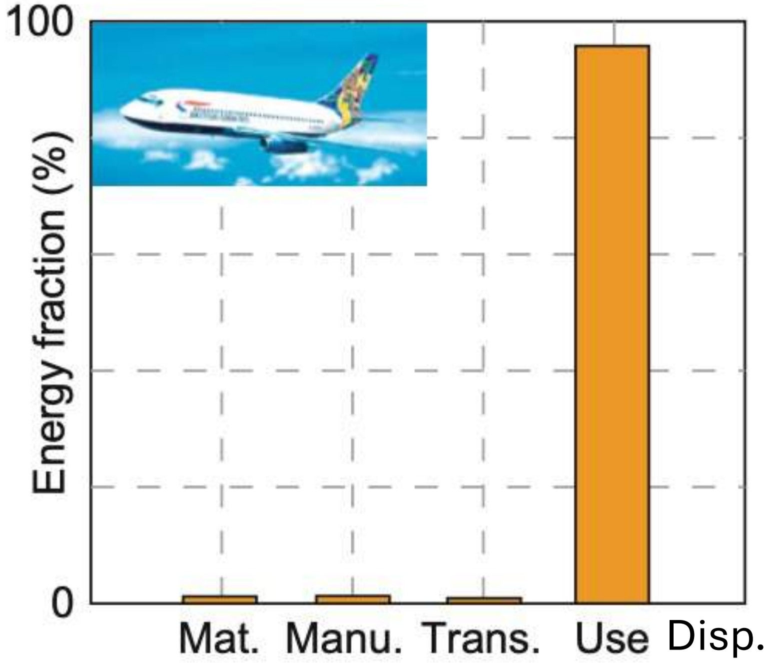




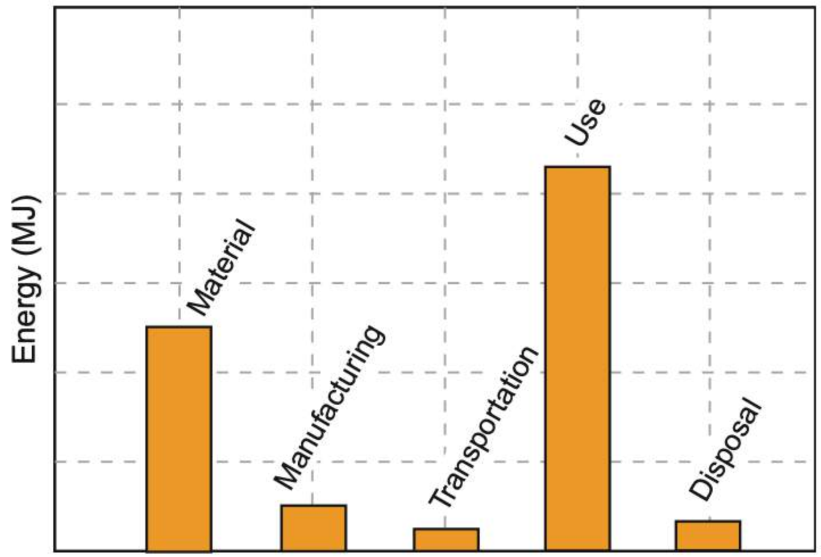


https://www.ansys.com/blog/the-impact-of-materials-on-sustainability-part-2

Energy ∝ CO_2 footprint



Future Sustainable Air vehicule

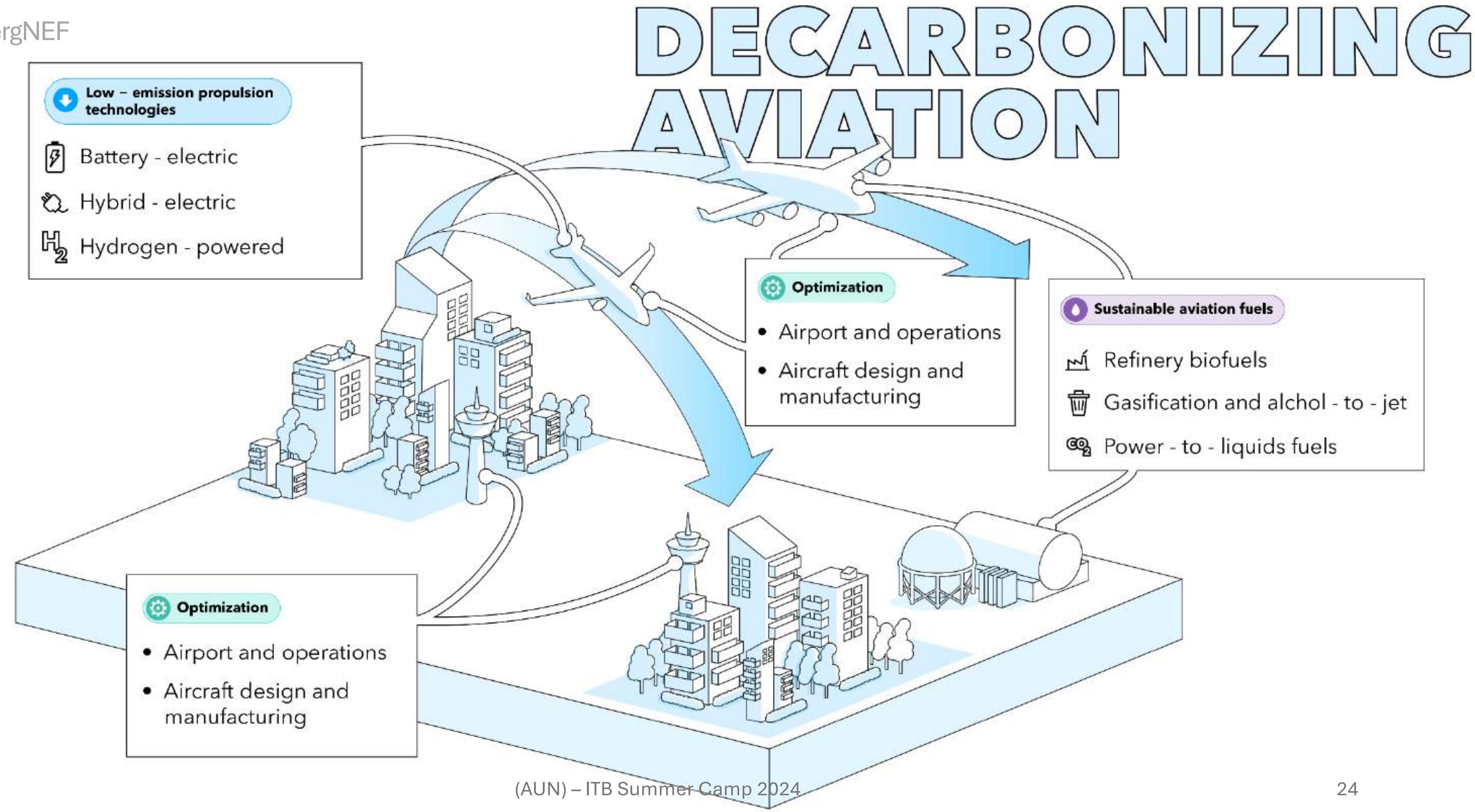


Breakdown of energy into that associated with each life phase

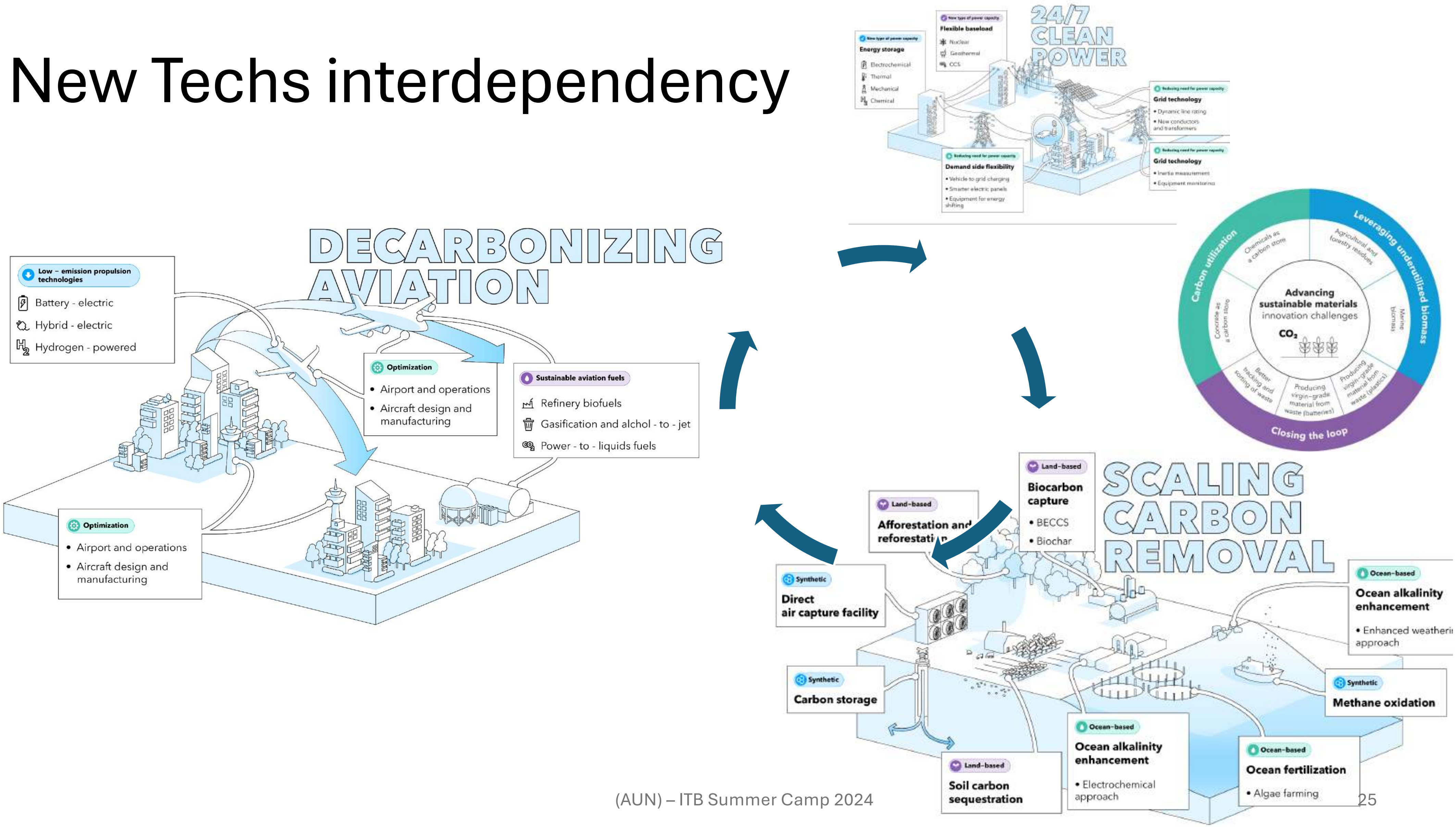
Hydrogen, SAF, Electric/Hybrid Propulsion...

Overview

from BloombergNEF



New Techs interdependency

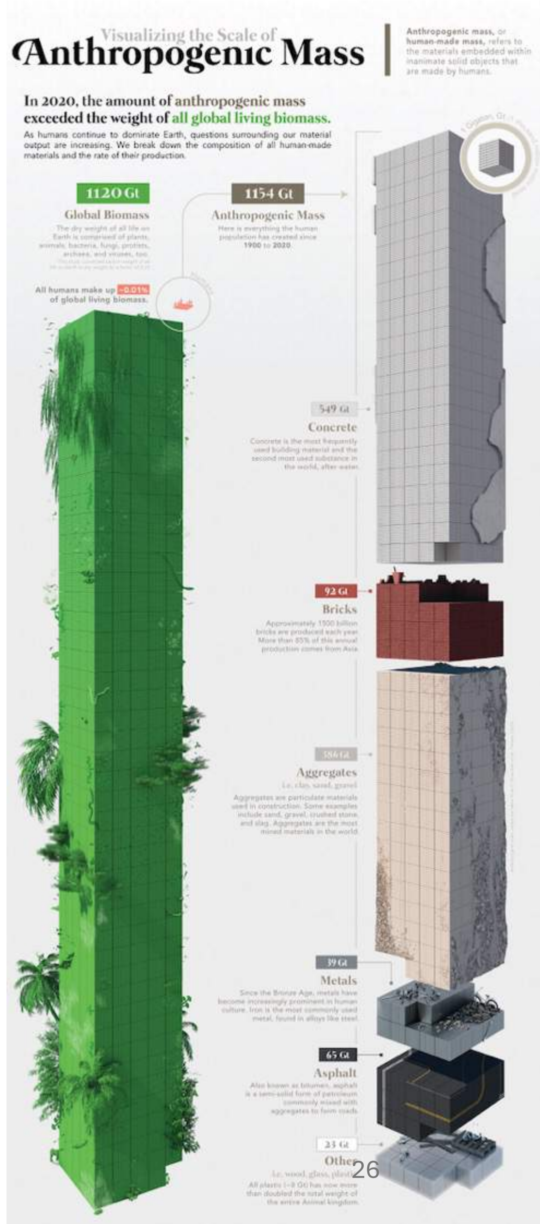


An important figure

In 2020, the amount of anthropogenic mass exceeded for the first time the dry weight of all life on Earth

Massive Demand in Energy and Materials

Over the past century Anthropogenic mass has increased rapidly, doubling approximately every 20 years. The collective mass of these materials has gone from 3% of the world's biomass in 1900 to being on par with it today [1]

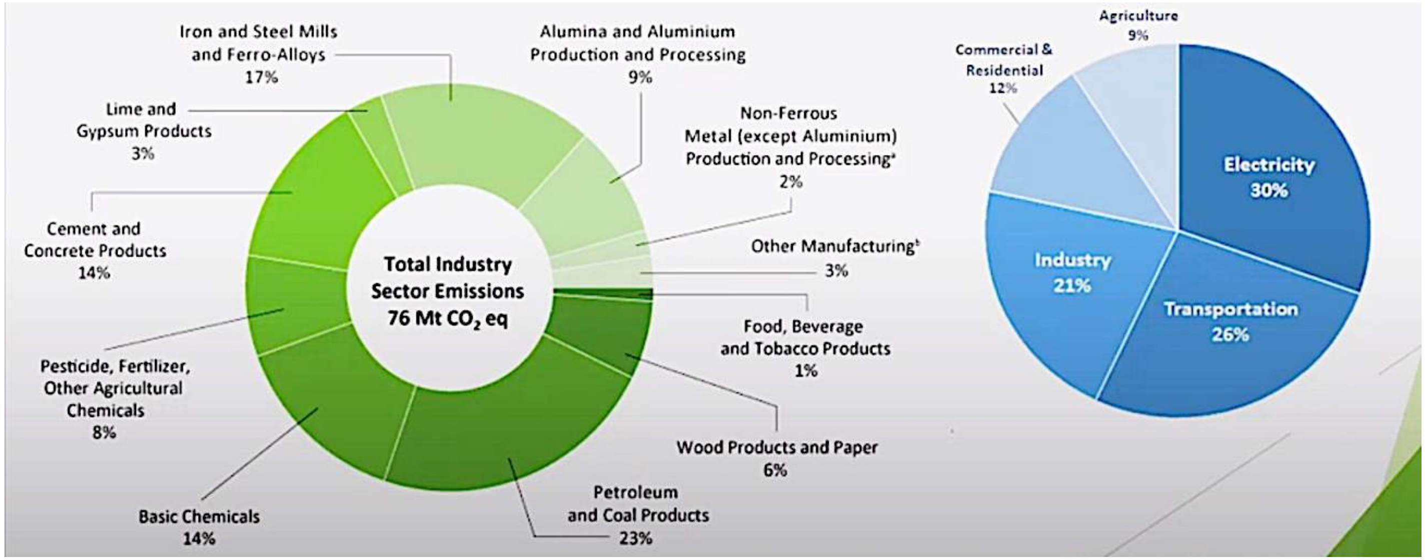


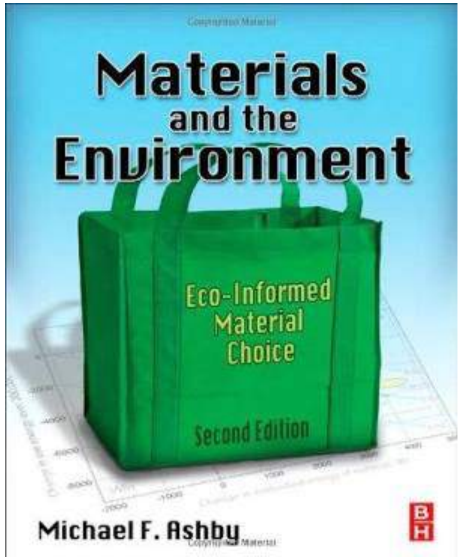
Materials and Energy ressources are linked and limited…

#Structural materials used in a massive way → huge environmental impact

#The essential technologies for the transition, in particular green energy, will translate into considerable demand for metals that have become strategic.

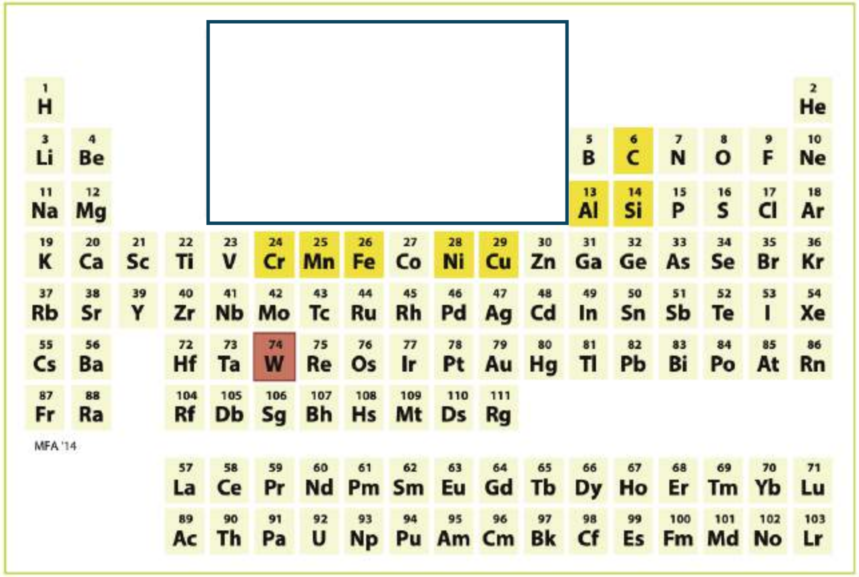
#In anticipation of 2050, the total tonnage of concrete, steel, aluminum etc… necessary for the development of these energies will be 2 to 8 times the world production of 2010. !!!

