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CENTRE NATIONAL D'ÉTUDES SPATIALES

ENVIRONMENTAL ASPECTS OF CNES SPACE MISSIONS

ISSUES AND SOLUTIONS

TOULOUSE

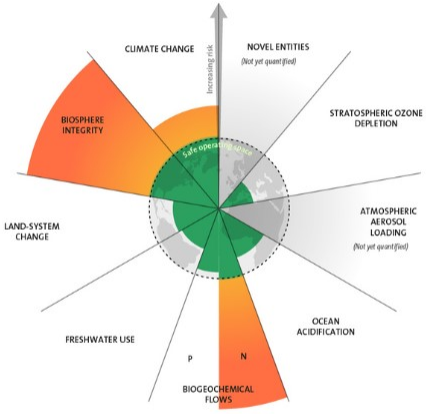
09/04/2025

Tristan Debonnet

DIAGNOSTIC : ENVIRONMENTAL ISSUES

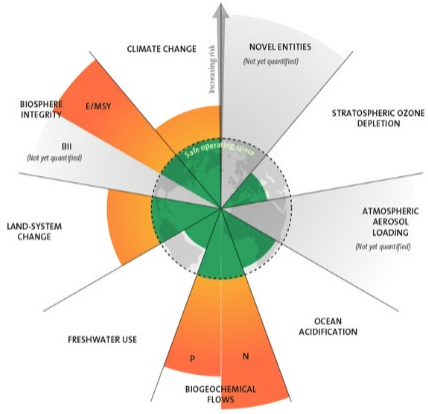
Planet boundaries : to what extent the Earth system can absorb anthropogenic pressures without compromising the human living conditions ?

2009



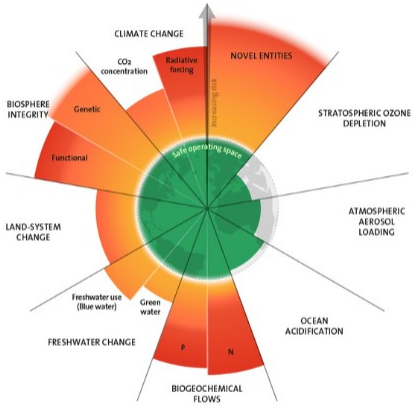
7 boundaries assessed,
3 crossed

2015



7 boundaries assessed,
4 crossed

2023



9 boundaries assessed,
6 crossed

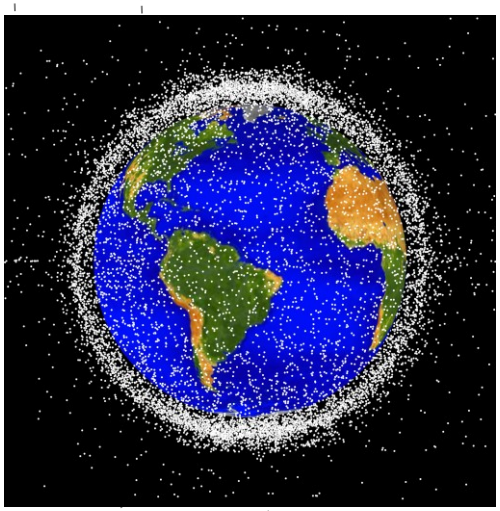
- Climate change
- Novel entities
- Biosphere integrity
- Land system change
- Freshwater change
- Biogeochemical flows

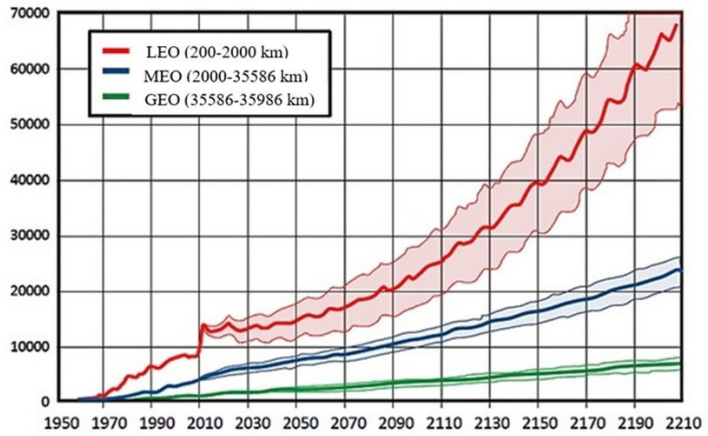
Source : https://www.stockholmresilience.org/research/planetary-boundaries.html

