Combining SA+DO

How to start with Python toolboxes?

UTM Summer 2025

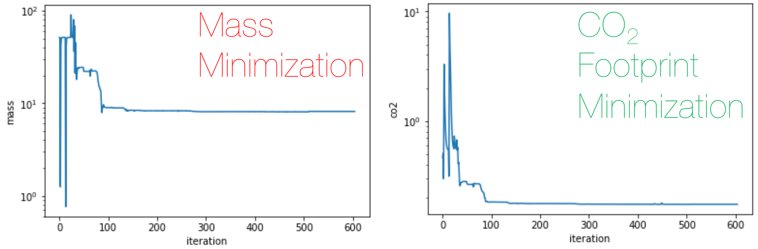
Aircraft Design

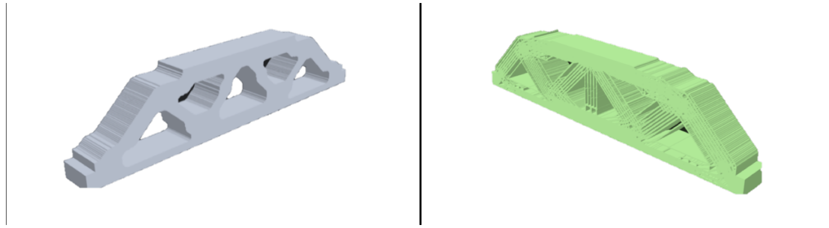
Fluid x control x physics x applied maths x structures &materials

Strong coupling Between Disciplines

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

Topology x Material x Process



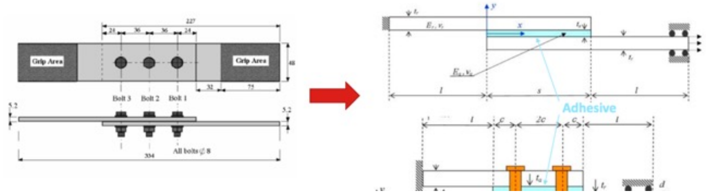


$$\text{Range} = Vt_f = V \times \underbrace{\left(\frac{L}{D}\right)}_{\text{aircraft designer}} \times \underbrace{I_{sp}}_{\text{propulsion system designer}} \times \underbrace{\ln\left(\frac{W_i}{W_f}\right)}_{\text{structural designer}}.$$

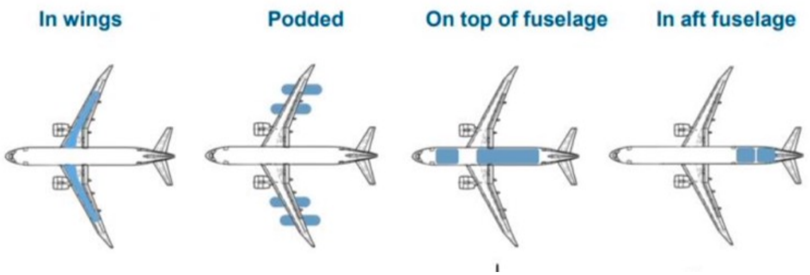
Structures/materials

Advanced assembling

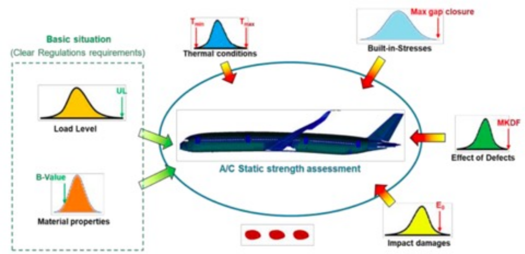
- Replacing rivets/bolts with bonding in aeronautical assemblies



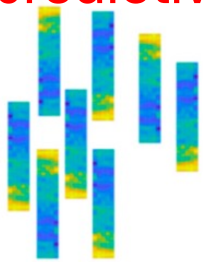
Advanced Structures for H2 tank



Worst case design

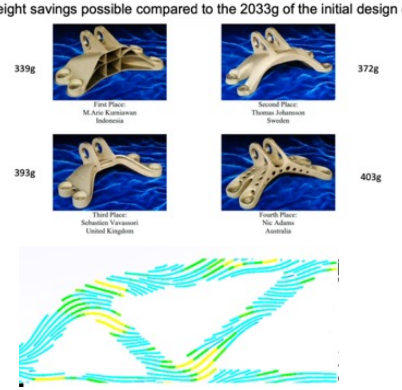


AI predictive maintenance



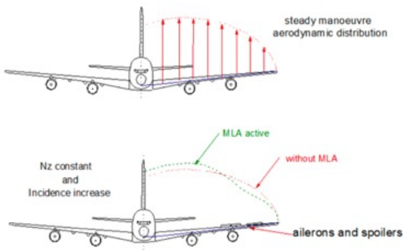
ALM and topogy optimization

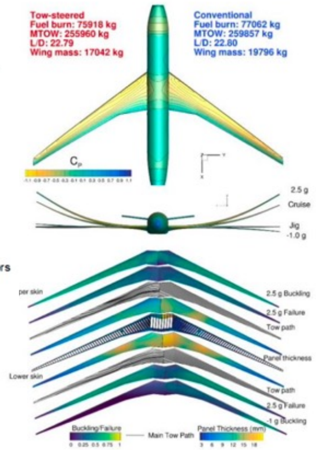
- Massive weight savings possible compared to the 2033g of the initial design (~80%)



FSI/Load Alleviation / HARW

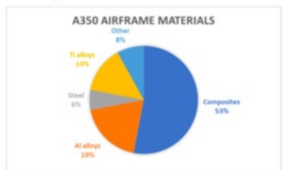
Reference fuel burn: 87558kg





Advanced materials/processes

- Composites



- Composite materials + advanced airframe design and optimization ➔ ~13t (~12%) airframe weight savings ➔ ~20t (~8%) MEW weight savings ➔ 6% fuel savings

First MDO example !