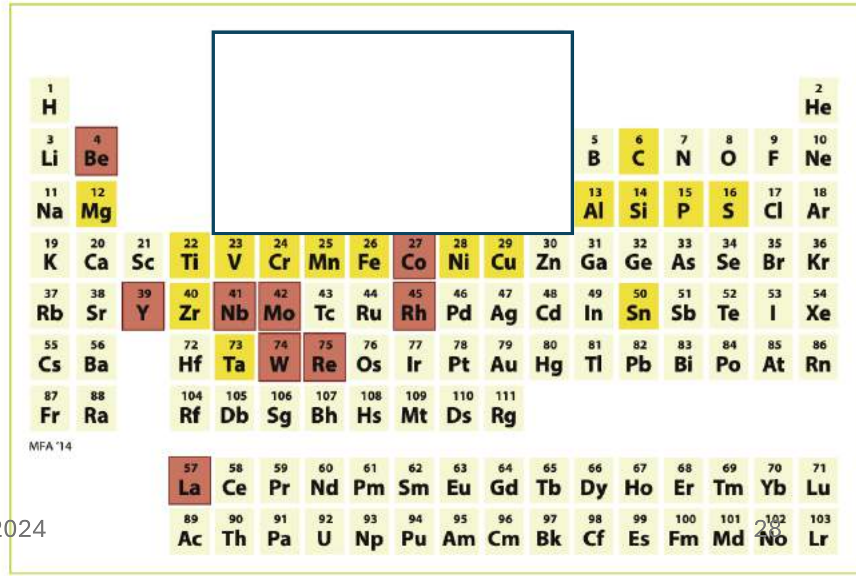




Quiz

- One system is older than the other !
- The elements in an early aircraft engine and a gas turbine of today mapped onto the periodic table.

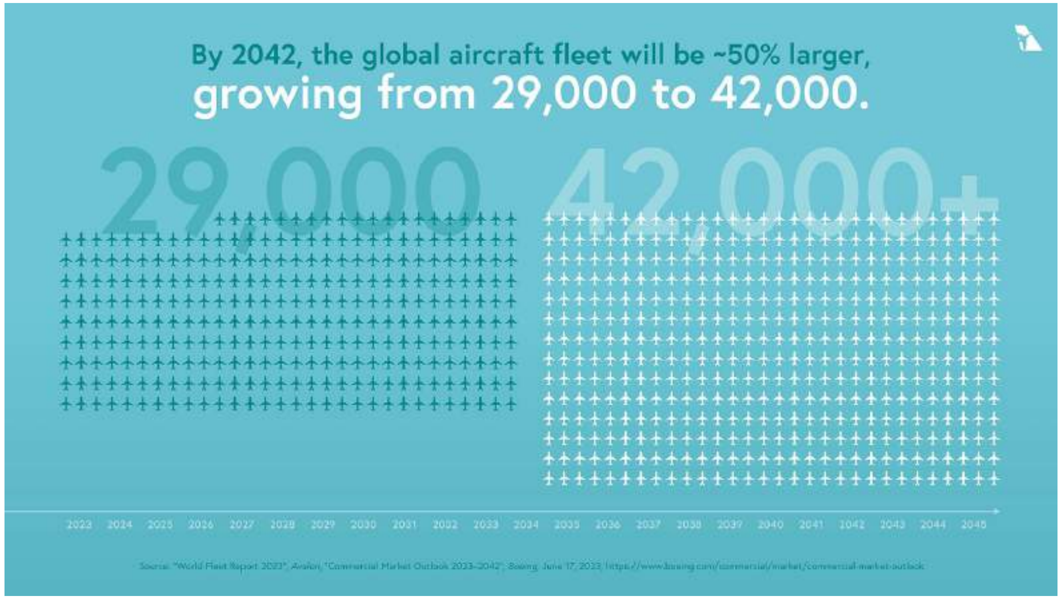


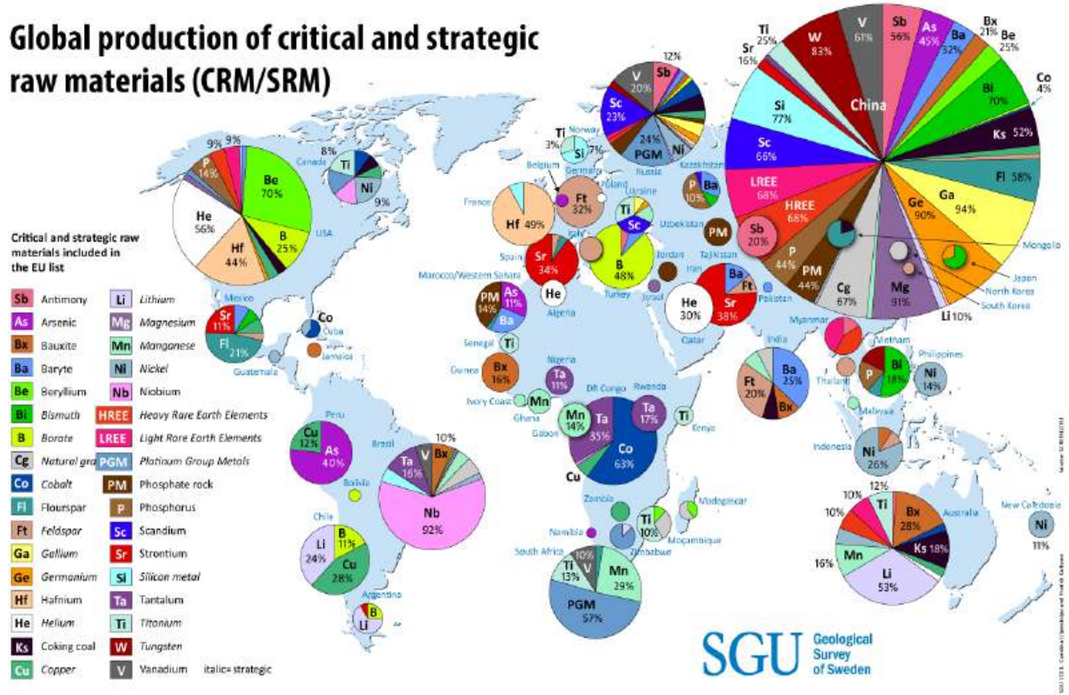


Critical materials are colored red,
other materials used in the product are in darker yellow.

Sustainable aviation?

Critical materials + geostrategic problem→ cost of materials will increase… delay …





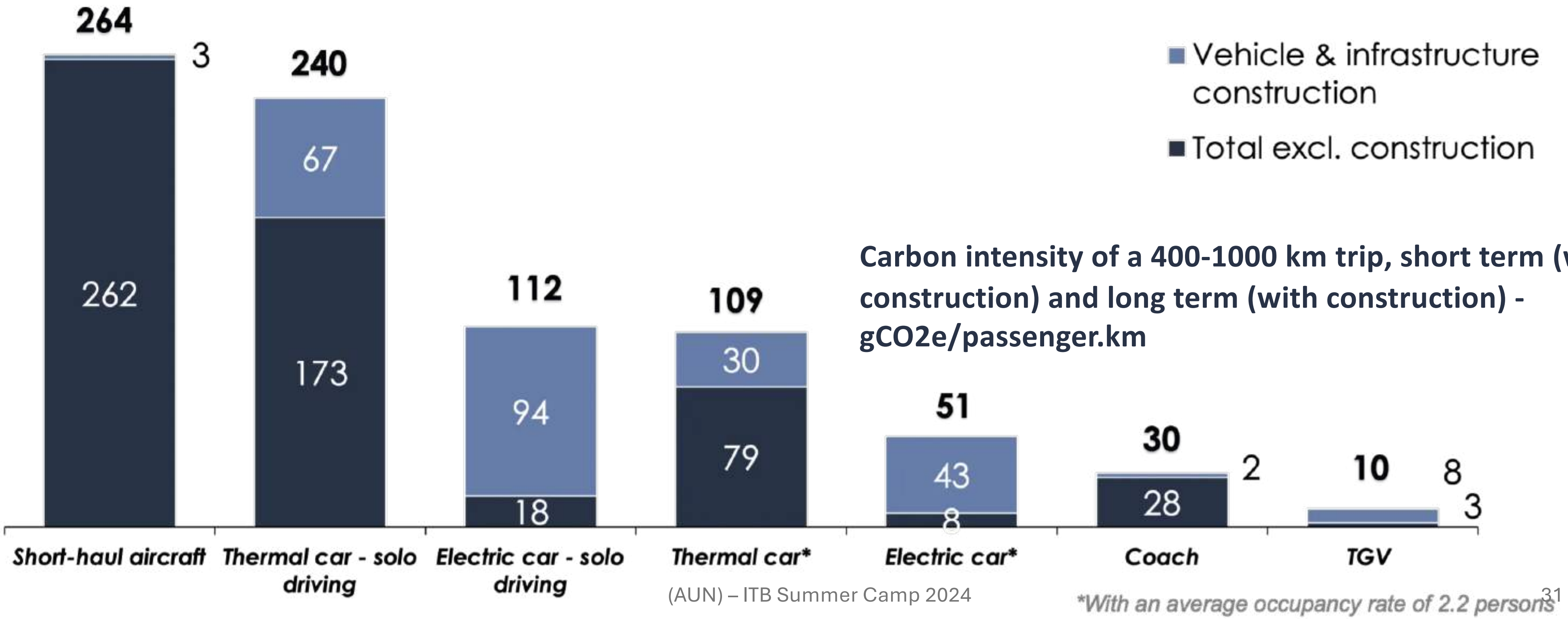
Quiz

- What are these coloured boxes ?

ReNew the way we travel from A to B

https://www.carbone4.com/en/analysis-faq-aviation-climate

Is it better to travel by plane or by car, even alone?



Carbon intensity of a 400-1000 km trip, short term (without construction) and long term (with construction) - gCO2e/passenger.km

ReNew the way we travel from A to B

Is air transport for the elite only?

Here are some figures to illustrate:

- less than 1% of the world's population is responsible for more than 50% of commercial aviation emissions.
- 80% of the world's population has never flown

Low cost air company (easyjet, ryanair) ?

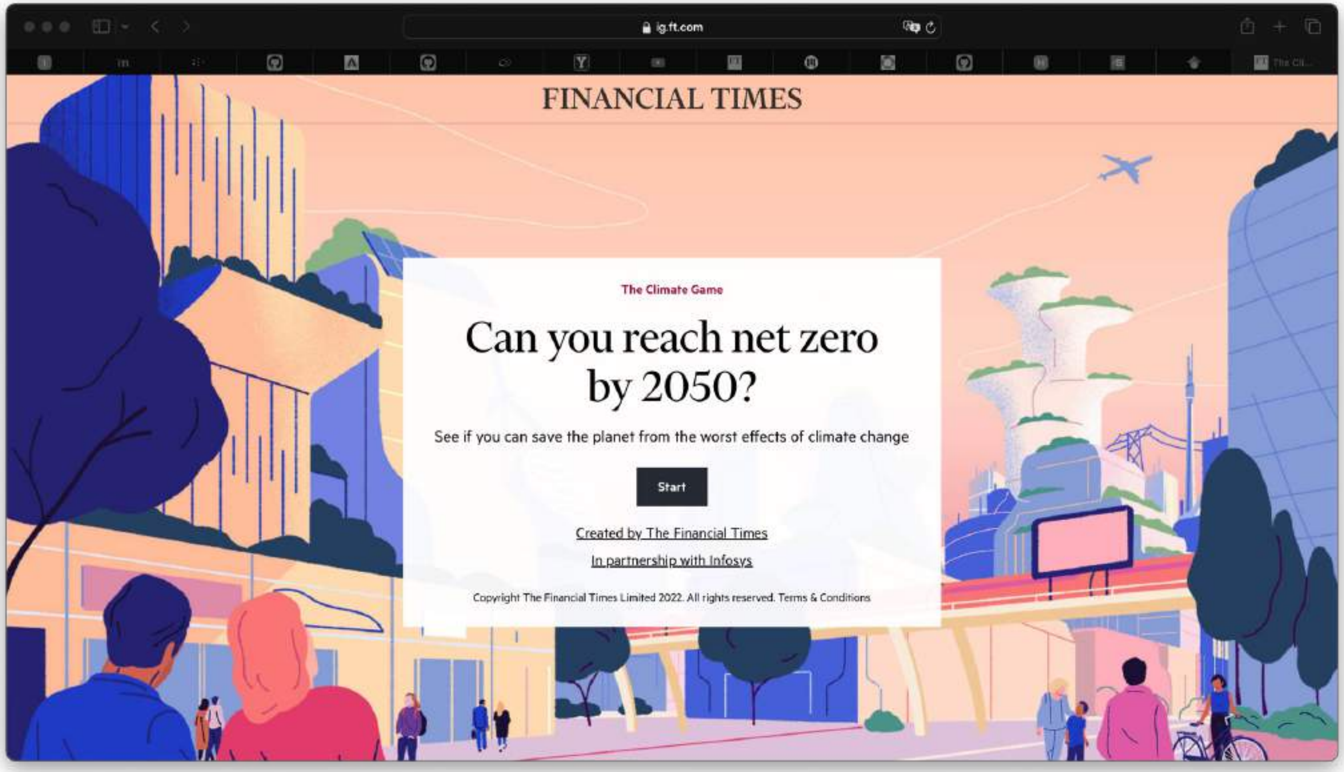
They do not permit to decarbonize the industry as they are cheaper than train

ReNew the way we travel from A to B


An artist's conception of an urban air mobility environment.
Credit: NASA / Lillian Gipson

UAM R&D
https://www.aurora.aero/2022/08/08/aurora-supports-university-of-california-san-diego-on-vehicle-design-for-urban-air-mobility/

https://ig.ft.com/climate-game/



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Take Away informations

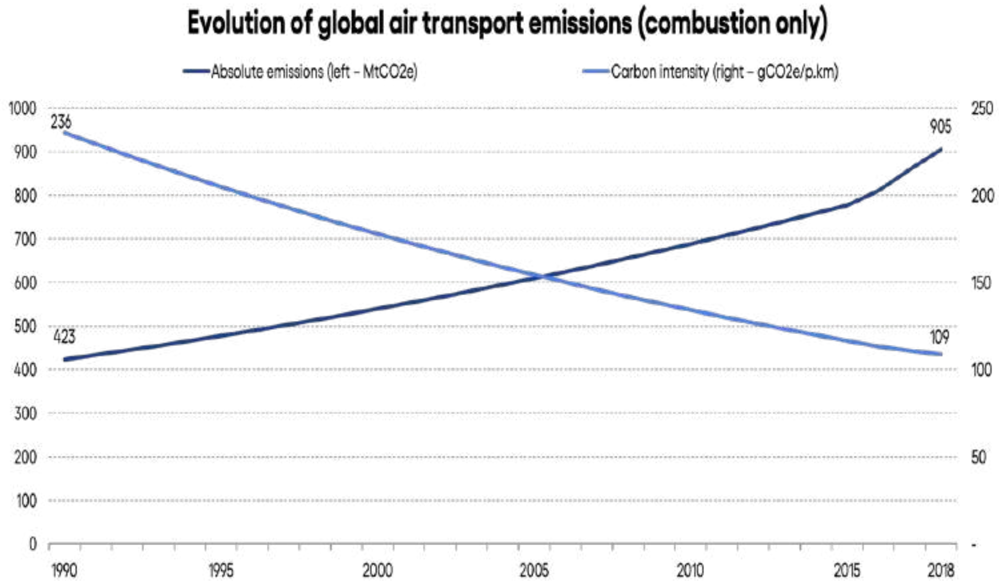
https://www.carbone4.com/en/analysis-faq-aviation-climate

Aviation greanER (not green)

This reflects a phenomenon called the "rebound effect": as fuel is saved, flying costs less, and therefore we fly more...

Hasn't aviation already halved its consumption since 1990?

with new generations of aircrafts and operational optimizations, fuel consumption per passenger-kilometer has been divided by **more than 2** between 1990 and 2018 → **carbon intensity as well.** However, carbon intensity (i.e. emissions per passenger.km) must not be confused with emissions! As **air traffic has multiplied by 4.6** over the same period, total emissions have **more than doubled.**



Aviation greanER (not green)

Isn’t the impact of aviation on climate change minor?

Commercial aviation represented:

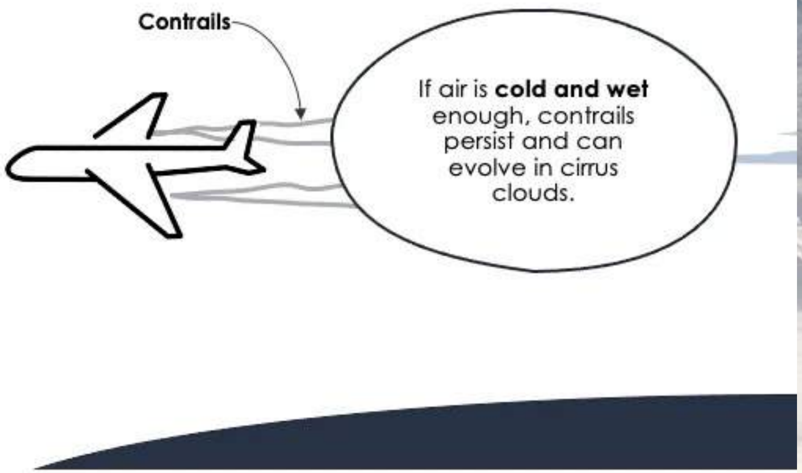
2.6% of greenhouse gases emissions worldwide in 2018
5.1% of anthropic global warming between 2000 and 2018 taking into account non-CO2 effect.
→ That corresponds to approximately **1 billion tons of CO2**, equivalent in order of magnitude to the **emissions of Japan (3rd global power and 5th emitting country).** It is far from being insignificant.

Aviation greanER (not green)

- And contrails ? (Heat trapping)

Latest studies show that their effect is equivalent to double or even triple the radiative impact due to GHG emitted by aircrafts.

beyond GHG emissions from the combustion of fossil fuel, it has an impact through physical and chemical atmospheric processes. The main non-CO2 impact of aviation is the effect of the contrails (condensation trails) appearing in an aircraft's wake.



Aviation greanER (not green)

It raises the question of the future of some hubs, such as Dubaï, fourth global airport in frequentation in 2019…

- Should aviation fear the physical effects of climate change?

Other climate hazards can also disrupt air traffic from running smoothly. The heat wave that **stuck 50 planes** to the ground in Phoenix (Arizona, USA) in 2017 was an illustration of the vulnerability of aviation to heat. No taking off on too short runways or with some types of regional aircrafts (hot air is less dense, reducing lift), and accelerated wearing of the tarmac with time.

Aviation greanER (not green)

Airbus recently announced its plan to develop a H2-powered single-aisle aircraft …
in 2035 range of1,500 km, i.e. a regional range,
… **6% of aviation emissions today.**

- Will hydrogen or electric aircrafts decarbonize aviation by 2050?

In the case of hydrogen, this could **reduce the carbon footprint by up to -65% (non-CO2 effects included).** Hydrogen has a better energy density per unit of mass, but not at all per unit of volume: even in its liquid form (**which requires cooling to -253°C!)**, it takes three times more space than kerosene, and also has greater safety constraints than the latter. Hydrogen therefore suffers from some of its physical characteristics, which also requires modifying the entire airport ecosystem and infrastructure (hydrogen production, storage, aircraft refueling, etc.).