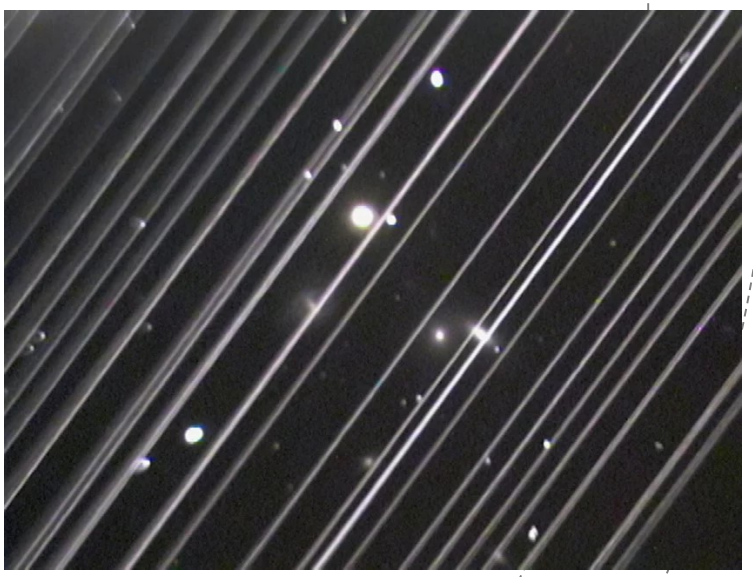
DIAGNOSTIC: SPACE

Space activities are also questionable because:

- On-earth impacts
- Stratosphere and ozone might be affected by launch phase and object re-entry
- Space congestion
- Orbit confiscation
- Dark sky
- Diet sky.

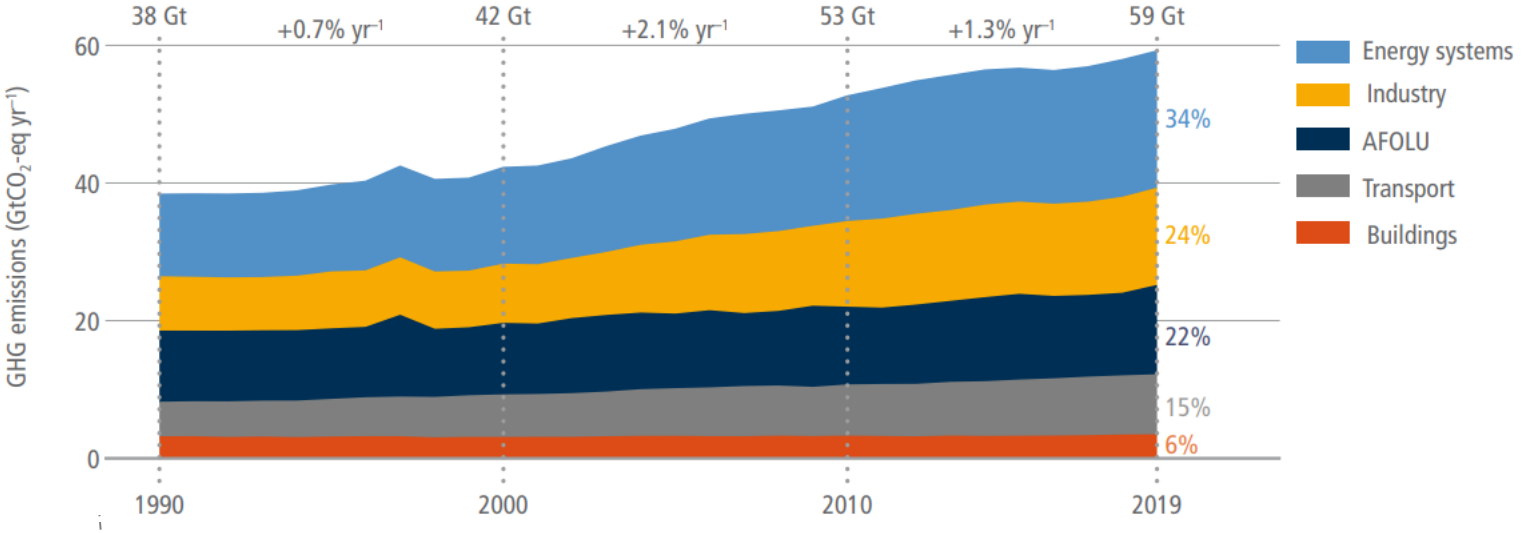






SPACE SECTOR ENVIRONMENTAL IMPACTS

Trends in global GHG emissions by sector (IPCC 2022)



Aviation is about 2.5% of the GHG emissions in 2023.