4 disciplines

- Low cost satellite
- HALE: No propulsion

→Only CO2 footprint **PP**

(no Fuel Burn)

www.nature.com/scientificreports

scientific reports

Check for updates

OPEN

CO_2 footprint minimization of solar-powered HALE using MDO and eco-material selection

Edouard Duriez[1,3], Víctor Manuel Guadaño Martín[2,3] & Joseph Morlier[1,3]

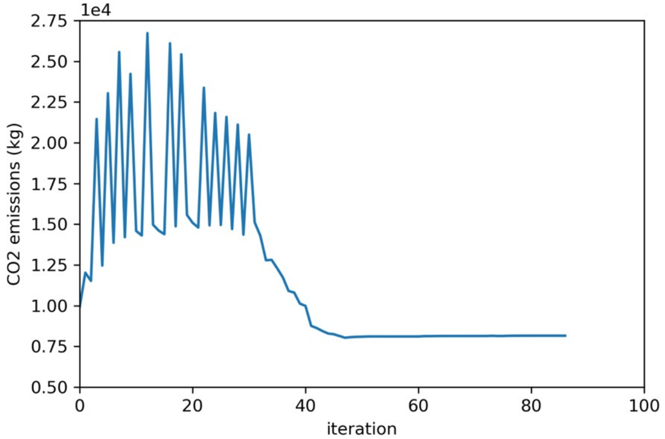
$$\text{Embodied carbon (kgCO}_2\text{e)} = \sum_{\text{Sum for all materials}} \left(\boxed{\text{Quantity (kg)}} \times \boxed{\text{Carbon factor (kgCO}_2\text{e/kg)}} \right)$$

Discipline	Method	Implementation	References
Aerodynamics	VLM	OAS	28
Structure	Wingbox beams	OAS	17
Energy	Simple in-house method	Section "OpenAeroStruct to Eco-HALE"	Data from[14]
Environmental	Proportional to mass	Section "MDO framework summary"	Data from[29,30]

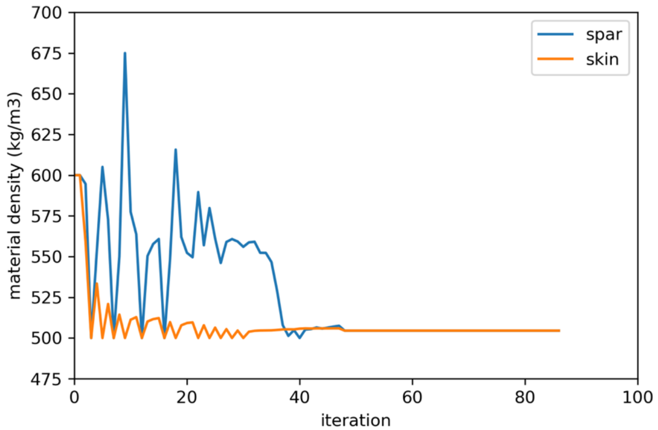
Fondation ISAE - SUPAERO

CO2 footprint minimization

(a) Objective function: total CO2 emitted:

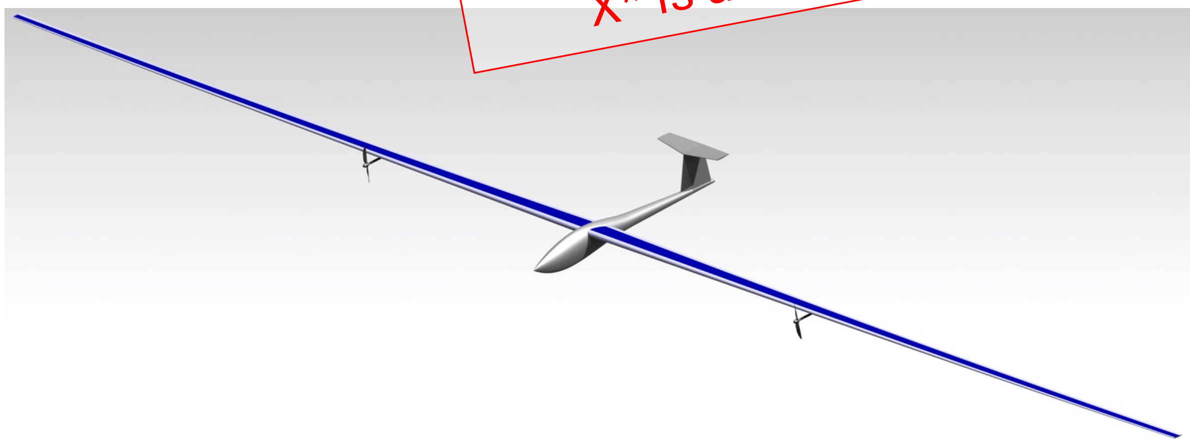


(b) Material density for skins and spars:



Convergence graphs

X* is a UHAR Wing ;)



CAD model of the optimal HALE obtained

A slight increase in the total weight of the drone leads to an increase in the weight of the battery and the solar panel in order to propel a heavier drone,

But also to: an increase in the weight of the wing structure that induces a more important lift to compensate → increase in the overall weight of the drone.

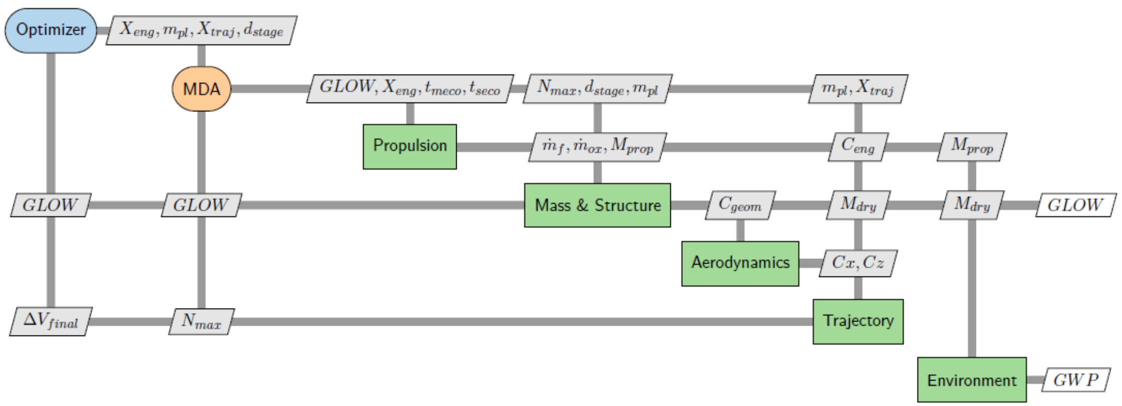
→ "snowball" effect.

Second MDO example !

Welcome in space ;)

https://hal.science/hal-03888108/

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



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

IAC-22,D2,IPB,26,x71719

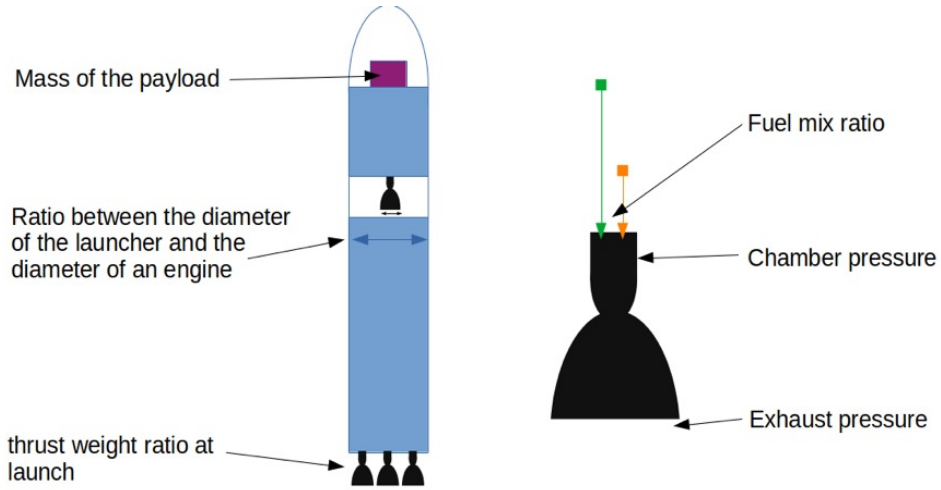
Impact of Life Cycle Assessment Considerations on Launch Vehicle Design