THE NEW HYDROGEN-FUELED CAR IS UNVEILED

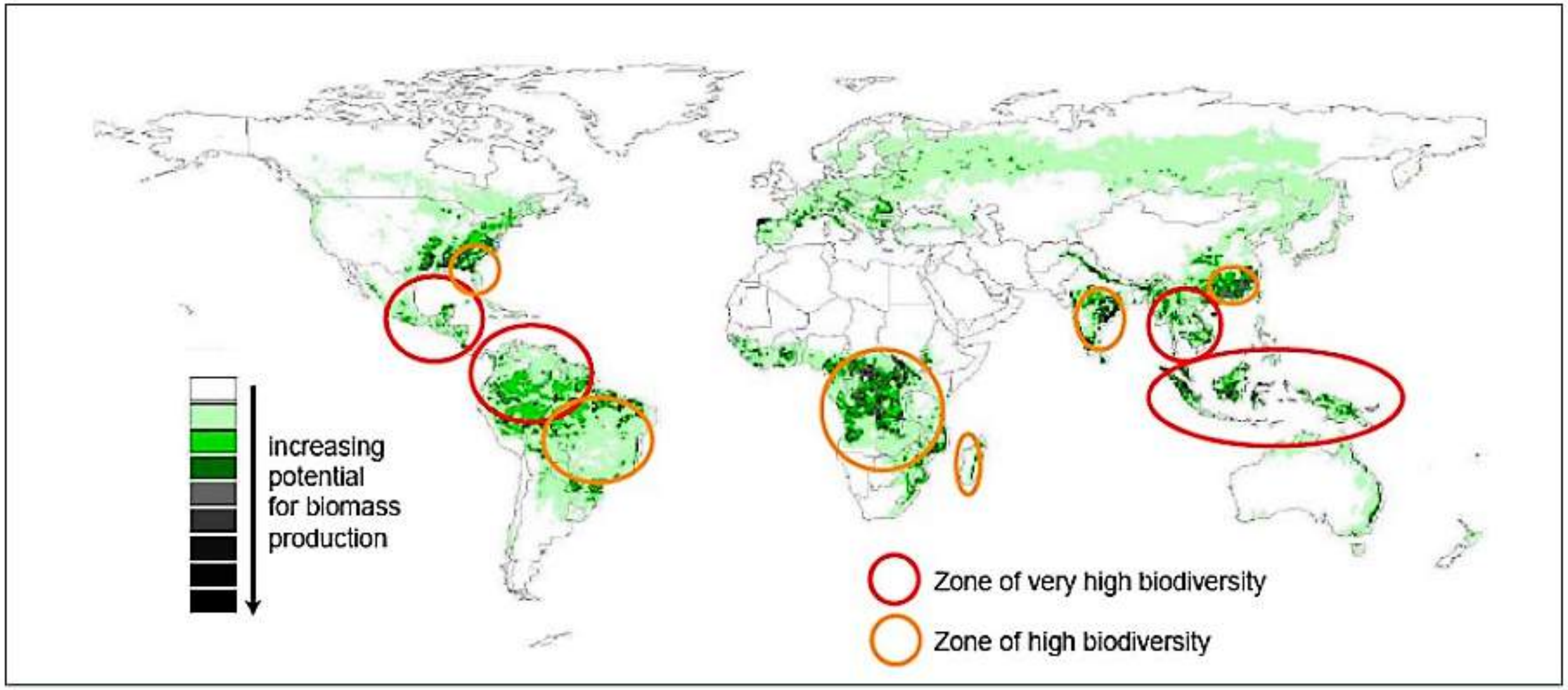
Aviation greanER (not green)

The massive production of intensively cultivated biofuels has environmental consequences (weaken the soil, threaten biodiversity, alter the water cycle etc...) and social risks.

You can buy SAF with your ticket... SAF are storable: a liter of SAF produced in May in Spain can be used in September in France

- Sustainable Aviation Fuels (known as "SAF") ?

Regarding GI ... CO2 storage
upstream (pl ... n of up to -
70/80% is obt
these new p ... me type of
combustion, ... **ly be about**
12%, which tr ... **rrently 2 to 5**
times more e



Source: IIASA, Kraxner 2007, Rokiyanskiy et al. 2006
Data from UNEP IMAPS

*Palm fatty acid distillate

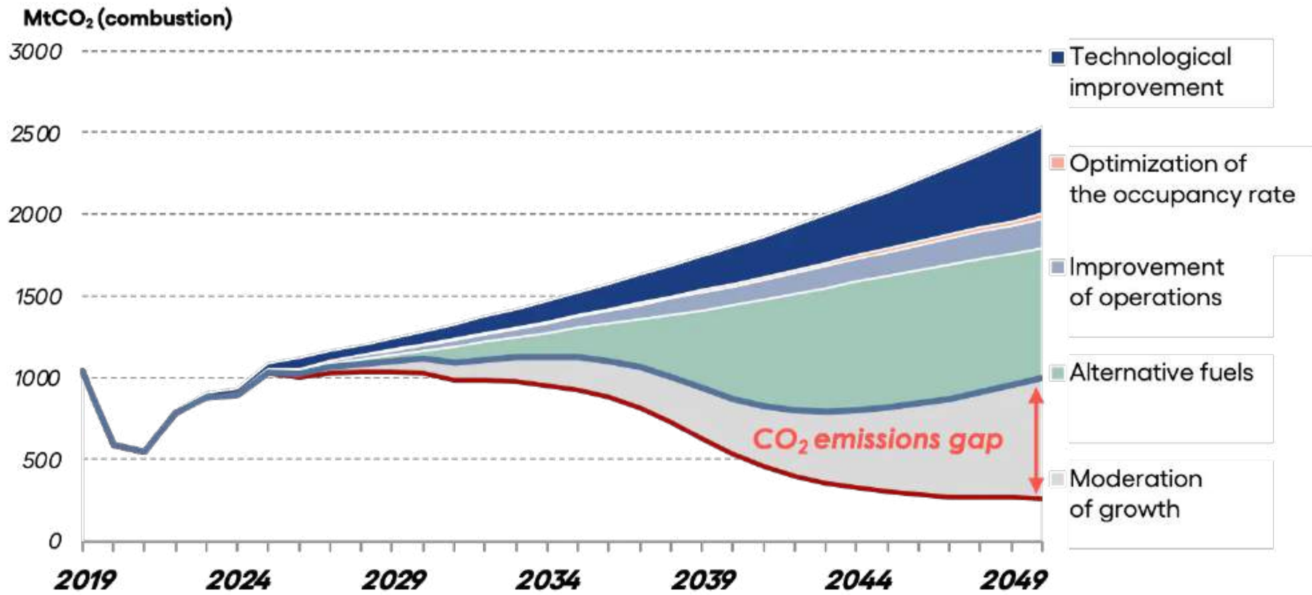
Aviation greanER (not green)

What if we limit traffic, instead the 3% increase per year?

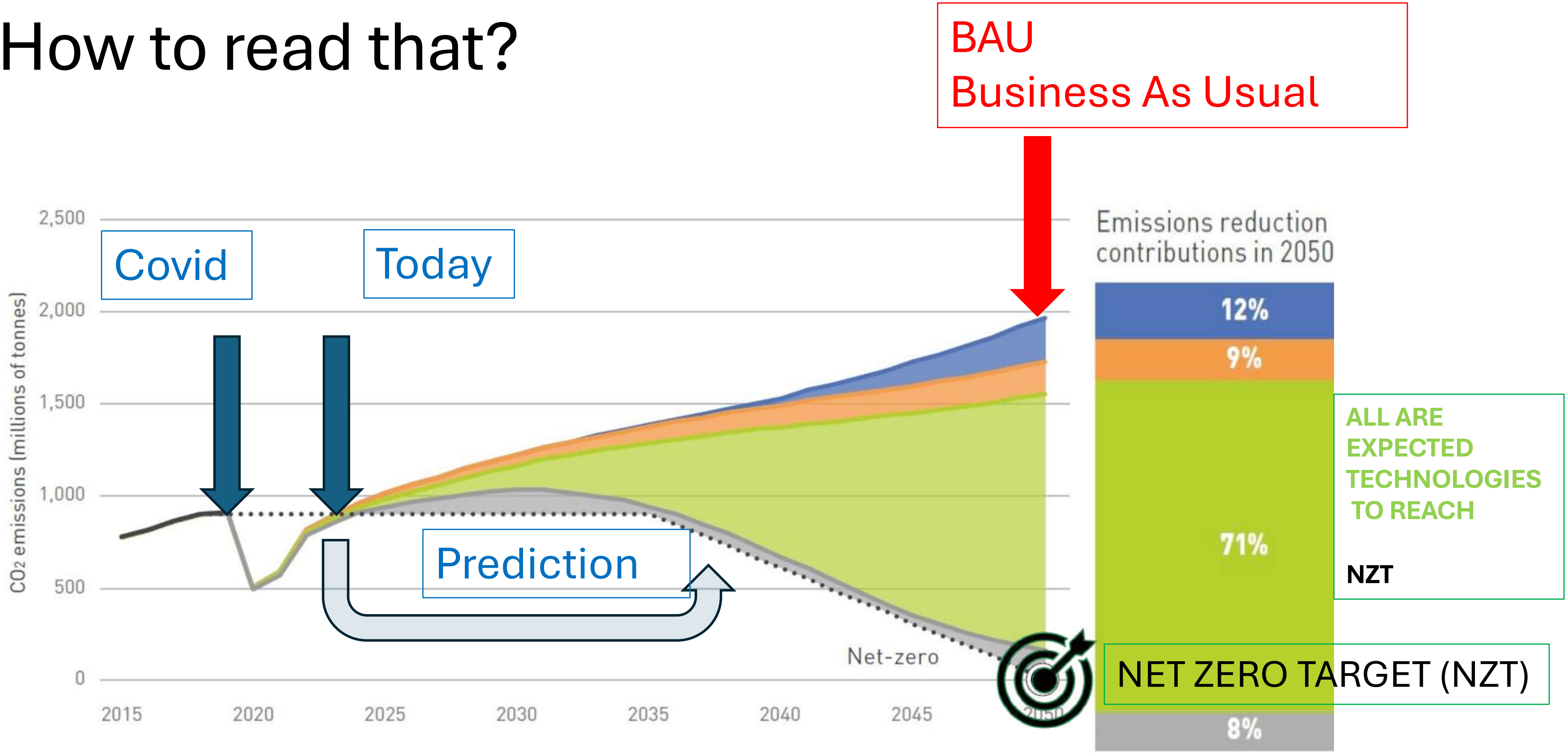
- Can aviation meet its climate targets without reducing growth?

In order to keep global warming below +2°C, the aviation sector has set a target of zero net emissions (with ~135 $MtCO_2$ of residual emissions, i.e. a reduction of 85%, according to ATAG). This challenge will be all the more ambitious given that it anticipates a growth in passenger traffic ranging from 3.1% to 3.6% per year, i.e. a **multiplication by at least 2.5 by 2050**.

Evolution of CO_2 emissions (combustion and upstream) of global air transport (excluding regional traffic), respecting a 2°C budget defined by ISAE Supaéro



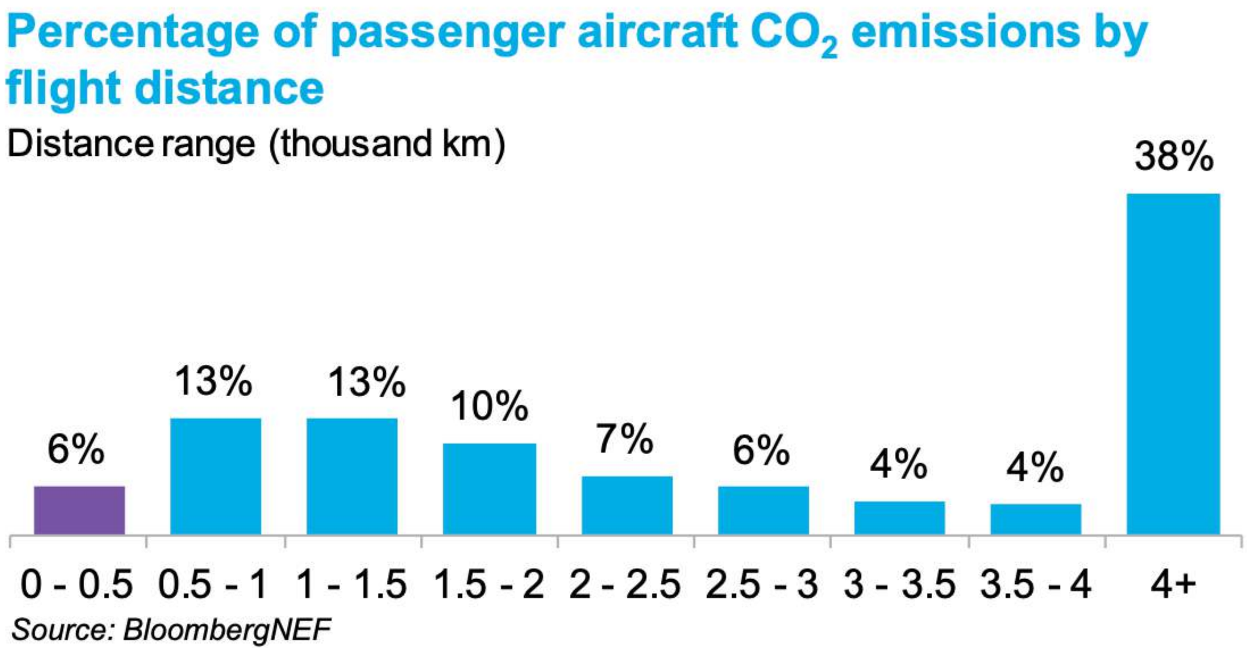
How to read that?



Simple ideas to start !

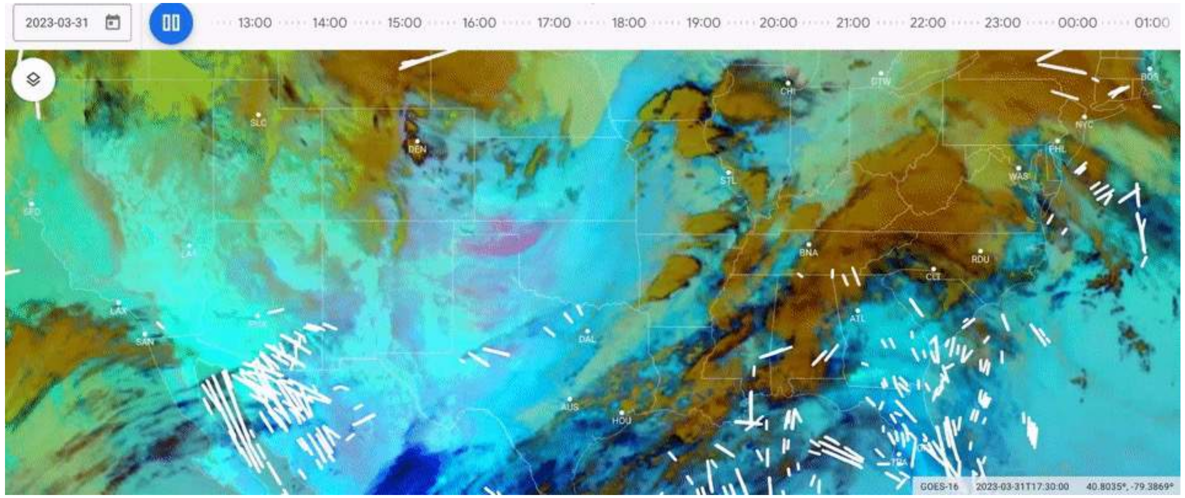
What should we tackle first with new Energy tech?

The best use cases for these technologies currently are short-haul flights (mostly <500km) due to the low volumetric and gravimetric energy densities of battery – and hydrogen – energy storage.



What should we tackle first for contrails?

The 2022 IPCC report noted that clouds created by contrails account for roughly 35% of aviation's global warming impact, over half the impact of the world's jet fuel.



flights that attempted to avoid creating contrails burned **2% additional fuel**. Recent studies show that a small percentage of flights need to be adjusted to avoid the majority of contrail warming. **Therefore, the total fuel impact could be as low as 0.3% across an airline's flights.**

AI is helping airlines mitigate the climate impact of contrails/

https://blog.google/technology/ai/ai-airlines-contrails-climate-change/

https://py.contrails.org

What should we tackle first with trajectory?

Use Physics/meteorological parameters for optimizing flight trajectories (contrails minimization)

https://github.com/junzis/fastmeteo

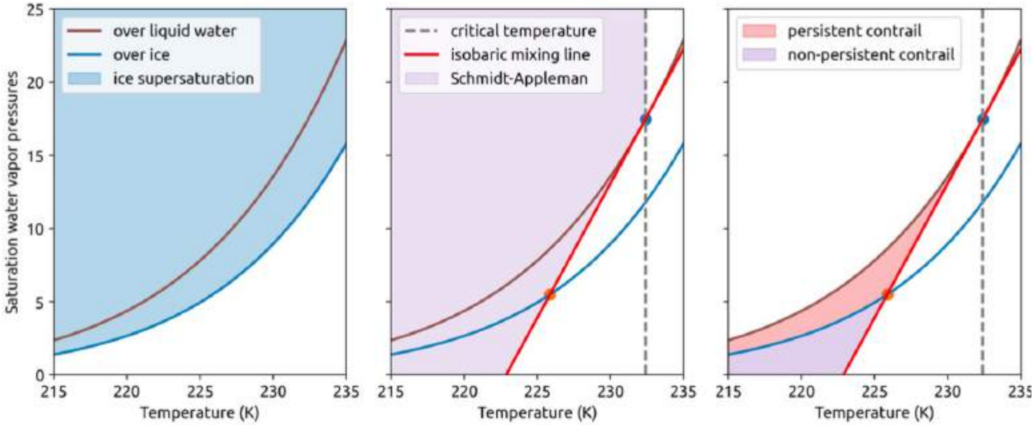
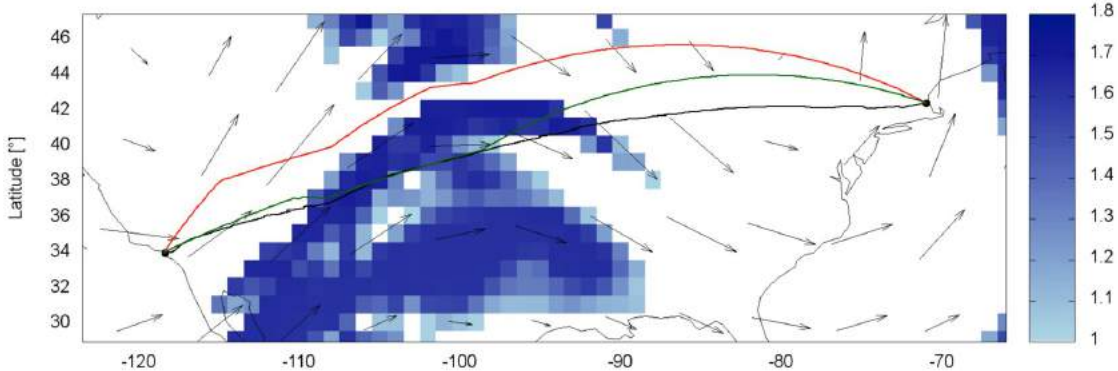


Figure 4. Contrail forming conditions

Figure 6. Persistent contrails (in red) determined from the example flight trajectory, based on the Schmidt-Appleman and ice supersaturation criteria.