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*

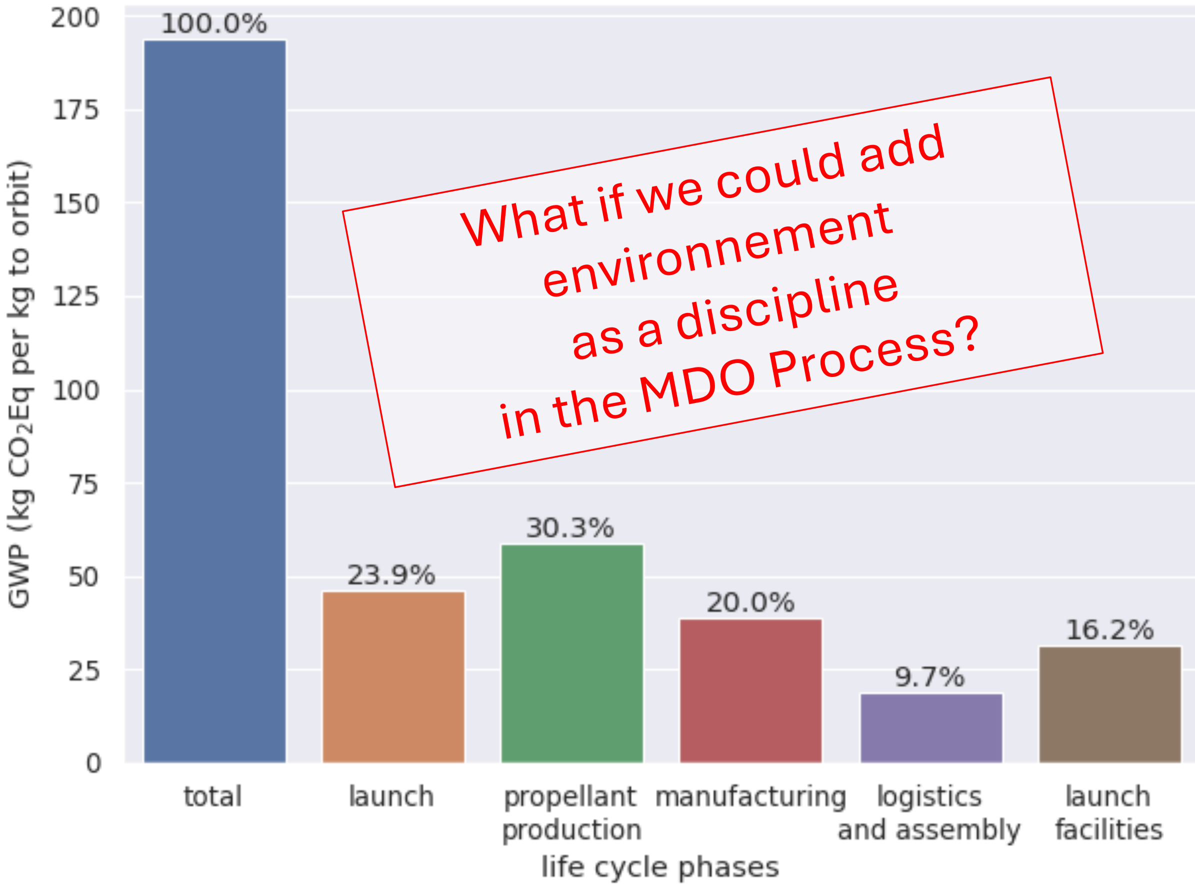
[2] *Royal Melbourne Institute of Technology (RMIT), Melbourne, Australia*

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



X* and LCA (X*)

And avoid Greenwashing !!!



What if we could add environnement as a discipline in the MDO Process?

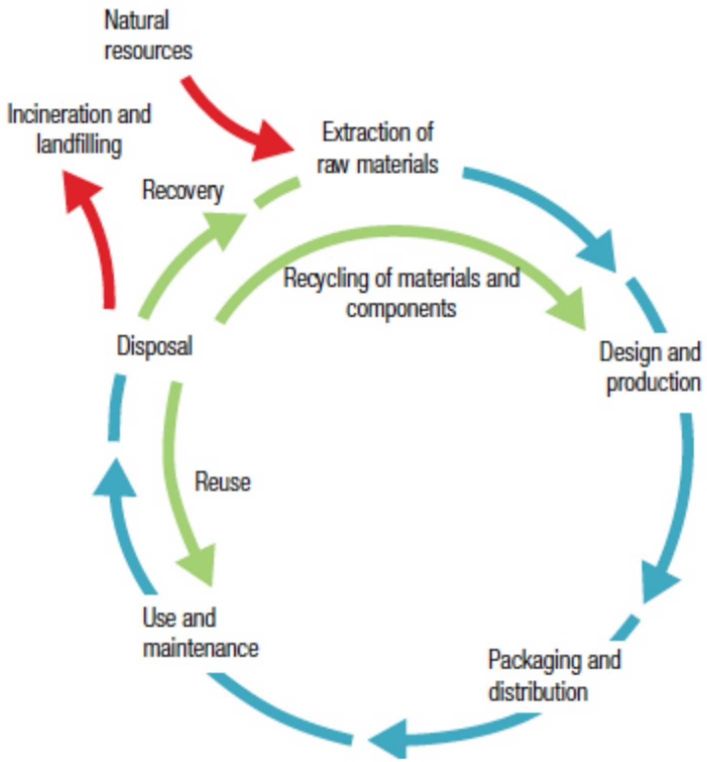
Early LCA results demonstrate that manufacturing take into account 20% of Global Warming Potential (wrt 1% in Aircraft)

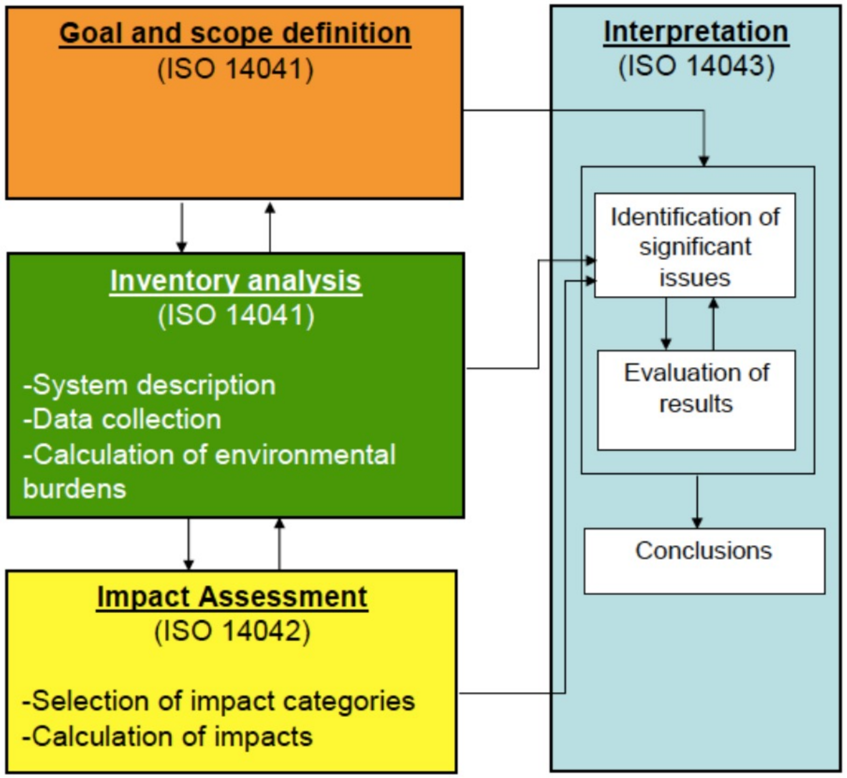
Before the Third MDO example !

LCA in a nutshell

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





A simple example

Minus (-) need
Plus (+) produce

P2

Production of electricity:

– expressed in flow diagram terms:

2 liters of fuel →

→ 10 kWh of electricity
→ 1 kg of CO_2
→ 0.1 kg of SO_2

– expressed in mathematical terms:

$$\begin{pmatrix} -2 \\ 10 \\ 1 \\ 0.1 \\ 0 \end{pmatrix}$$

Need ***X2*** liters of fuel to produce ***Y2*** kWh of electricity and ***Z21*** kg of CO2 and ***Z22*** kg of SO_2

P1

Production of fuel:

– expressed in flow diagram terms:

50 liters of crude oil →

→ 100 liters of fuel
→ 10 kg of CO_2
→ 2 kg of SO_2

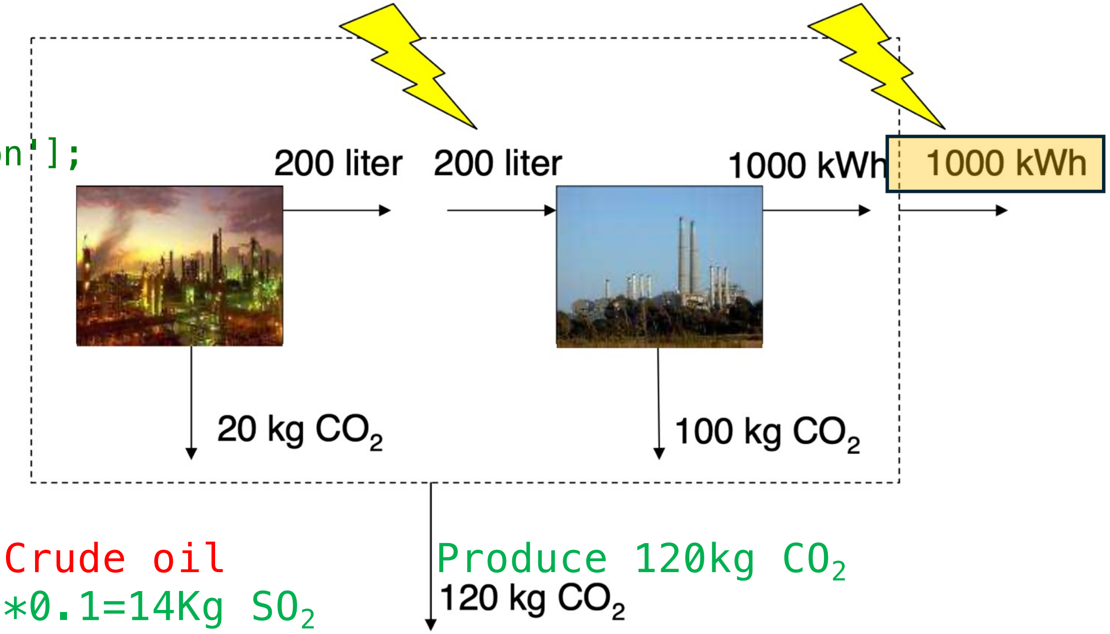
– expressed in mathematical terms:

$$\begin{pmatrix} 100 \\ 0 \\ 10 \\ 2 \\ -50 \end{pmatrix}$$

But to produce ***Y1*** liters of fuel,
You need ***X1*** liters of crude oil
and you produce ***Z11*** kg of CO2
and ***Z12*** kg of SO_2

A simple LCA

We need to match supply and demand.




```
%process=['fuel production'; 'electricity production'];
%econflow=['litre of fuel'; 'kWh of electricity'];
%envflow=['kg of carbon dioxide'; 'kg of sulphur
dioxide'; 'litre of crude oil'];

%definition of the system:
%the technology matrix
A=[-2 100;10 0];
%the intervention matrix
B=[1 10;0.1 2;0 -50];
%the final demand vector
f=[0; 1000];

LCAcalc
```

Need 2*50=100L Crude oil

Produce 2*2+100*0.1=14Kg SO_2

Produce 120kg CO_2

P1 **Production of fuel**:
– expressed in flow diagram terms:

P2 **Production of electricity**:
– expressed in flow diagram terms:

Phases of an LCA

- Goal and scope definition
- Inventory
- Impact assessment
- Interpretation

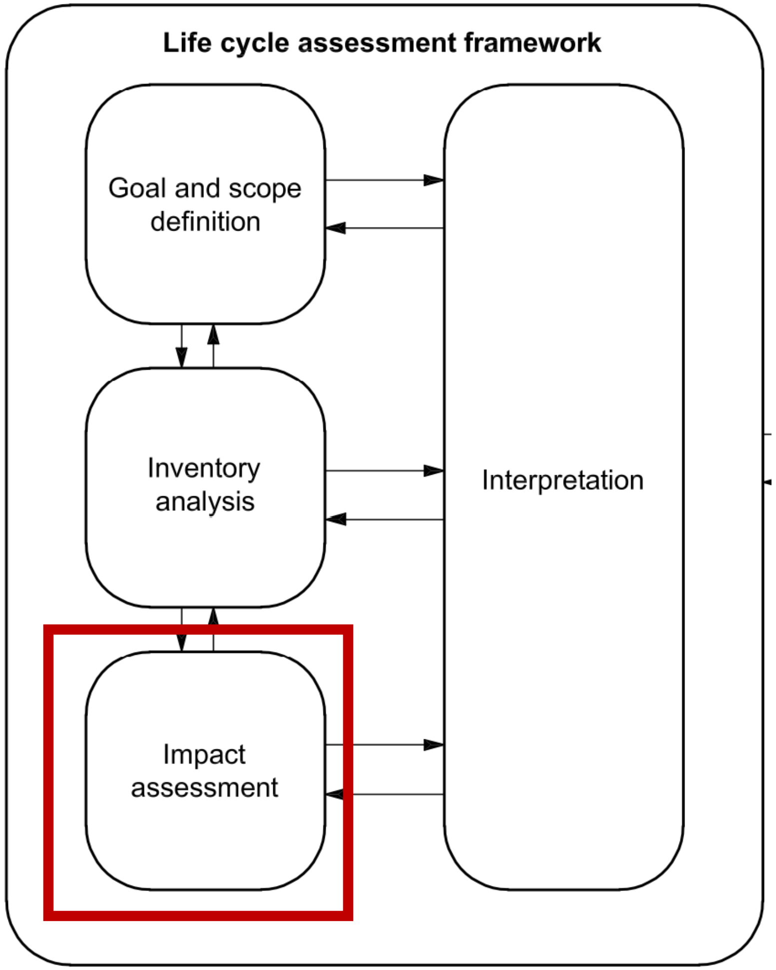


Figure: ISO 14040

Third MDO example !

MOO

%f1=Minimize (f_sellar) and f2=minimise (GWP)

f1=Minimize (-range) and f2=minimise (GWP) % second problem

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

https://pymoo.org

Hybrid Aircraft Problem (MDOlab)

- Hybridised King Air C90GT from OpenConcept, built in *OpenMDAO* format
- Four disciplines:
  - Aero (wing geometry)
  - Propulsion (with hybrid system)
  - Structure
  - Trajectory simulation
- 6 variables converted into LCA database entries

Model parameter	Ecoinvent entry
Battery weight	battery cell production, Li-ion
Motor weight	electric motor production, vehicle
Engine weight	internal combustion engine production, passenger car
Empty weight	aluminium production, primary, ingot
Fuel used	market for kerosene
Electricity used	market group for electricity, low voltage

Benjamin J. Brelje and Joaquim R. R. A. Martins, "Development of a Conceptual Design Model for Aircraft Electric Propulsion with Efficient Gradients", 2018 AIAA/IEEE Electric Aircraft Technologies Symposium, AIAA Propulsion and Energy Forum, (AIAA 2018-4979) DOI: 10.2514/6.2018-4979

Eytan J. Adler and Joaquim R. R. A. Martins, "Efficient Aerostructural Wing Optimization Considering Mission Analysis", Journal of Aircraft, 2022. DOI: 10.2514/1.c037096

Design Variables

Trajectory optimization overconstrained i.e.; standard mission

Table 3 presents the design variables values and results after optimisation for this problem, with the range fixed at 400NM and using the GWP as the sole objective, using COBYLA [41]. Figure 6 presents the resulting trajectory and energy consumption for this 400 nautical miles range solution.

Table 3: Example of hybrid aircraft optimisation for a range of $400NM$

variable	min	init	max	value	units
MTOW	4000	5000	5700	5700	kg
wing surface	15	25	40	34	m^2
engine power	0	1000	3000	298	kW
motor power	450	1000	3000	652	kW
battery weight	20	1000	3000	1607	kg
fuel capacity	500	1000	3000	500	kg
cruise hybridisation	0	0.5	1	0.71	
climb hybridisation	0	1	1	0.785	
descent hybridisation	0	0.5	1	0.337	
GWP				0.712	$kgCO_2eq/km$

minimise (GWP)
wrt range=400NM

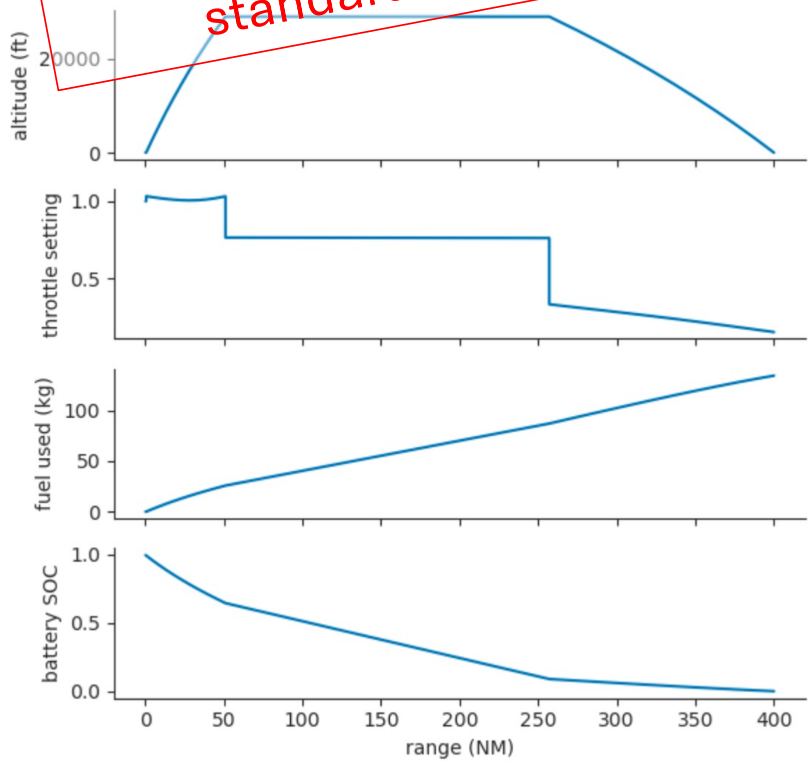
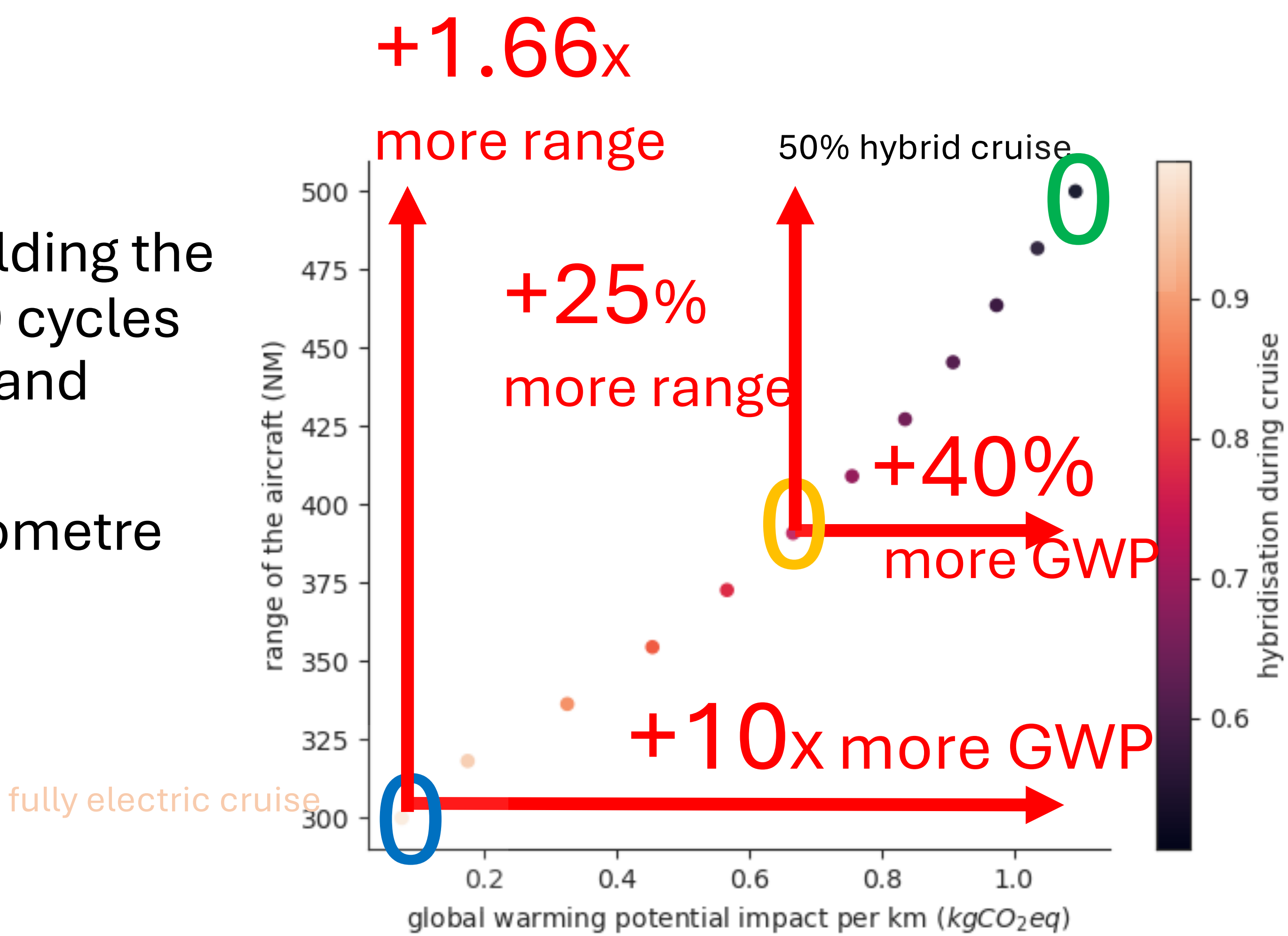