Sustainability 2019, 11(21), 6082; https://doi.org/10.3390/su11216082

Lateral routes of optimized trajectories between Los Angeles and Boston with different contrail weightings in an ice-supersaturated atmosphere (blue squares). Significant differences between three different modes of optimization are shown.

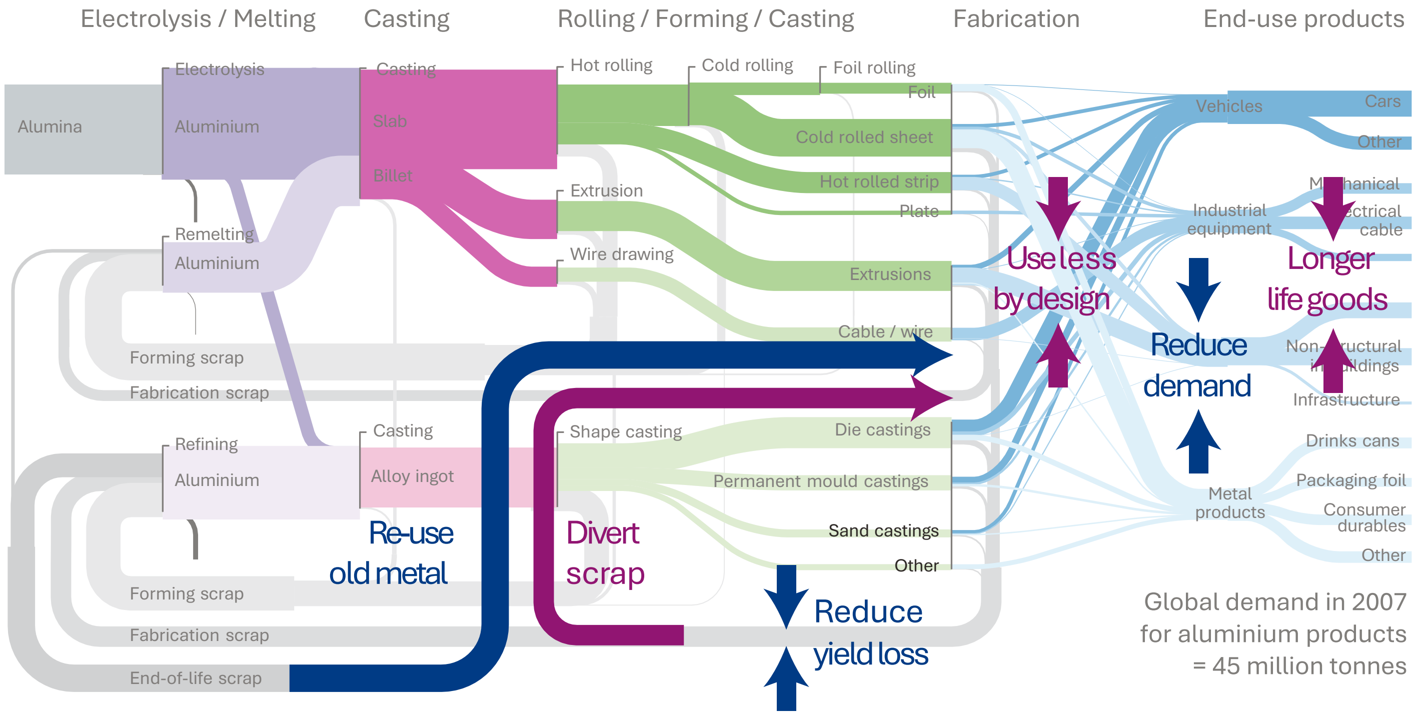


With both eyes open in Aircraft Manufacturing

HTTPS://TINYURL.COM/CO2AEROSPACE

https://microlearning.groupe-isae.fr/nugget/environmental-impact-of-the-aerospace-manufacturing-sector/view/4530ea46-9f08-4230-8f5f-fd1570ccc69f#nugget_top

With both eyes open in Product design — what else can we do??

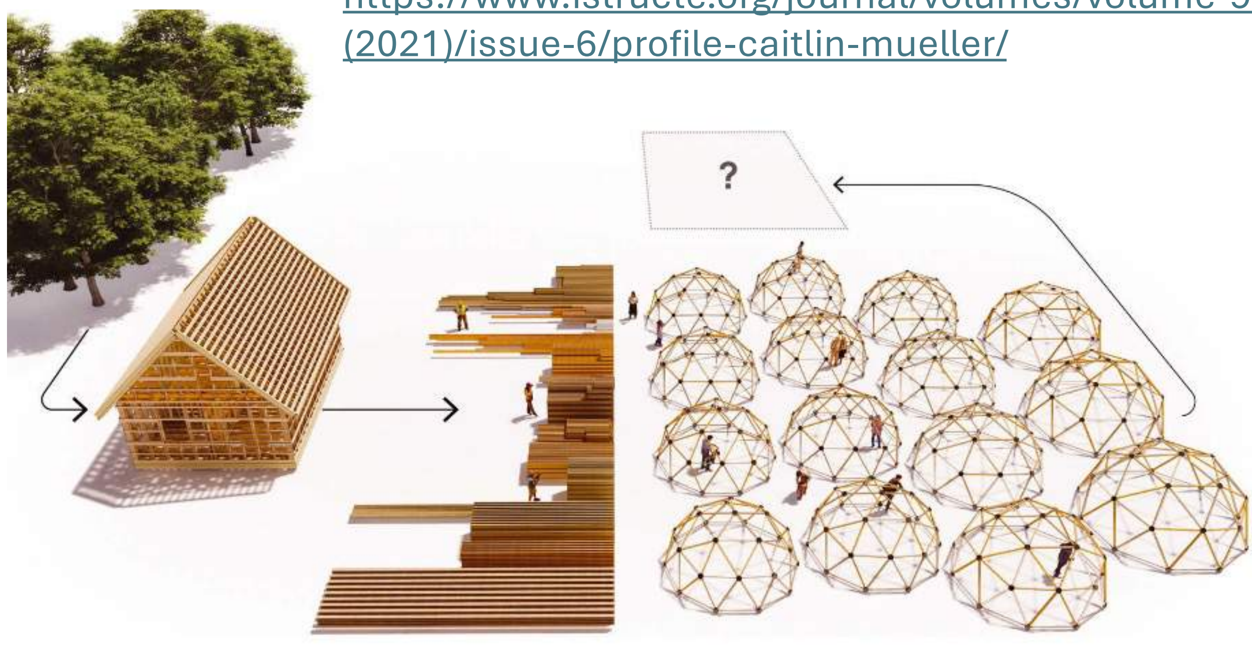


https://www.uselessgroup.org

With both eyes open in Product design — what else can we do??

Inspiration from Civil Engineering: developing algorithms to allow designers to reuse material from a structure in new designs : DESIGN FOR ZERO

https://www.istructe.org/journal/volumes/volume-99-(2021)/issue-6/profile-caitlin-mueller/



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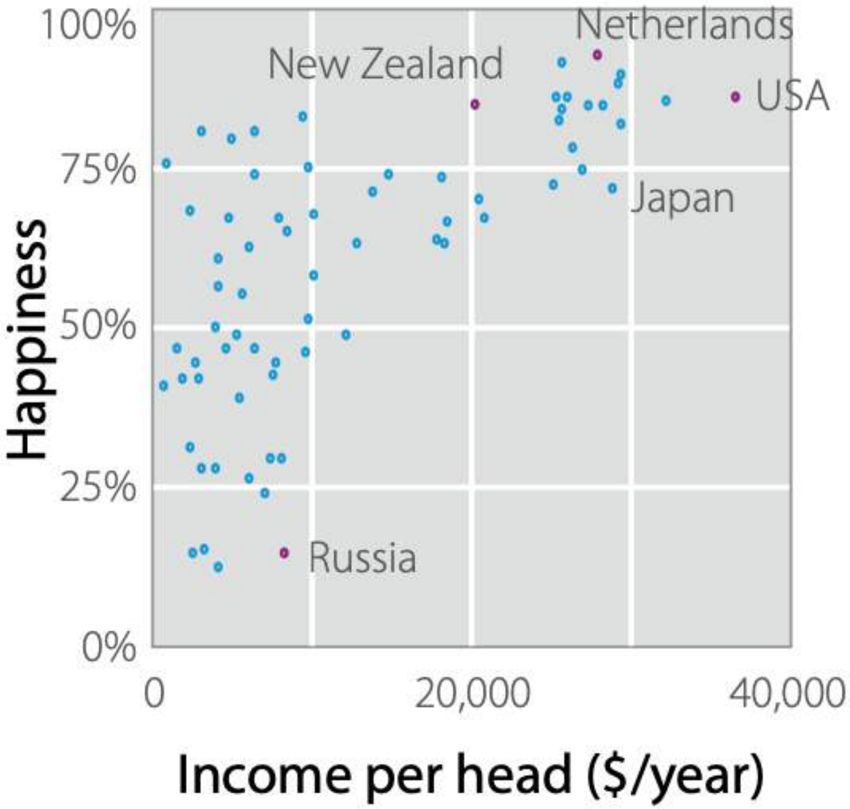


If not material efficiency, then demand reduction?
→ Consume Less
→ Reuse, Repair, Recycle

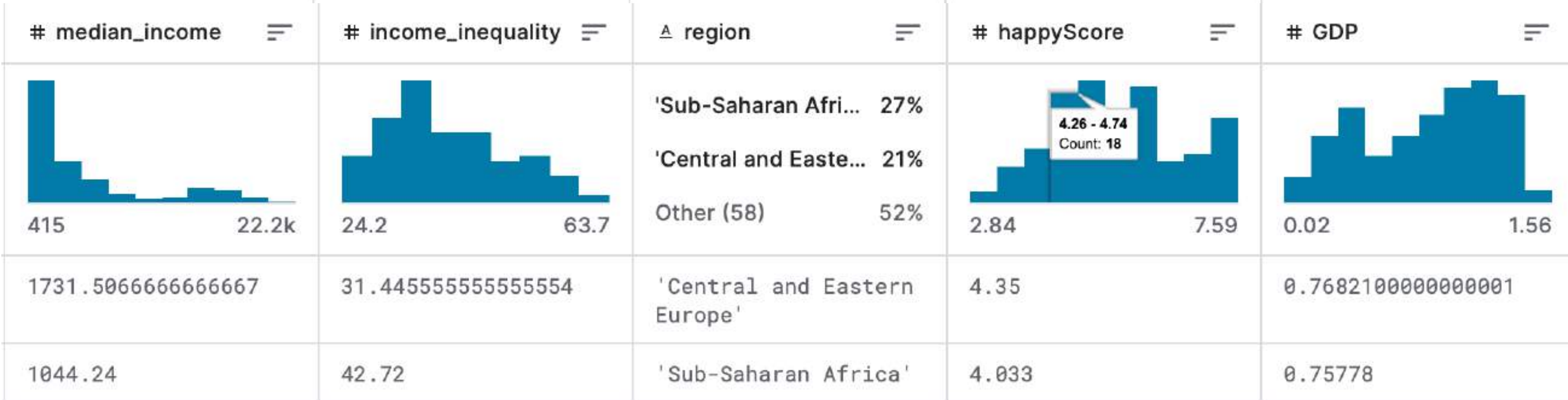
https://www.uselessgroup.org

Can data explain this ?

https://www.kaggle.com/code/mansibhardwaj71/happiness-regional-variations

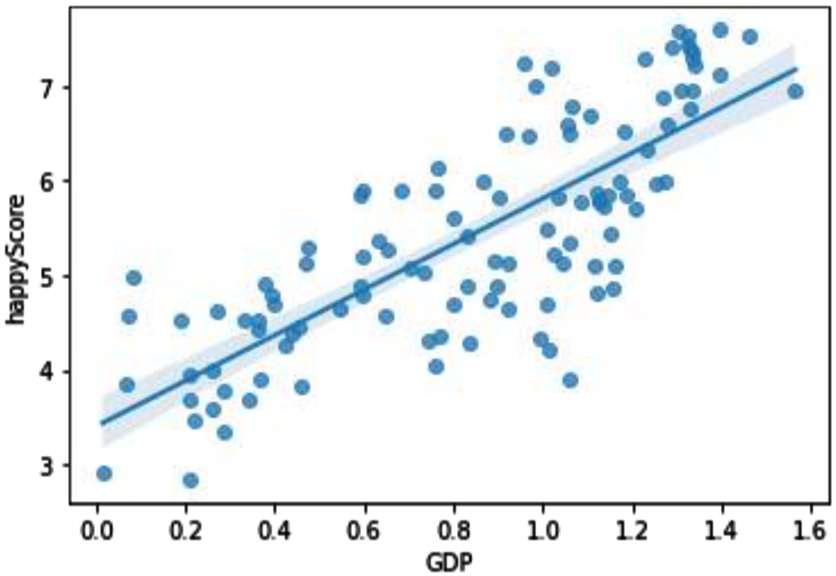
country	adjusted_satisfa...	avg_satisfaction	std_satisfaction	avg_income
111 unique values	19 – 74	2.5 – 8.5	1.38 – 3.19	573 – 26.2k
Armenia	37.0	4.9	2.42	2096.7599999999998
Angola	26.0	4.3	3.19	1448.88

GDP per Country v self-reported happiness(An old paradox lives on)
This dataset reflects the relationship between income and happiness of 111 countries



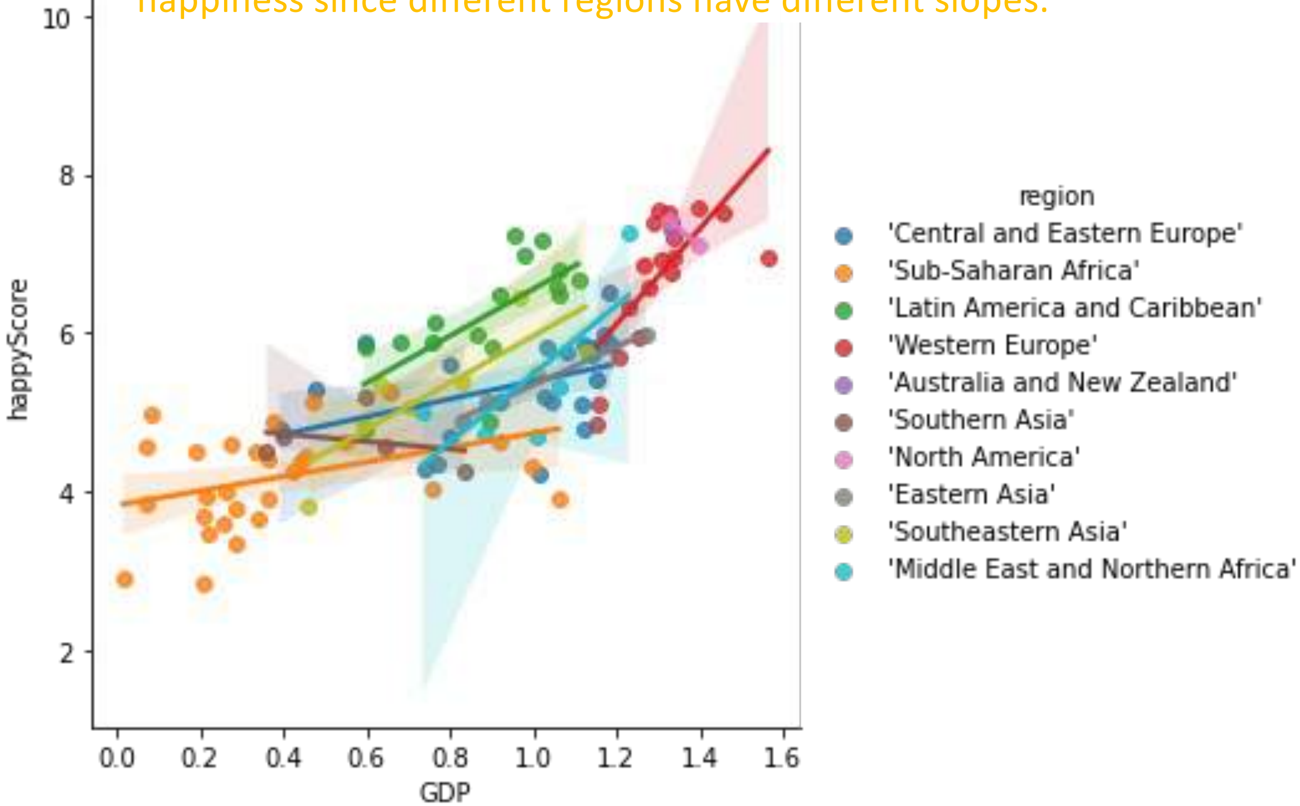
median_income	income_inequality	region	happyScore	GDP
415 – 22.2k	24.2 – 63.7	'Sub-Saharan Afri... 27% 'Central and Easte... 21% Other (58) 52%	2.84 – 7.59	0.02 – 1.56
1731.5066666666667	31.445555555555554	'Central and Eastern Europe'	4.35	0.7682100000000001
1044.24	42.72	'Sub-Saharan Africa'	4.033	0.75778

Correlation between Happiness and GDP?



there is a positive correlation between Happiness and GDP

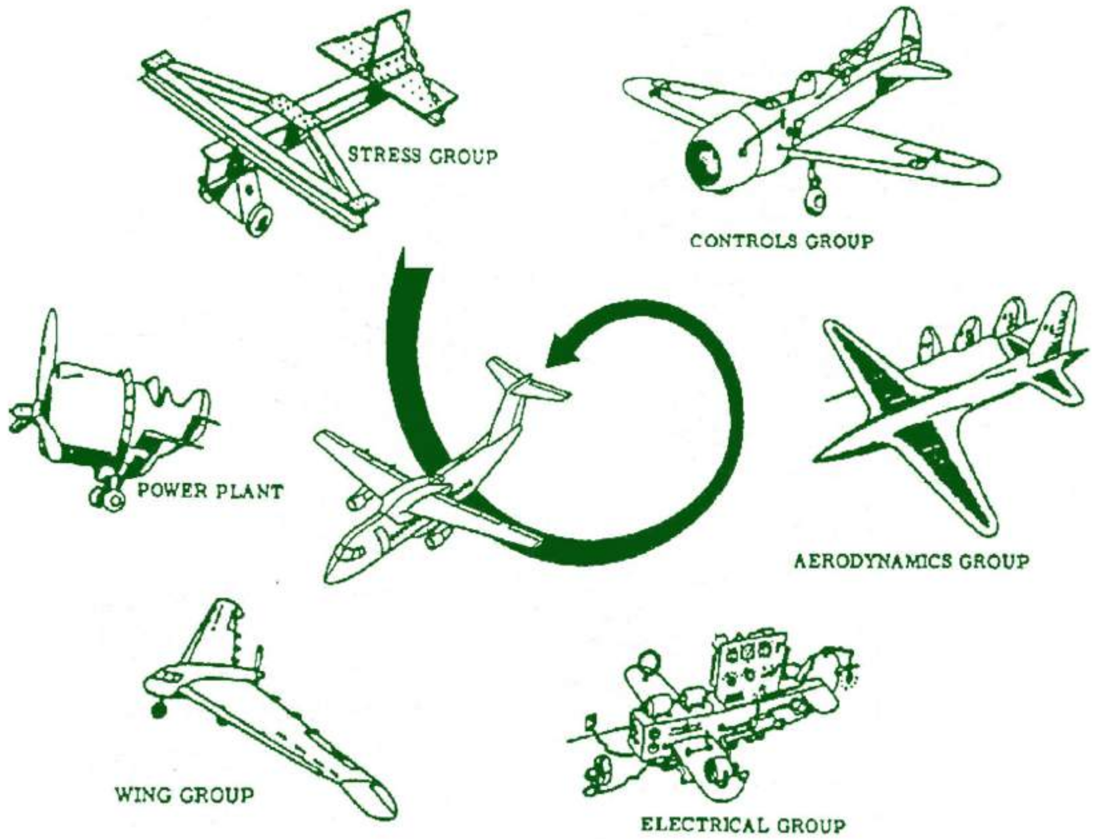
It seems that GDP is not the only factor responsible for increased happiness since different regions have different slopes.