Figure 6: Optimal trajectory and energy utilisation for a hybrid aircraft with 400 nautical miles range

Results MOO

- LCA scope include building the aircraft and flying 1000 cycles at max range with fuel and electricity
- Functional unit is a kilometre flown



LCA4MDAO

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

- **LCA database ecoinvent**
https://ecoinvent.org/database

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

- OpenMDAO
https://github.com/OpenMDAO

Agenda for today

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

4. Conclusions

Conclusion

In Aircraft Design:

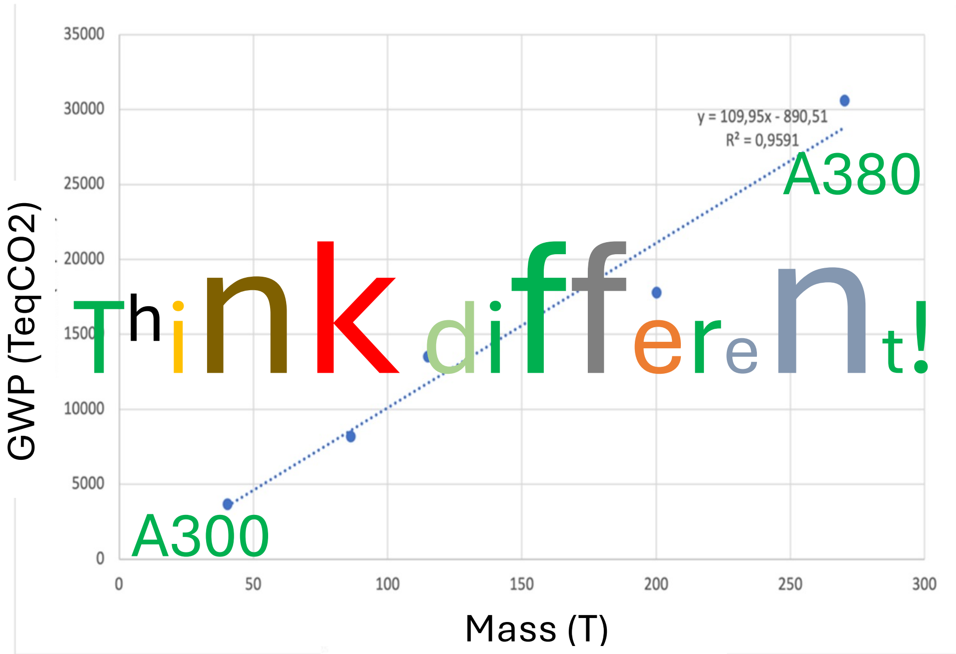
min {mass} is proportional to min {CO2PP}

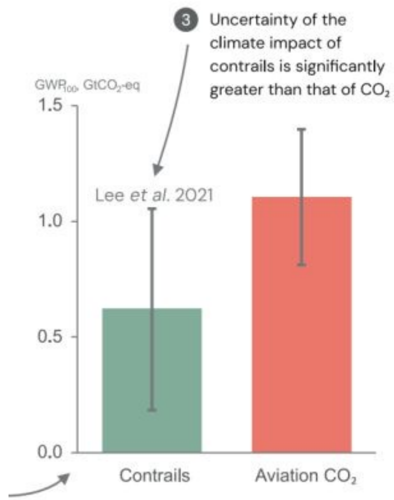
Manufacturing <1% of total aircraft emissions