Agenda for today

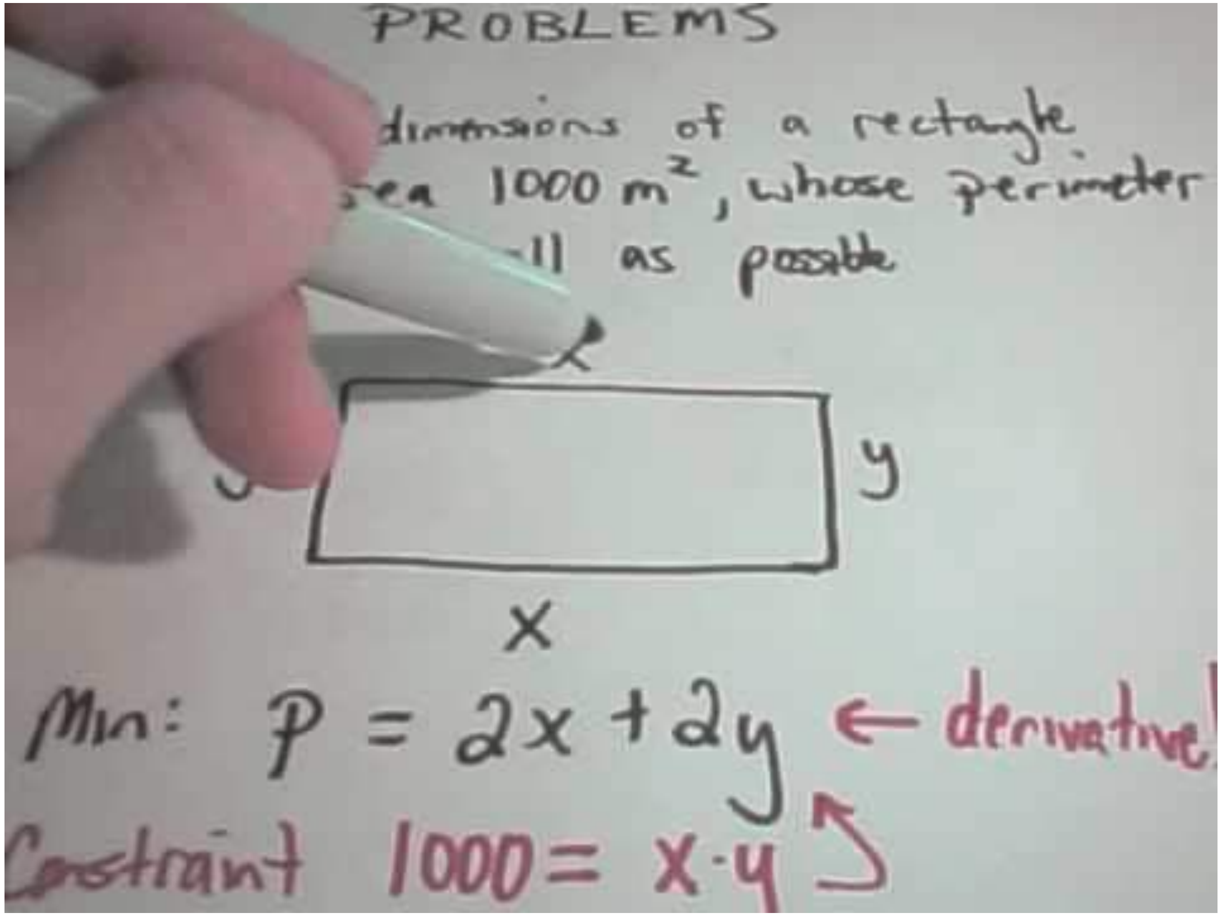
1. Sustainable Aviation (SA) With one eye open / With two eyes open
2. **Design Optimization (DO)**
3. Combining SA+DO for my research
4. Conclusions

Methods

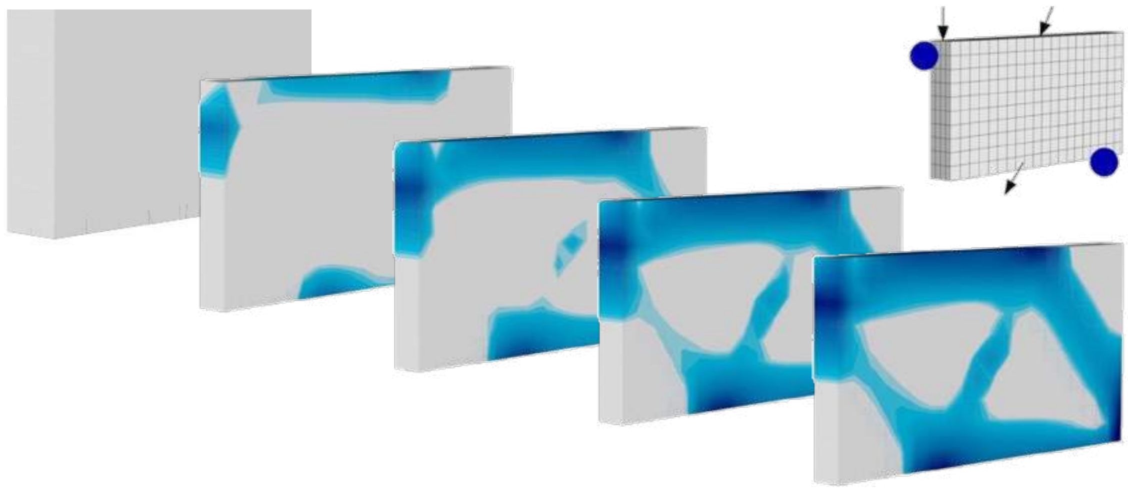


Multidisciplinary Design Optimization (MDO)

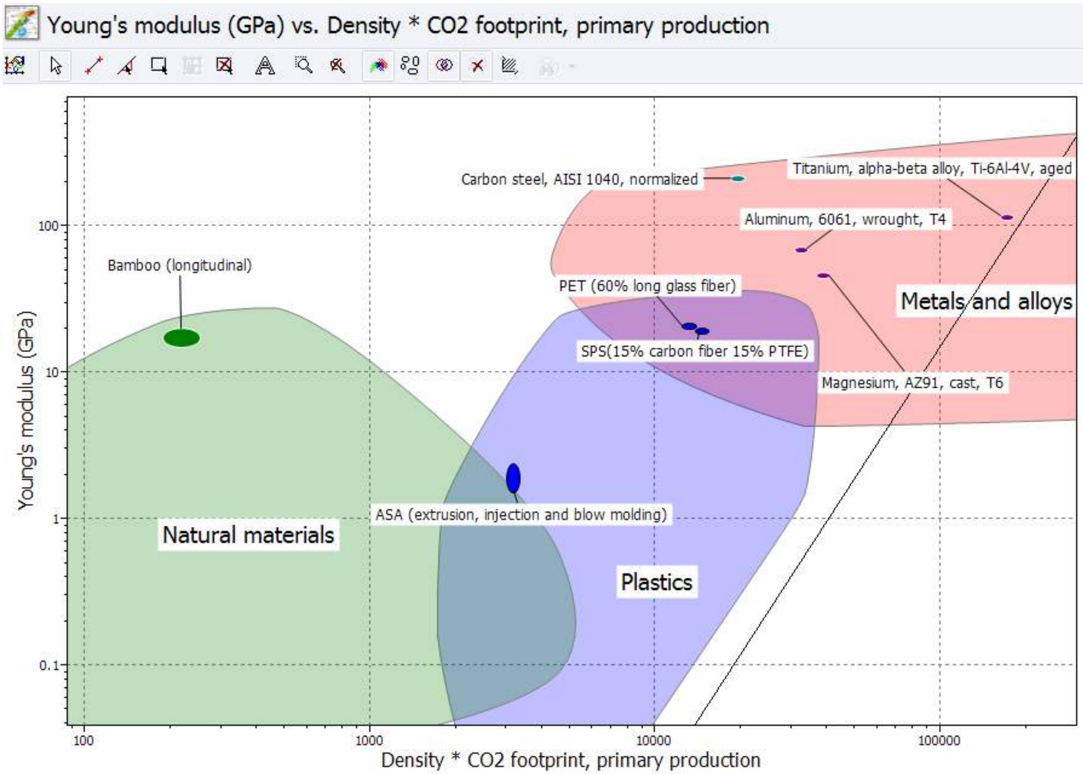
From engineering to maths



design of bicycle frame by optimization

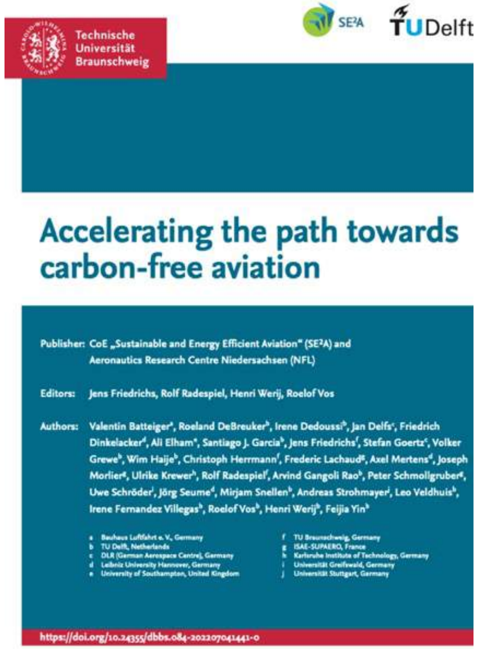


design of bicycle frame by EcoDesign



Tools

Lot of Academic (multidisciplinary) Initiative


Technische Universität Braunschweig

SE²A

TUDelft

Accelerating the path towards carbon-free aviation

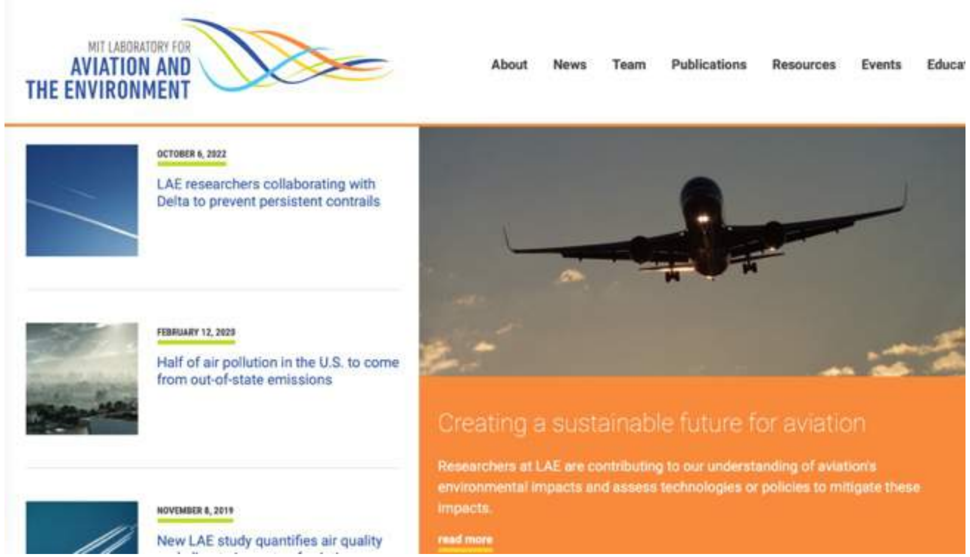
Publisher: CoE „Sustainable and Energy Efficient Aviation“ (SE²A) and Aeronautics Research Centre Niedersachsen (NFL)

Editors: Jens Friedrichs, Rolf Radespiel, Henri Werij, Roelof Vos

Authors: Valentin Batteiger[a], Roeland DeBreuker[b], Irene Dedoussi[b], Jan Delfs[c], Friedrich Dinkelacker[d], Ali Elham[e], Santiago J. Garcia[b], Jens Friedrichs[f], Stefan Goertz[c], Volker Grewe[b], Wim Haije[b], Christoph Herrmann[f], Frederic Lachaud[g], Axel Mertens[d], Joseph Morlier[g], Ulrike Krewer[h], Rolf Radespiel[f], Arvind Gangoli Rao[b], Peter Schmollgruber[g], Uwe Schröder[i], Jörg Seume[d], Mirjam Snellen[b], Andreas Strohmayer[j], Leo Veldhuis[b], Irene Fernandez Villegas[b], Roelof Vos[b], Henri Werij[b], Feijia Yin[b]

- a Bauhaus Luftfahrt e. V., Germany
- b TU Delft, Netherlands
- c DLR (German Aerospace Centre), Germany
- d Leibniz University Hannover, Germany
- e University of Southampton, United Kingdom
- f TU Braunschweig, Germany
- g ISAE-SUPAERO, France
- h Karlsruhe Institute of Technology, Germany
- i Universität Greifswald, Germany
- j Universität Stuttgart, Germany

https://doi.org/10.24355/dbbs.084-202207041441-0




MISA - Michigan Initiative for Sustainable Aviation

Who We Are:

We represent multidisciplinary fields that seek solutions to improve the environmental and societal impacts of aviation. We are faculty and students across campus that are united in our commitment to creating sustainable innovations in aviation.

What We Do

We aim to reduce the harmful impact of aviation on the environment through new practices and radical innovation. Sustainable Aviation has broad implications across disciplines from engineering to environmental and climate sciences, public policy, business and law. University and industry partners across disciplines can converge under MISA to bring a holistic approach that considers the full life-cycle impact of design, development, and operation of aircraft systems on the environment and society.

Our Mission

Leverage interdisciplinary partnerships to solve environmental challenges in aviation.

Our Vision

Empower the University of Michigan to advance our world leadership in sustainable aviation.

Our research focus addresses:

- High efficiency airframes
- Propulsion technologies
- Sustainability-driven system design and integration
- Energy generation, storage, and management on- and off-ground
- Thermal and power management
- Advanced multi-functional materials and ecomaterials
- Next-generation air traffic management and operational improvements
- Environmental, economical, and societal impacts

Get involved with our efforts

To join our affiliate list and working groups, join our interest list at **myumi.ch/Ek1r7** or scan the QR code.

COLLEGE OF ENGINEERING
AEROSPACE ENGINEERING
UNIVERSITY OF MICHIGAN

aero.engin.umich.edu //// François-Xavier Bagnoud | 1320 Beal Avenue | Ann Arbor, MI 48109-2140

INSTITUTE FOR SUSTAINABLE AVIATION

A Curated list of Academic Initiative

- https://www.tudelft.nl/en/ae/sustainable-aviation
- https://www.cranfield.ac.uk/themes/aerospace/aviation-and-the-environment
- https://www.imperial.ac.uk/green-aviation/about-us/
- https://www.imperial.ac.uk/brahmal-institute/
- https://ae.gatech.edu/sustainable-transportation-energy-systems
- https://www.tu-braunschweig.de/en/se2a
- https://www.utias.utoronto.ca/centre-for-research-in-sustainable-aviation/
- https://uwaterloo.ca/sustainable-aeronautics/
- https://isa-toulouse.com
- https://aero.engin.umich.edu/research/research-areas/sustainable-aviation/michigan-initiative-for-sustainable-aviation-misa/
- ...many more

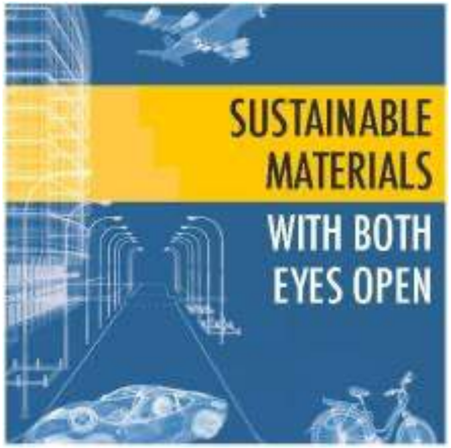
Interdisplinary centers:

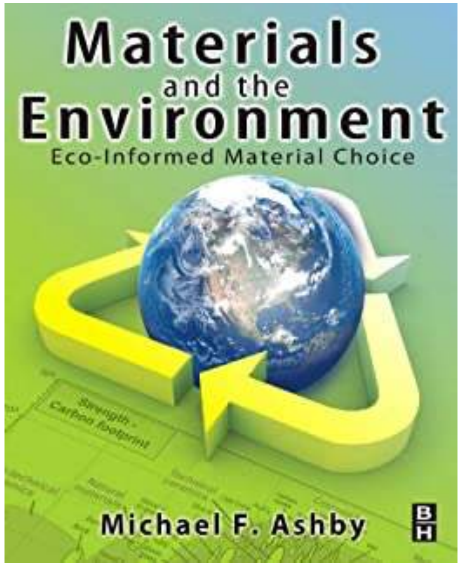
1. **Social**
2. **environmental/siences**
3. **economic**

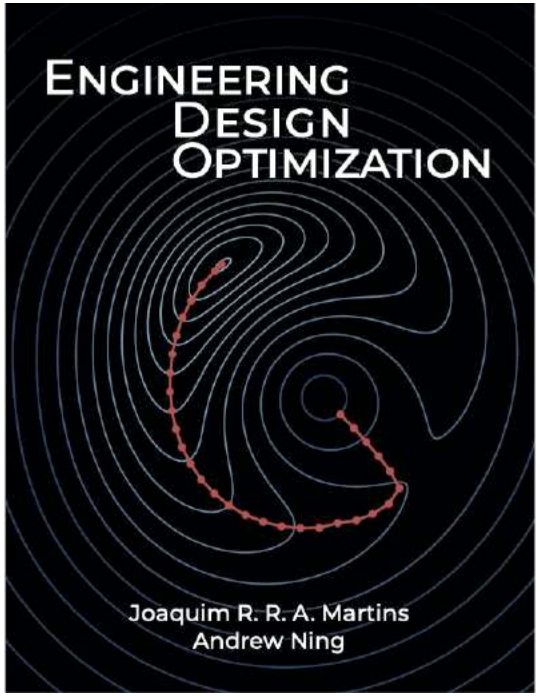
AND the interconnections between them – to create meaningful, long-term solutions

Some books

- Cambridge







A Curated list of (mostly) opensource softwares

A good example

https://mdolab.engin.umich.edu/software

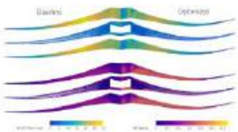
Software

The software packages listed below are all distributed under open source licenses. These are research codes, so they require a strong background in programming and some persistence to get them to work. Unfortunately we are not able to provide support except for collaborators and sponsors. However, we strive to provide as much documentation as we can and continually work towards improving the usability.

Webfoil: This is an online tool for airfoil analysis and optimization. It also includes a vast database of airfoils. [Webfoil site] [Paper]

interface to various optimization packages. pyOptSparse includes OptView, a visualization tool to explore the optimization history. [Code] [Documentation]

TACS: A general purpose structural finite-element code with adjoint derivatives that is developed by Prof. Graeme Kennedy. [Code] [Paper]

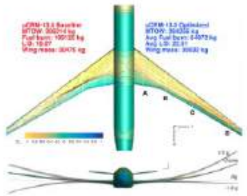


SMT: The surrogate modeling toolbox (SMT) is an open-source Python package consisting of libraries of surrogate modeling methods (e.g., radial basis functions, kriging), sampling methods, and benchmarking problems. SMT is designed to make it easy for developers to implement new surrogate models in a well-tested and well-document platform, and for users to have a library of surrogate modeling methods with which to use and compare methods. [Code] [Paper]

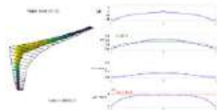
ADflow: (pronounced "A-D-flow") CFD solver that can handle structured multi-block and overset meshes. It includes an adjoint solver for computing derivatives and can be used in the MACH-Aero framework for aerodynamic shape optimization. [Code] [Documentation] [Paper]

DAFOAM: (pronounced "dahfoam") Is a suite of adjoint solvers for OpenFOAM that enable the computation of derivatives for aerodynamic shape optimization. [Code] [Documentation] [Paper]

MACH-Aero: A framework for aerodynamic design optimization that couples a CFD solver (e.g. ADflow or OpenFOAM), geometry parametrization (e.g. pyGeo), mesh deformation (e.g. IDWarp), and optimizer interface (pyOptSparse). [Code] [Documentation and Tutorials]



OpenAeroStruct: A lightweight aerostructural optimization code that can optimize a wing design in minutes on a laptop. [Code] [Documentation]



OpenMDAO: A framework for coupling multiple numerical models and performing multidisciplinary analysis and optimization. OpenMDAO is developed by NASA and uses numerical techniques developed in the MDO Lab. [OpenMDAO in a nutshell] [OpenMDAO site] [Paper]

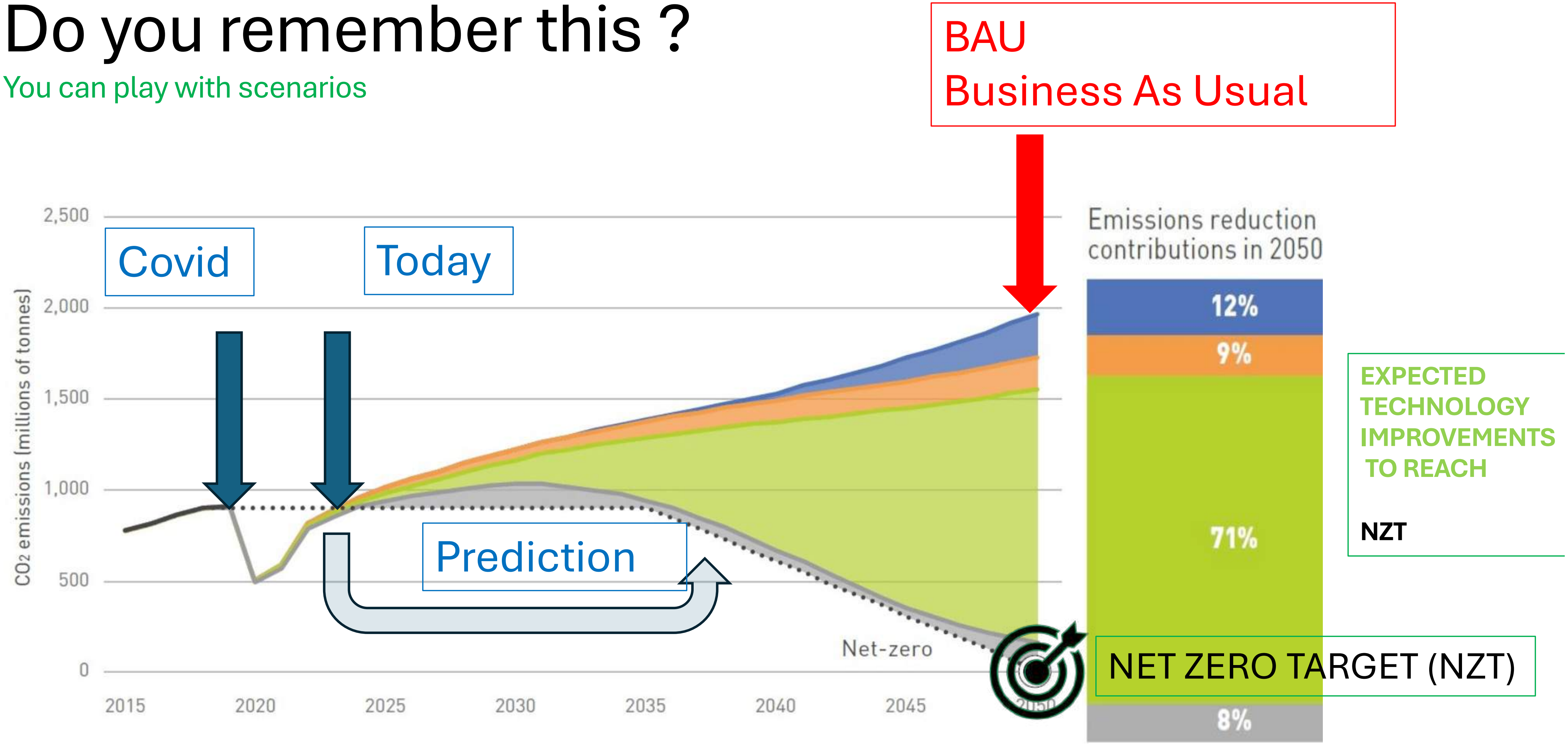
A Curated list of (mostly) opensource softwares

Tools for decarbonizing air transportation:
https://cascade.boeing.com/
https://aeromaps.eu
https://github.com/AeroMAPS/AeroMAPS
https://www.leadsresearchgroup.com/technology-dashboard
https://github.com/contrailcirrus/pycontrails?tab=readme-ov-file
https://github.com/sustainableaviation
https://github.com/Aircraft-Operations-Lab
https://psesh.github.io/aviation.html
https://github.com/leadsgroup
https://www.leadsresearchgroup.com/software
https://github.com/protontypes/open-sustainable-technology
https://www.witness4climate.org/optimizing-investments-in-energy-production-technology
https://junzis.com/open-source

Tools for aircraft design
https://github.com/peterdsharpe/AeroSandbox/tree/master
https://openmdao.github.io/Aviary/examples/OAS_subsystem.html
https://github.com/OpenMDAO/Aviary
https://github.com/ideas-um/FAST
https://github.com/MIT-LAE/TASOPT.jl
https://github.com/mdolab/OpenAeroStruct
https://github.com/mdolab/openconcept
https://github.com/fast-aircraft-design/FAST-OAD
https://web.mit.edu/drela/Public/web/
https://lsdo.eng.ucsd.edu/software
https://github.com/mid2SUPAERO/LCA4MDAO
https://github.com/ImperialCollegeLondon/sharpy
https://www.aircraftflightmechanics.com/NotesIntroduction.html
https://github.com/MIT-LAE
https://github.com/OpenVSP/OpenVSP
https://github.com/suavecode
https://github.com/camUrban/PteraSoftware
https://github.com/cfsengineering/CEASIOMpy
https://github.com/DLR-AE/PanelAero
https://github.com/DLR-AE
https://github.com/ImperialCollegeLondon/PinhoLab-WingBox
https://commonresearchmodel.larc.nasa.gov
https://github.com/facebookarchive/FBHALE
https://github.com/mid2SUPAERO/ecoHALE
https://hkust-octad-lab.github.io/AeroFuse.jl/stable

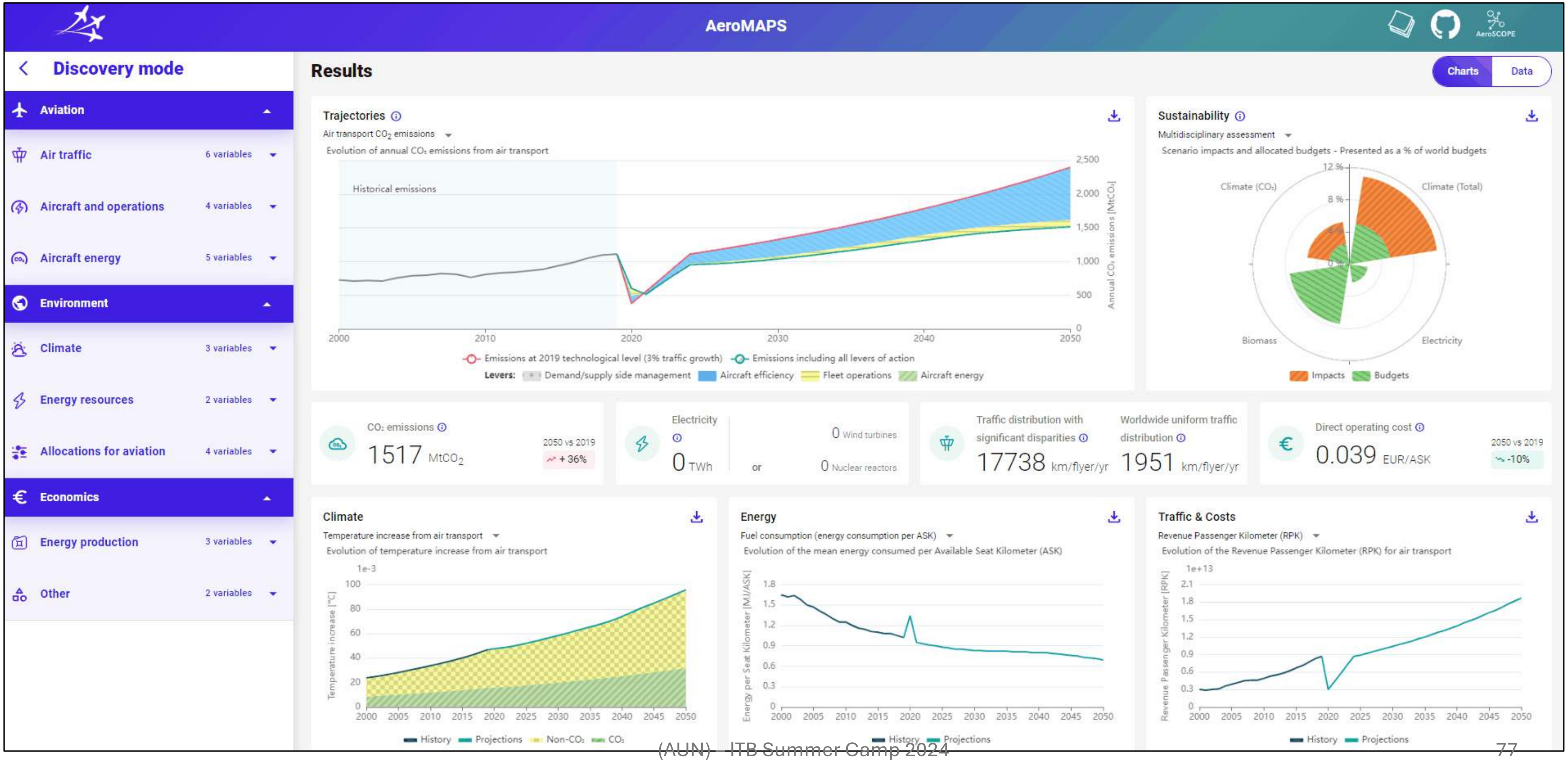
Do you remember this ?

You can play with scenarios



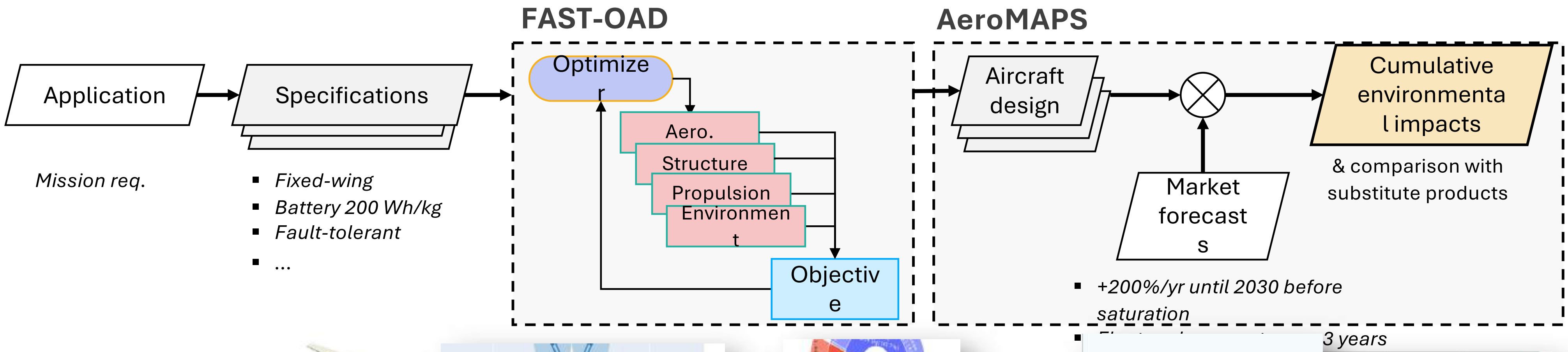
AeroMAPS: an opensource framework for air transport prospective scenarios

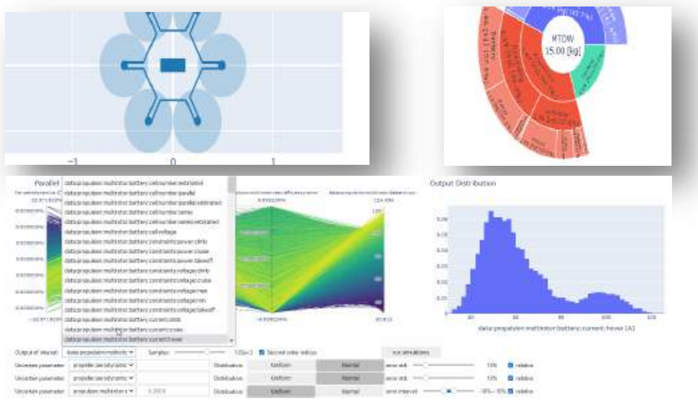
https://github.com/AeroMAPS/AeroMAPS

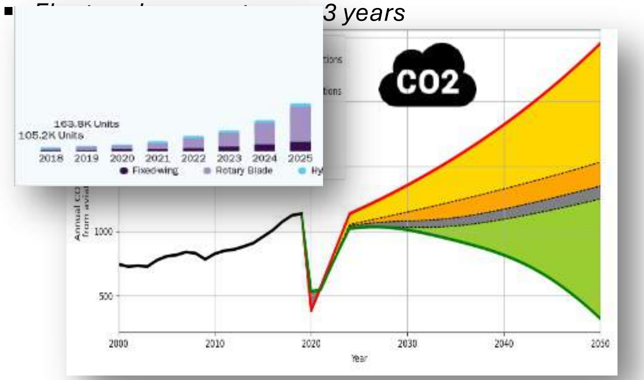


FastOAD : An open source framework for rapid Overall Aircraft Design

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







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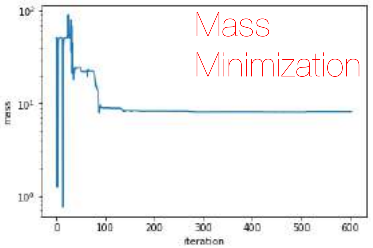
Aircraft Design

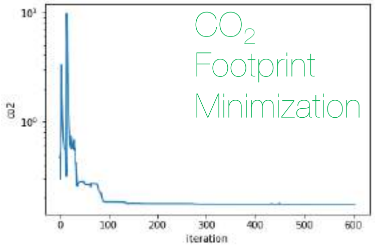
Fluid x control x physics x applied maths x structures &materials

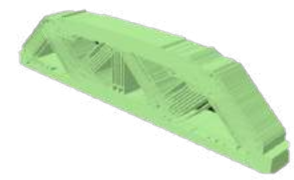
Topology x Material x Process

Strong coupling Between Disciplines

		Avionics group	Electrical group	Escape system	Armament	Landing gear	Hydraulies group	Flight control system	Environment and control system	Power plant group	Fatigue group	Aero elastic group	Stress group	Materials group	Fly wheel	Empennage group	Rear fuselage	Fuselage group
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Avionics group	1	●	●	●	●	●	●	●	●	●						●	●	●
Electrical group	2	●	●	●	●	●	●	●	●	●					●	●	●	●
Escape system	3	●	●	●	●													●
Armament	4	●	●		●						●	●	●	●		●		●
Landing gear	5	●	●			●	●				●	●	●			●		●
Hydraulies group	6						●			●							●	●
Flight control system	7	●	●					●			●	●	●	●	●	●	●	●
Environment and control	8								●		●	●	●					●
Power plant group	9	●	●				●			●	●	●	●				●	
Fatigue group	10			●	●	●	●	●	●	●	●	●	●		●	●	●	●
Aero elastic group	11			●	●	●	●	●	●	●	●	●	●		●	●	●	●
Stress group	12		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Materials group	13										●	●	●	●	●	●	●	●
Empennage group	14	●	●					●			●	●	●	●	●		●	
Wing group	15		●		●	●				●	●	●	●	●		●	●	
Rear fuselage	16	●	●				●	●		●	●	●	●	●	●	●	●	●
Fuselage group	17	●	●	●		●	●	●	●		●	●	●	●	●	●	●	●







$$\text{Range} = V t_f = V \times \underbrace{\left(\frac{L}{D}\right)}_{\text{aircraft designer}} \times \underbrace{I_{sp}}_{\text{propulsion system designer}} \times \underbrace{\ln\left(\frac{W_i}{W_f}\right)}_{\text{structural designer}}.$$

Welcome in space ;)

73rd International Astronautical Congress (IAC) 2022 – Paris, France

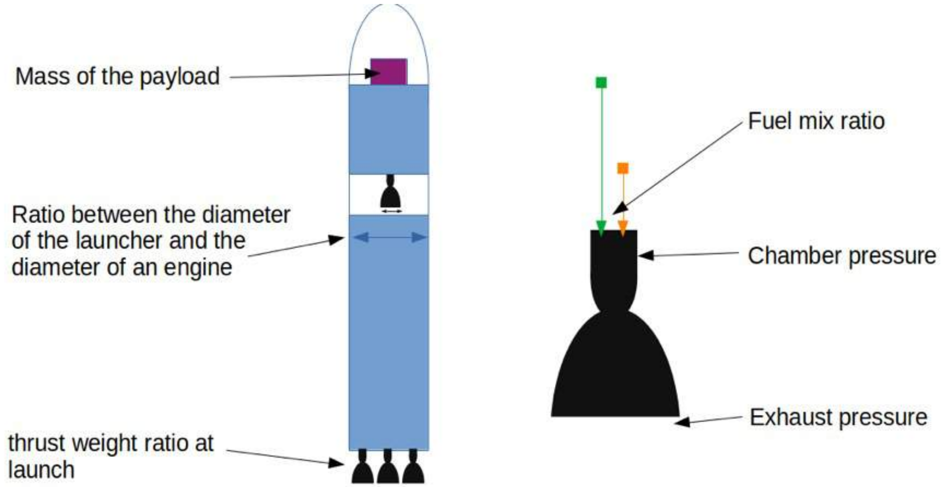
IAC-22,D2,IPB,26,x71719

Impact of Life Cycle Assessment Considerations on Launch Vehicle Design

Thomas Bellier[1, 2, *], Annafederica Urbano[1], Joseph Morlier[1], Cees Bil[2], and Adrian Pudsey[2]