Meaning it is an energetic problem

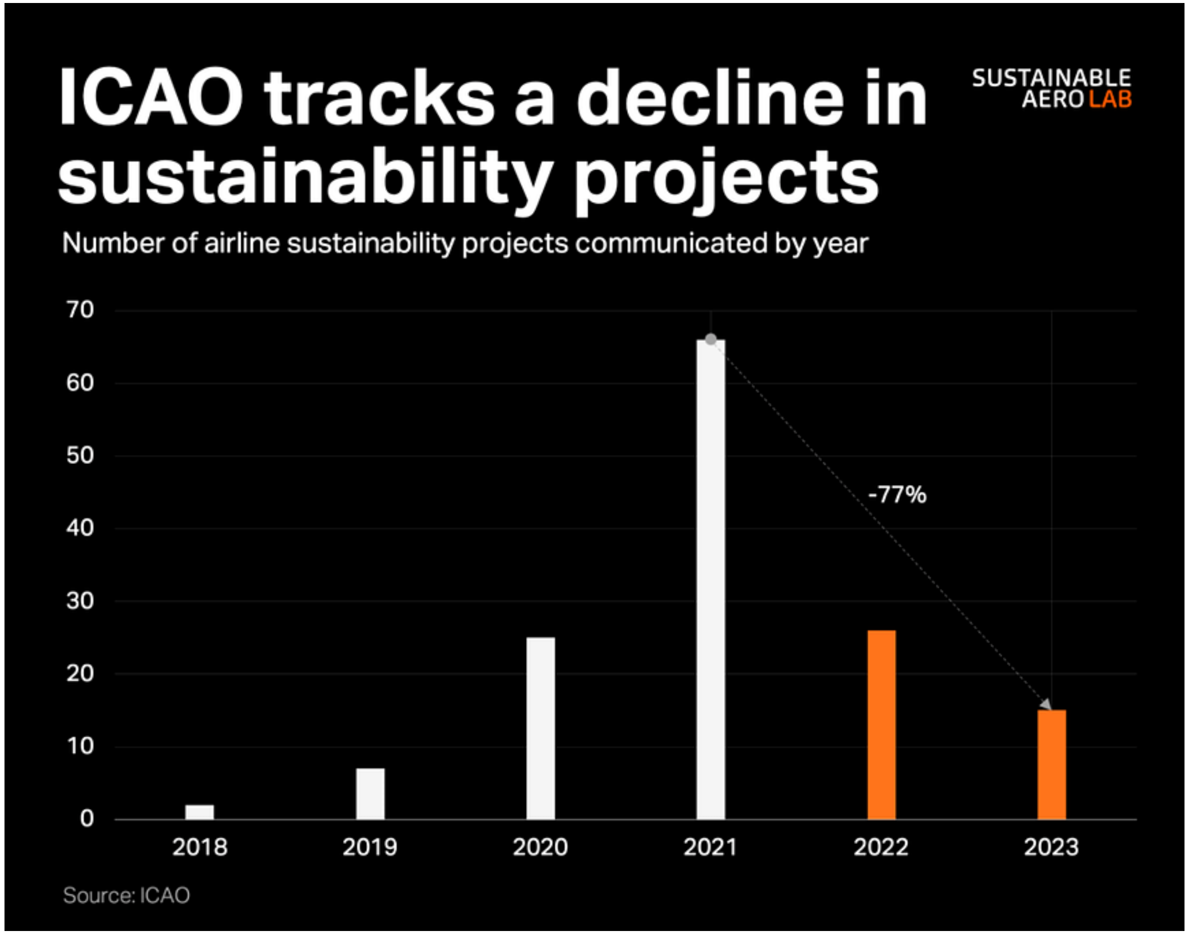
Uncertainties CO_2 versus nonCO_2

But what about others flying vehicules? Wind turbine?

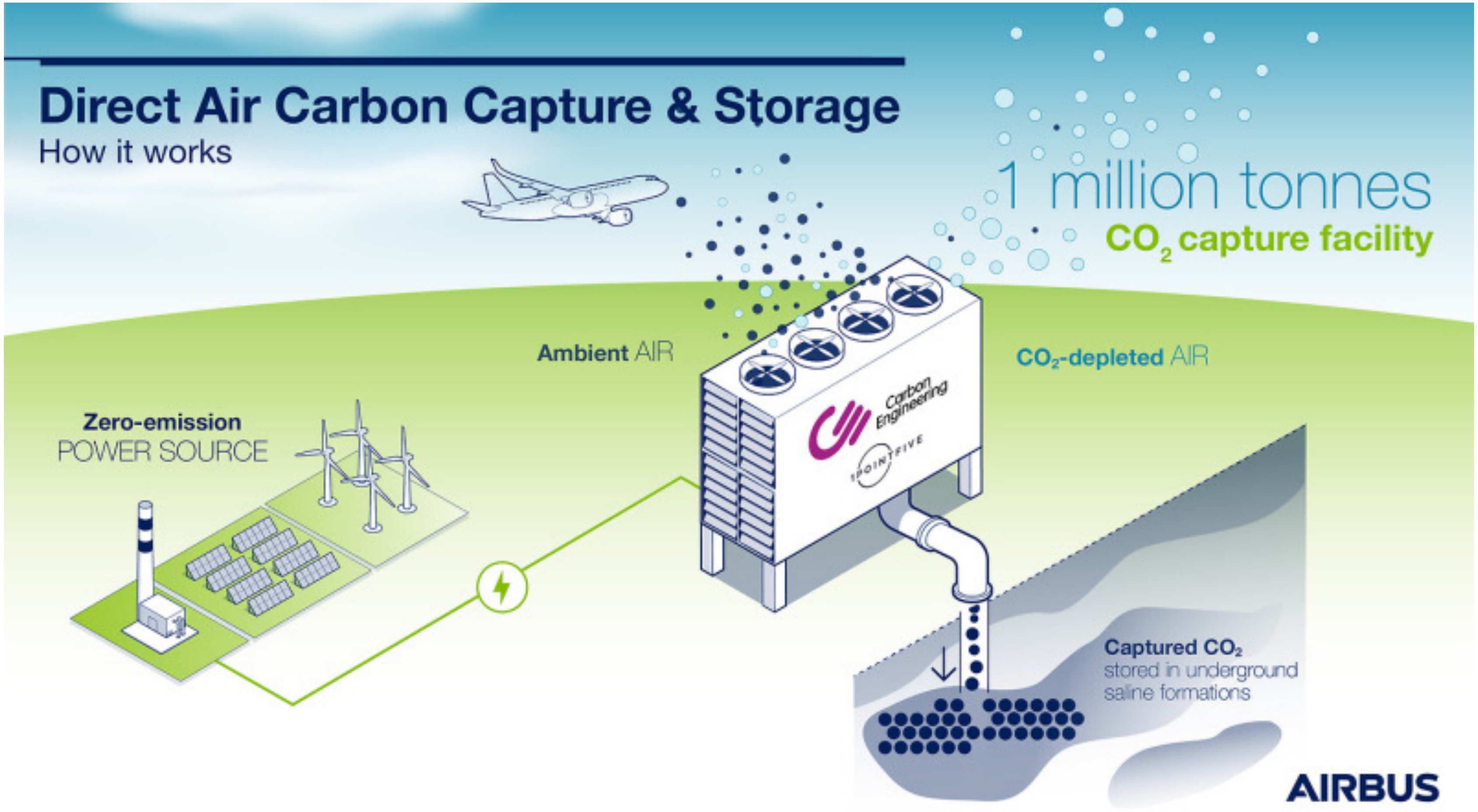




Some airline projects are sunseting…



Ohter projects are progressing...



It’s up to YOU!!!!!!!!

https://drawdown.org/

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.

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	-

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

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)
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	-

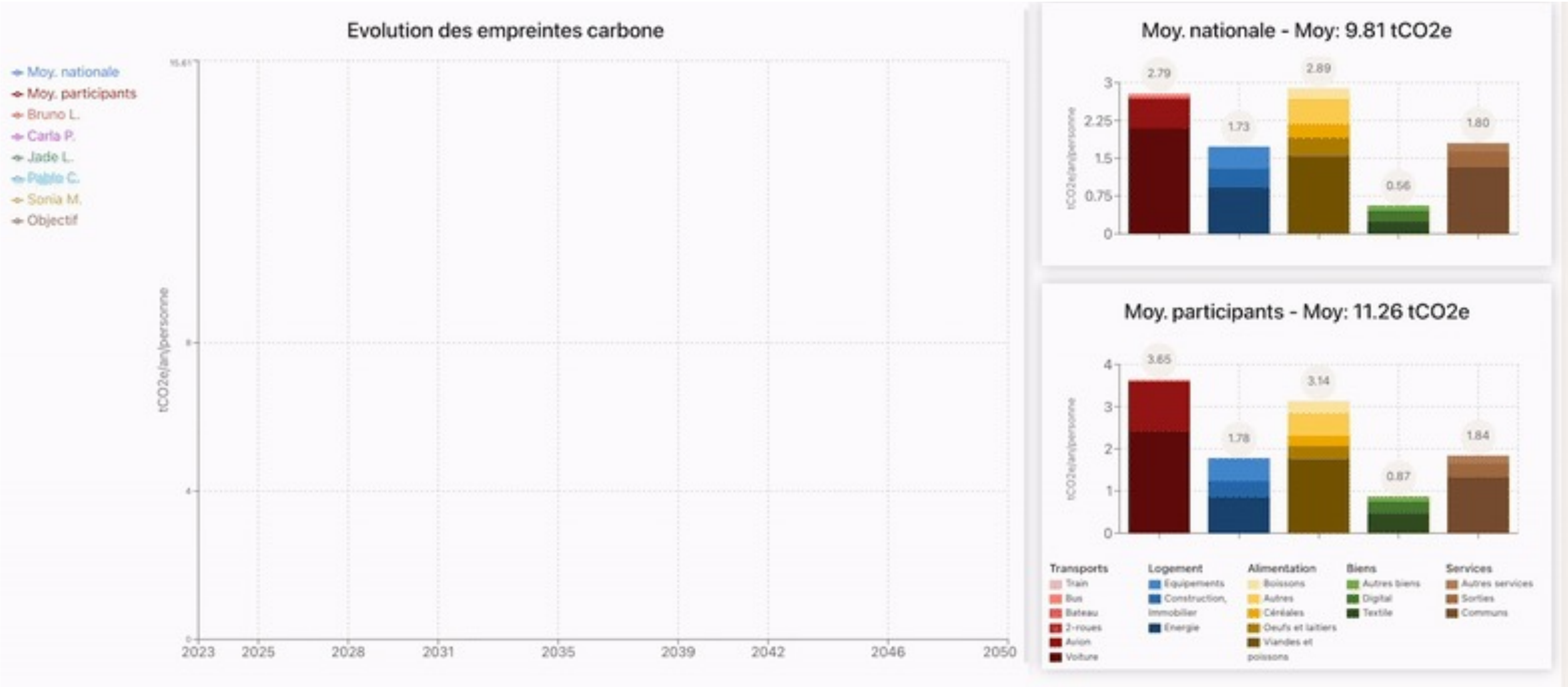
It’s up to YOU!!!!!!!!!!

https://www.istructe.org/

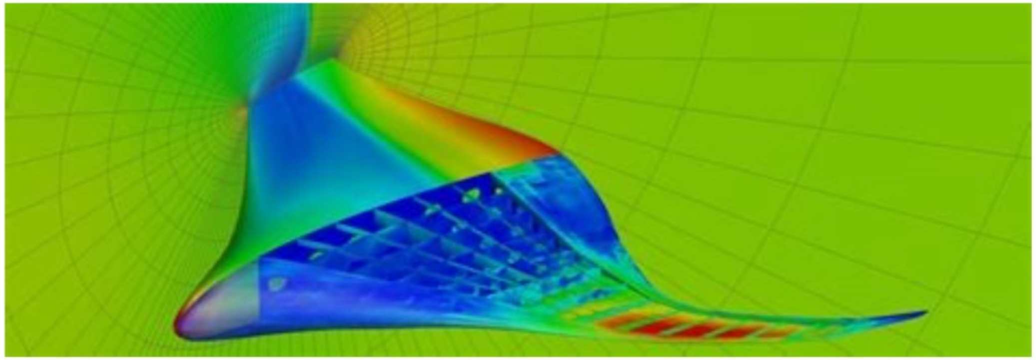
Theme	Discussion subtopics
Individuals	How might your work most effectively respond to the UNSDGs?
	How do you plan to help others in the industry to achieve more change?
	What makes you proudest about your job?
Institution	What aspects of broader sustainability should the Institution be prioritising?
	How can the Institution help the membership to think in terms of ‘more good’ rather than ‘less harm’?
	What might the Institution do to overcome key barriers to better UNSDG alignment?
Future	How will the structural engineer’s role have changed 20 years from now?
	What ‘norms’ will be extinct 20 years from now that lead to a more positive future?
	What can we do today to accelerate this change?

My Advice: Fly Less ! Travel Better

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



UTM Summer 2025



joseph.morlier@isae-supaero.fr

http://mdolab.engin.umich.edu

Optimization [MDO] for connecting people?

Publié le 14 février 2019 Modifier l'article | Voir les stats

joseph morlier
Professor in Structural and Multidisciplinary Design Optimization, ... any idea?
2 articles

74 31 3 0

https://www.linkedin.com/pulse/optimization-mdo-connecting-people-joseph-morlier/

https://www.tripadvisor.fr/LocationPhotoDirectLink-g187529-d574612-i349532022-Museum_of_Natural_Science_Museo_de_Ciencias_Naturales-Valencia_Province_o.html

Is it possible to build an aircraft wing in LEGO® ?

Publié le 17 février 2020 Modifier l'article | Voir les stats

joseph morlier
Professor in Structural and Multidisciplinary Design Optimization, ... any idea?
5 articles

https://www.linkedin.com/pulse/possible-build-aircraft-wing-lego-joseph-morlier/?articleId=6627240732975480832