[1] *Institut Supérieur de l'Aéronautique et de l'Espace SUPAERO, Université de Toulouse, Toulouse, France*
[2] *Royal Melbourne Institute of Technology (RMIT), Melbourne, Australia*

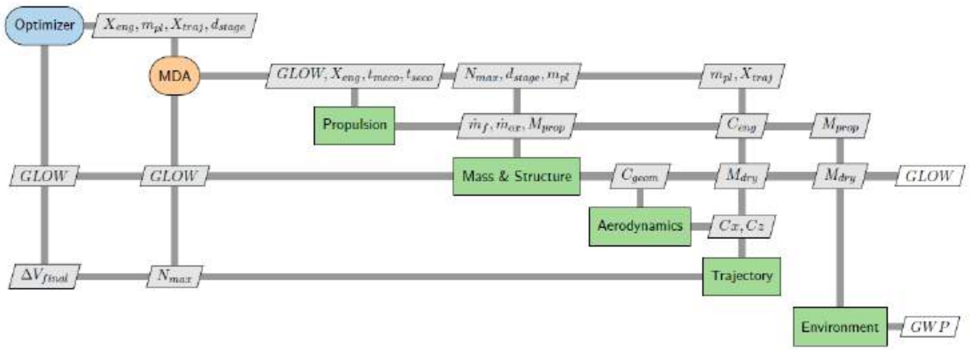
[*]Corresponding author
Email: thomas.bellier@isae-supaero.fr

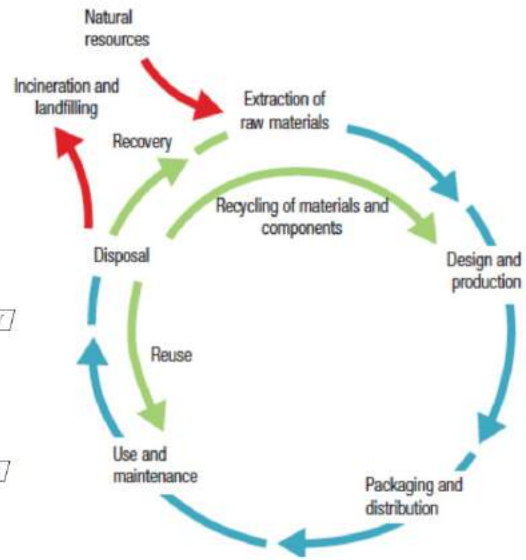


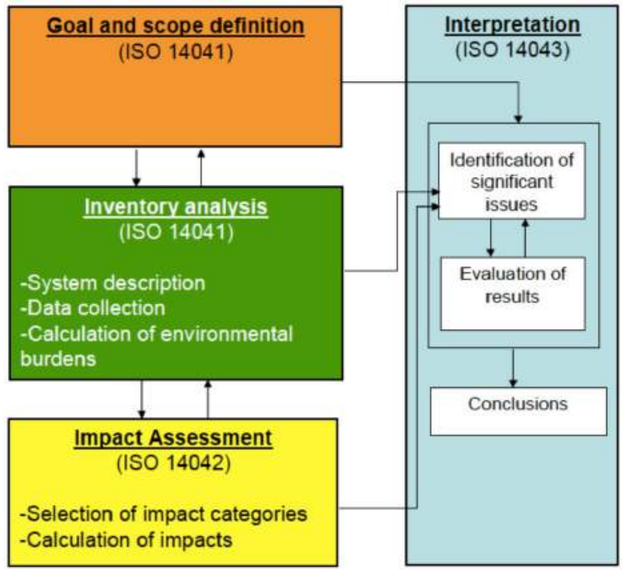
Life Cycle Assessment

ISO norm:
- Proper goal and scope definition, including functional unit
- Inventory analysis and the database problem
- Selection of impacts, and difference between raw flux, midpoint, and endpoint impacts

Objective function : GLOW
Design variables : $X_{eng}, m_{pl}, X_{traj}, d_{stage}$
Constraints : $\Delta V_{final} \geq 0$

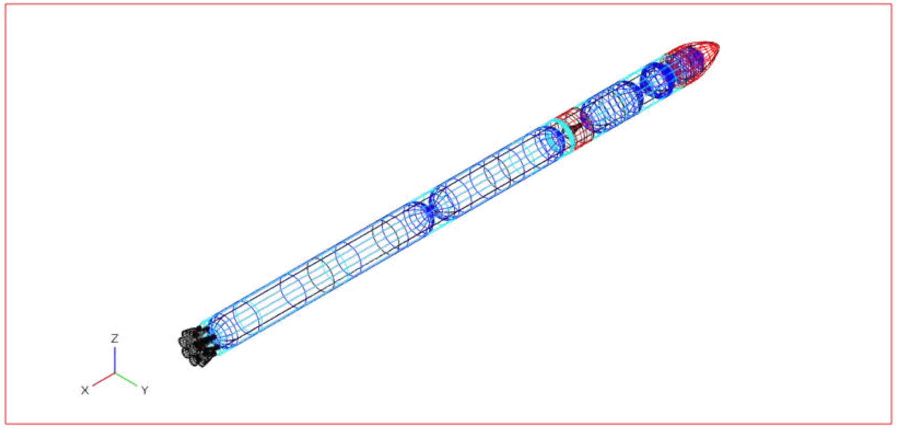


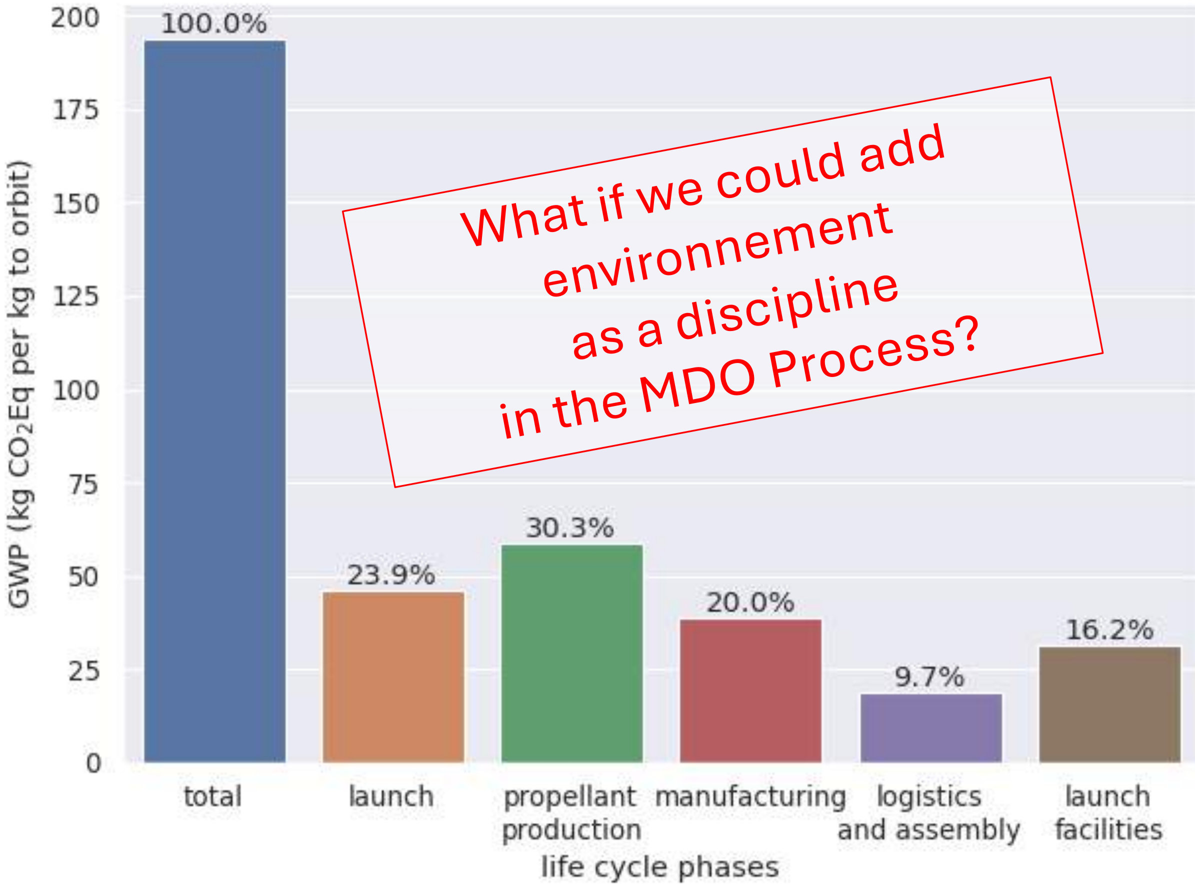




X* →LCA (X*)

X* and LCA (X*)





Early LCA results demonstrate that manufacturing take into account 20% of Global Warming Potential (wrt 1% in Aircraft)

Second MDO example ! Same recipe

- LCA4MDAO
https://github.com/mid2SUPAERO/LCA4MDAO

- **LCA database ecoinvent (need to pay)**
https://ecoinvent.org/database

- Brightway2
https://github.com/brightway-lca

- OpenMDAO
https://github.com/OpenMDAO

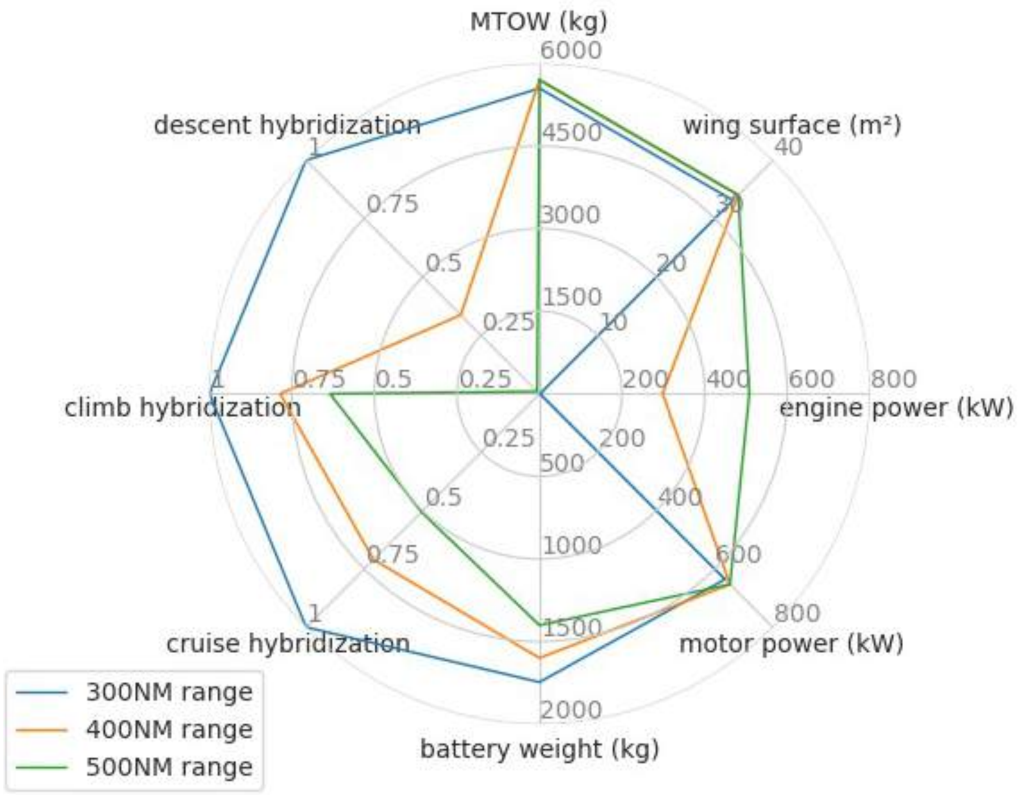
Multi Objective Optimization (MOO)

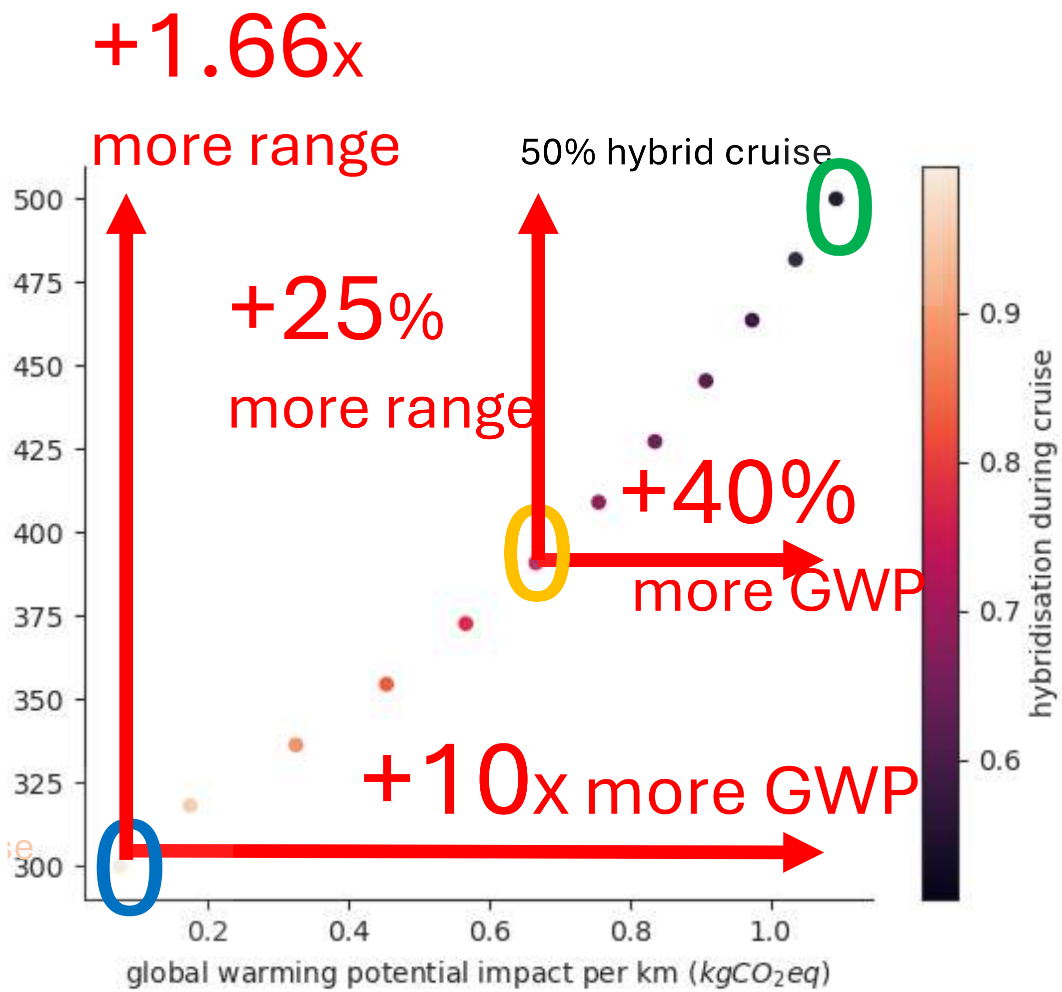
f1=Minimize (-range) and f2=minimise (GWP), α belong to [0 1]

$$f = \alpha * f1 + (1 - \alpha) * f2$$

https://pymoo.org

Results MOO


MTOW (kg)
wing surface (m²)
engine power (kW)
motor power (kW)
battery weight (kg)
cruise hybridization
climb hybridization
descent hybridization
300NM range
400NM range
500NM range


+1.66x
more range
50% hybrid cruise
+25%
more range
+40%
more GWP
+10x more GWP
global warming potential impact per km ($kgCO_2eq$)
hybridisation during cruise

Agenda for today

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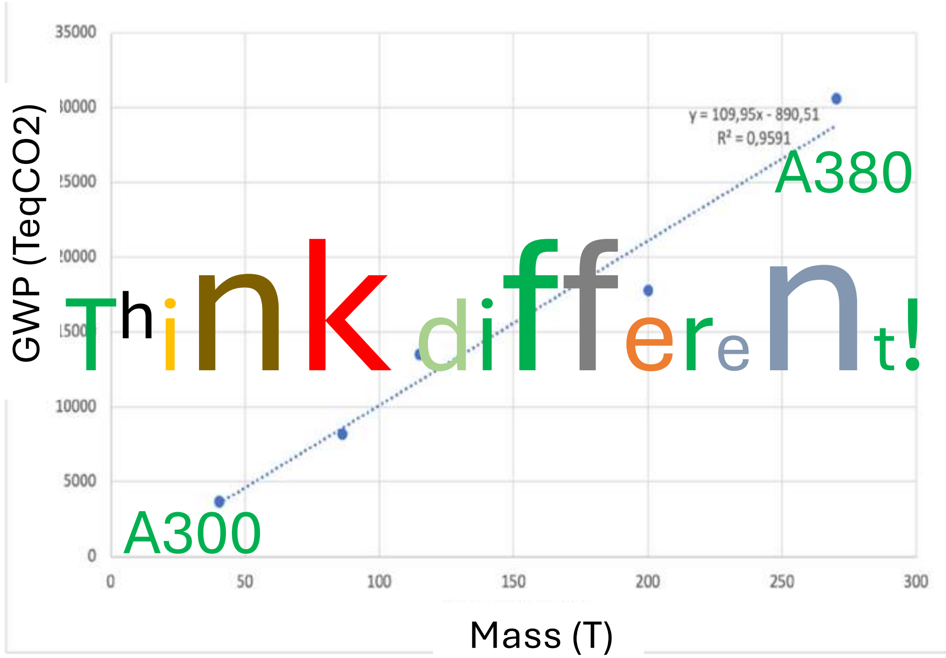
Conclusion

In Aircraft Design:

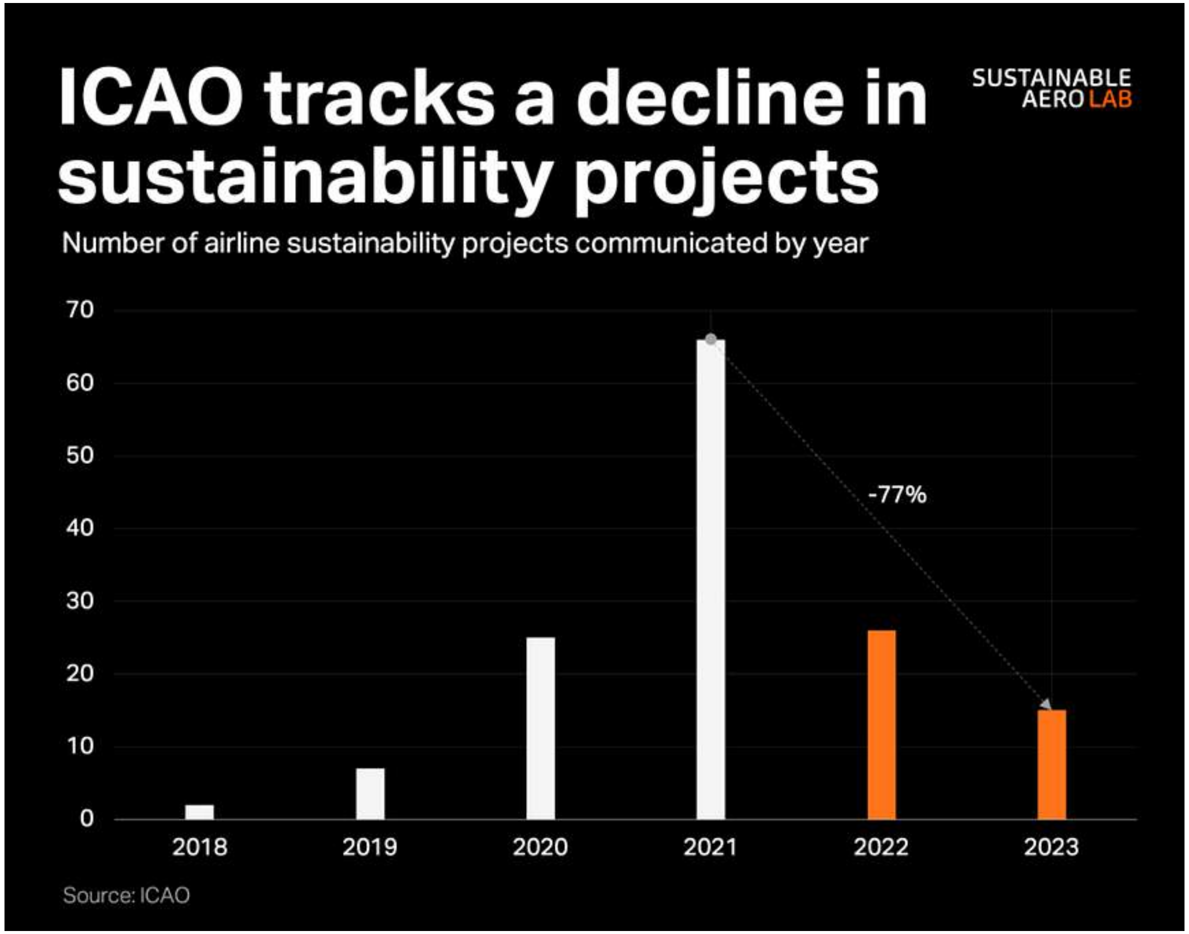
min {mass} is proportional to min {CO2PP}

Manufacturing <1% of total aircraft emissions

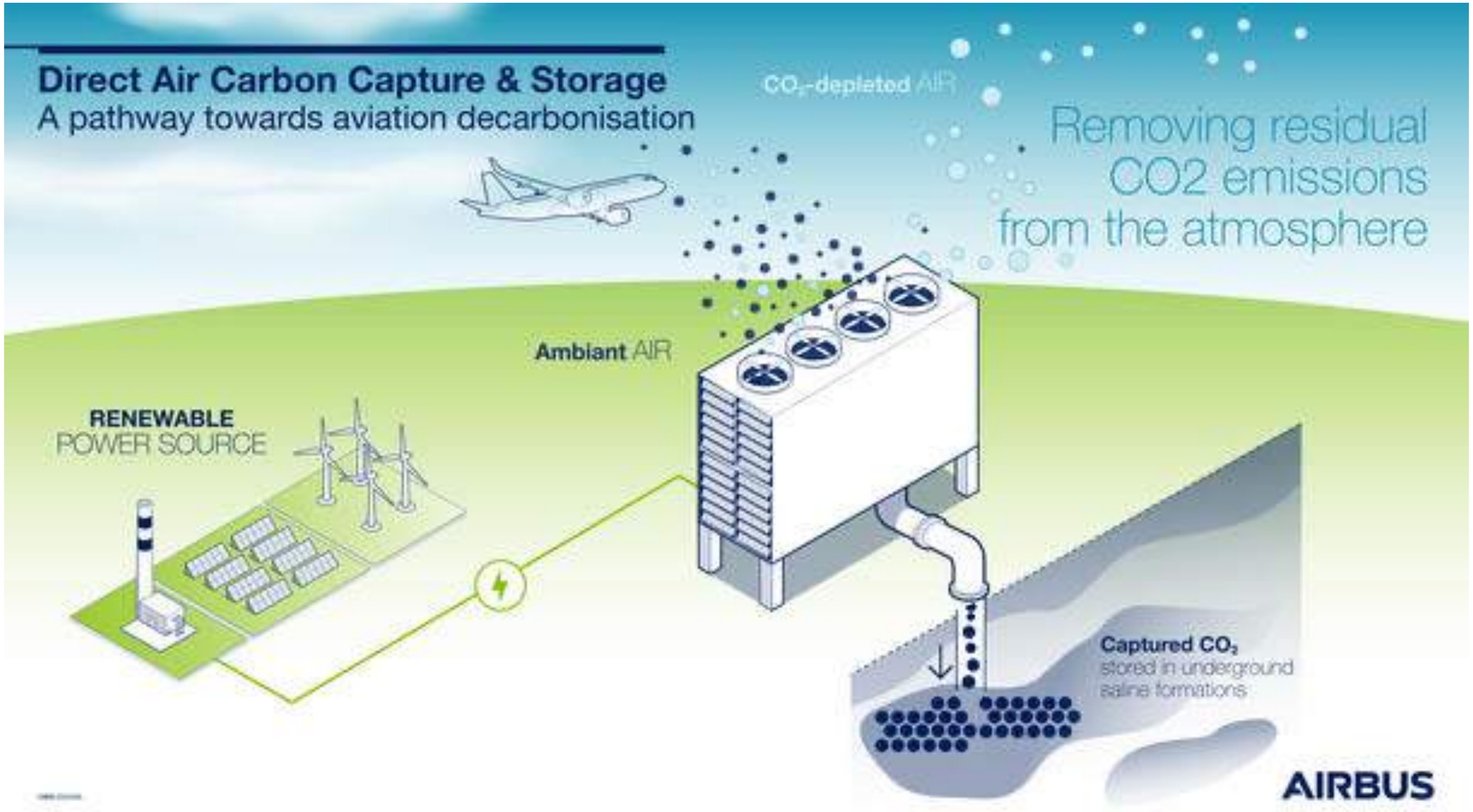


But what about others flying vehicules?

Some airline projects are sunseting...



Ohter projects are progressing...



It’s up to YOU!!!!!!!!

The rankings shown here are based on projected emissions impact globally. The relative importance of a given solution can differ significantly depending on context and particular ecological, eco- nomic, political, or social conditions.

https://drawdown.org/

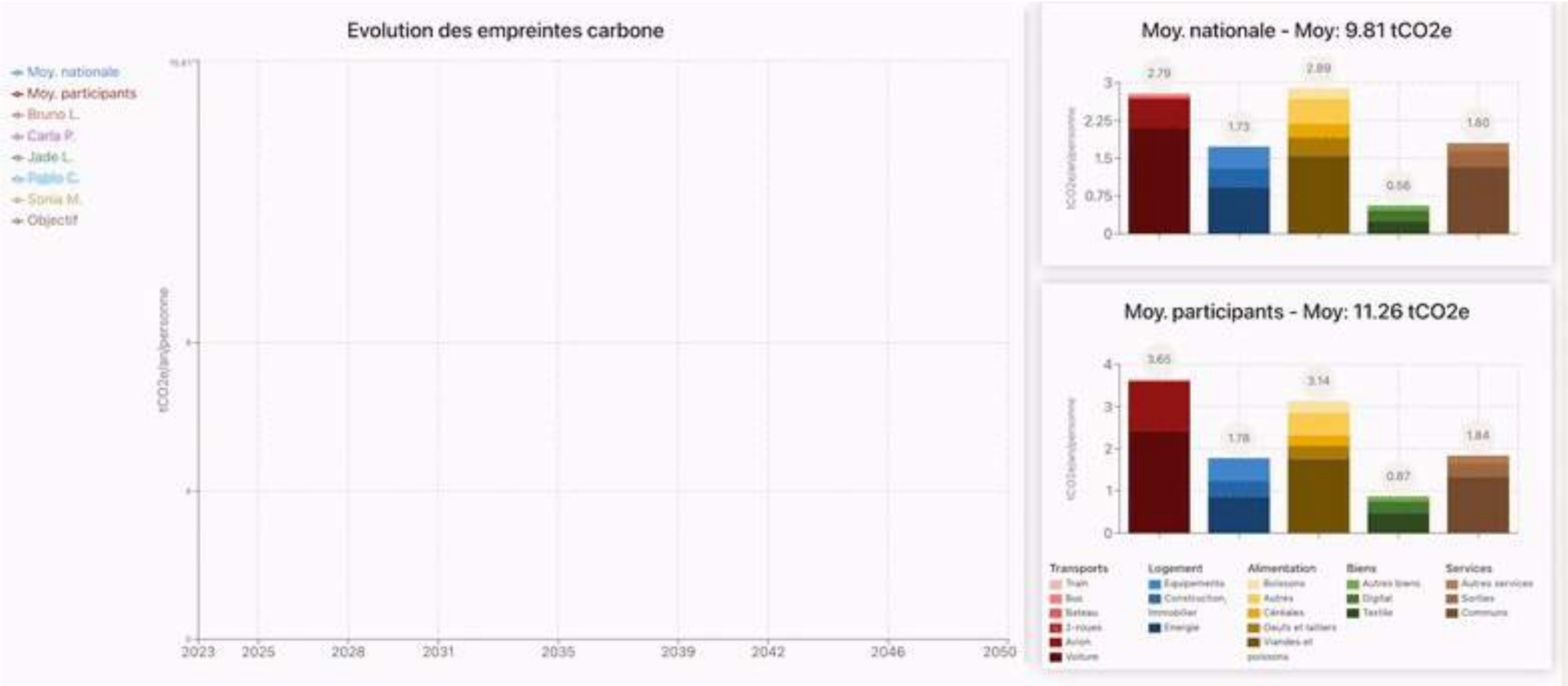
Scenario 1

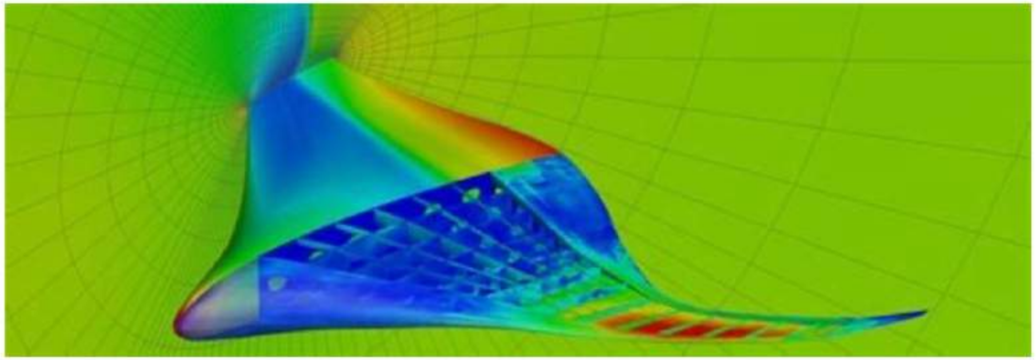
Overall Ranking	Solution	Total CO_2-eq (Gt) Reduced/Sequestered (2020–2050)	Net First Cost to implement solution (Billions $US)	Net Lifetime Cost to operate solution (Billions $US)	Net Lifetime Profit after implementation and operation (Billions $US)
1	Reduced Food Waste	87.4	-	-	-
2	Health & Education	85.4	-	-	-
3	Plant-Rich Diets	65.0	-	-	-
4	Refrigerant Management	57.7	-	600	-
5	Tropical Forest Restoration	54.4	-	-	-
6	Onshore Wind Turbines	47.2	800	-3,800	-
7	Alternative Refrigerants	43.5	-	-	-
8	Utility-Scale Solar Photovoltaics	42.3	-200	-12,900	-
9	Improved Clean Cookstoves	31.3	100	1,900	-
10	Distributed Solar Photovoltaics	27.9	400	-7,800	-
11	Silvopasture	26.5	200	2,300	1,700
12	Peatland Protection & Rewetting	26.0	-	-	-
13	Tree Plantations (on Degraded Land)	22.2	16	100	2,100
14	Temperate Forest Restoration	19.4	-	-	-
15	Concentrated Solar Power	18.6	400	800	-
16	Insulation	16.9	700	-21,700	-
17	Managed Grazing	16.4	33	-600	2,100
18	LED Lighting	16.0	-1,700	-4,500	-
19	Perennial Staple Crops	15.4	83	800	1,400
20	Tree Intercropping	15.0	100	600	200
21	Regenerative Annual Cropping	14.5	77	-2,300	100
22	Conservation Agriculture	13.4	91	-2,800	100
23	Abandoned Farmland Restoration	12.4	98	3,200	2,600
24	Electric Cars	11.8	4,400	-15,200	-
25	Multistrata Agroforestry	11.2	54	100	1,700
26	Offshore Wind Turbines	10.4	600	-600	-
27	High-Performance Glass	10.0	9,000	-3,300	-
28	Methane Digesters	9.8	200	2	-
29	Improved Rice Production	9.4	-	-400	200
30	Indigenous Peoples' Forest Tenure	8.6	-	-	-
31	Bamboo Production	8.2	52	500	1,700
32	Alternative Cement	7.9	-63	-	-
33	Hybrid Cars	7.8	3,400	-6,100	-
34	Carpooling	7.7	-	-5,300	-
35	Public Transit	7.5	-	-2,100	-
36	Smart Thermostats	6.9	100	-1,800	-
37	Building Automation Systems	6.4	200	-1,700	-
38	District Heating	6.2	200	-1,500	-
39	Efficient Aviation	6.2	800	-2,400	-
40	Geothermal Power	6.1	80	-800	-
41	Forest Protection	5.5	-	-	-
42	Recycling	5.5	10	-200	-
43	Biogas for Cooking	4.6	23	100	-
44	Efficient Trucks	4.6	400	-3,400	-
45	Efficient Ocean Shipping	4.3	500	-600	-
46	High-Efficiency Heat Pumps	4.1	76	-1,000	-
47	Perennial Biomass Production	3.9	200	1,500	900
48	Solar Hot Water	3.5	700	-200	-
49	Grassland Protection	3.3	-	-	-
50	System of Rice Intensification	2.7	-	-14	500
51	Nuclear Power	2.6	100	-300	-
52	Bicycle Infrastructure	2.5	-2,600	-800	-
53	Biomass Power	2.5	51	-200	-
54	Nutrient Management	2.3	-	-23	-
55	Biochar Production	2.2	100	700	-
56	Landfill Methane Capture	2.1	-4	6	-
57	Composting	2.1	-60	100	-
58	Waste-to-Energy	2.0	100	96	-

NOTE: *Where a cost is a negative number, it indicates savings. Where a dash is shown, results are not available.*

My Advice: Fly Less ! Travel Better

Try to reach collectively 2t/y per individual https://en.2tonnes.org





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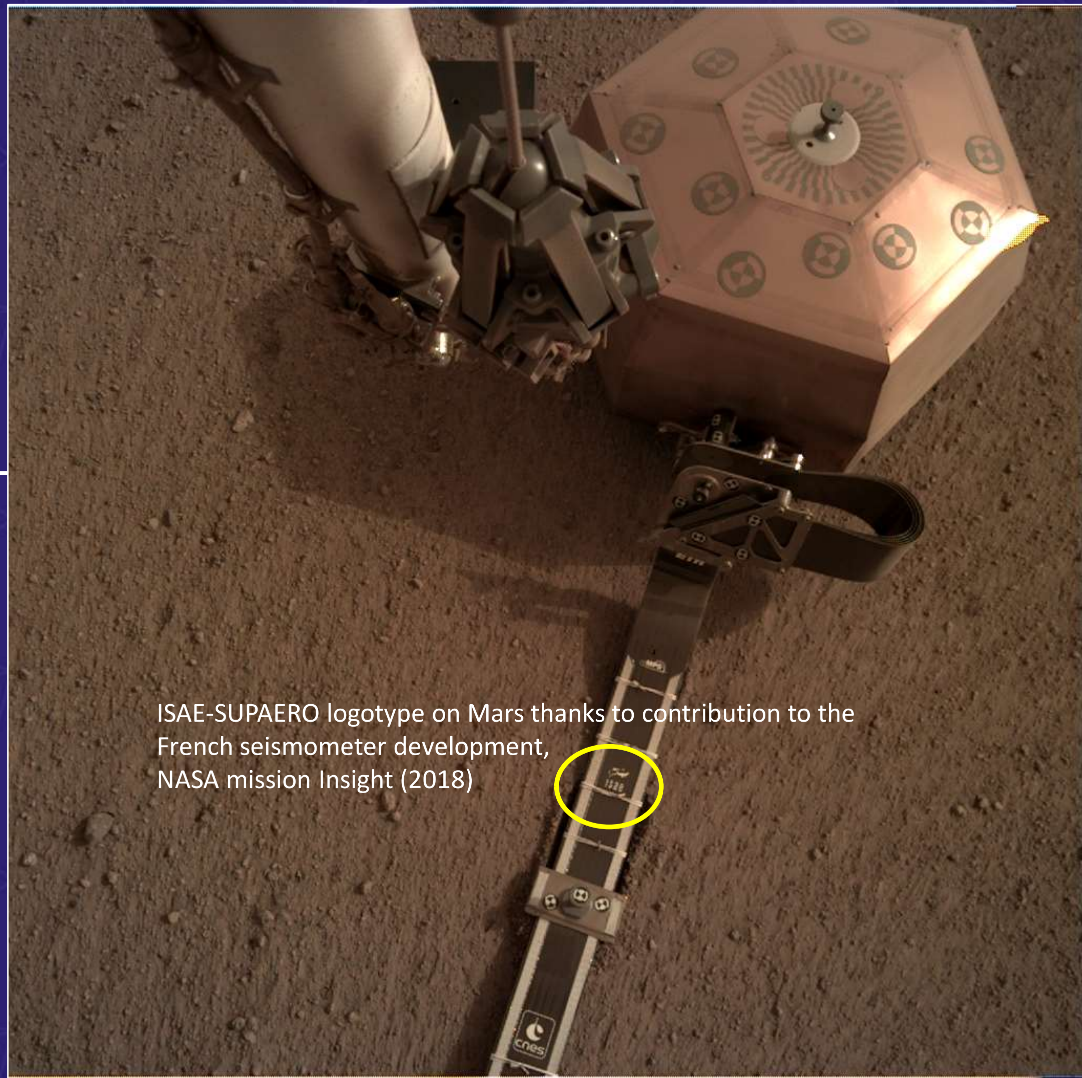
Thank you
for your attention

Thanks ITB



ISAE-SUPAERO logotype on Mars thanks to contribution to the French seismometer development,
NASA mission Insight (2018)