In 2022, Wilson et al. (2022) estimates 6 MT CO2eq (0.01% in 2018) for the space sector and 120 MTCO2eq (0.21% (ref : 2018) for future scenarios

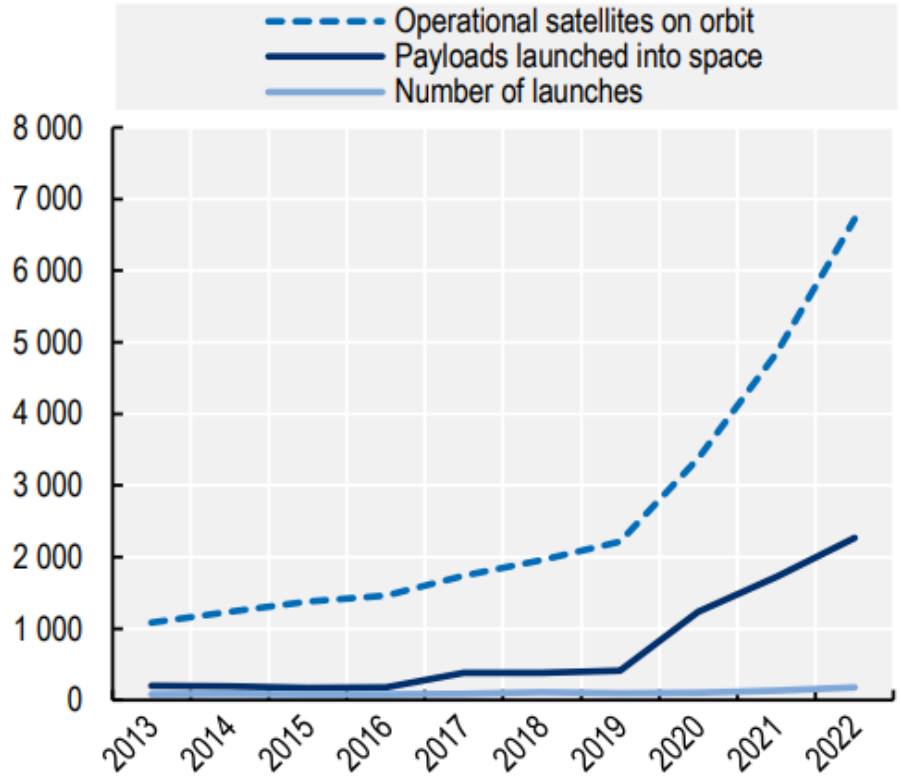
Regarding climate change planet boundaries it represents 0.09% contribution for the 2018 scenario and 1.77% for the future scenario.

Ozone layer depletion : 5.13% (2018) which represents 1.54% contribution to the planetary boundary in the future

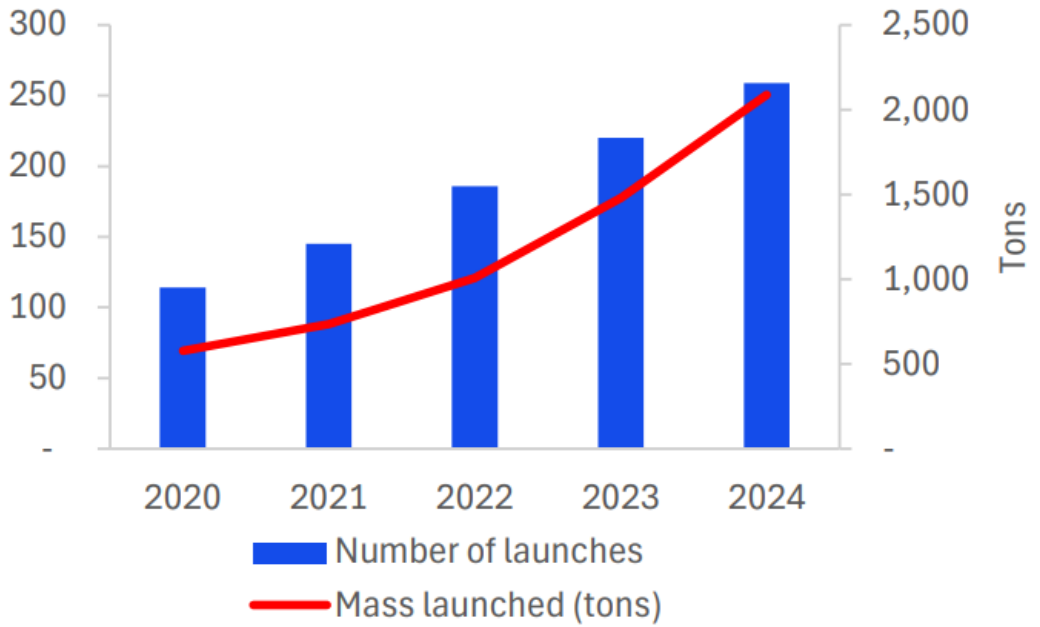
- Wilson, A. R., Vasile, M., Maddock, C. A., & Baker, K. J. (2022). Ecospheric life cycle impacts of annual global space activities. *Science of the Total Environment*, *834*, 155305.
- Dhakal, S., J.C. Minx, F.L. Toth, A. Abdel-Aziz, M.J. Figueroa Meza, K. Hubacek, I.G.C. Jonckheere, Yong-Gun Kim, G.F. Nemet, S. Pachauri, X.C. Tan, T. Wiedmann, 2022: Emissions Trends and Drivers. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.004

SPACE GROWTH

Number of payloads launched into space



Number of launches and mass launched, 2020-2024

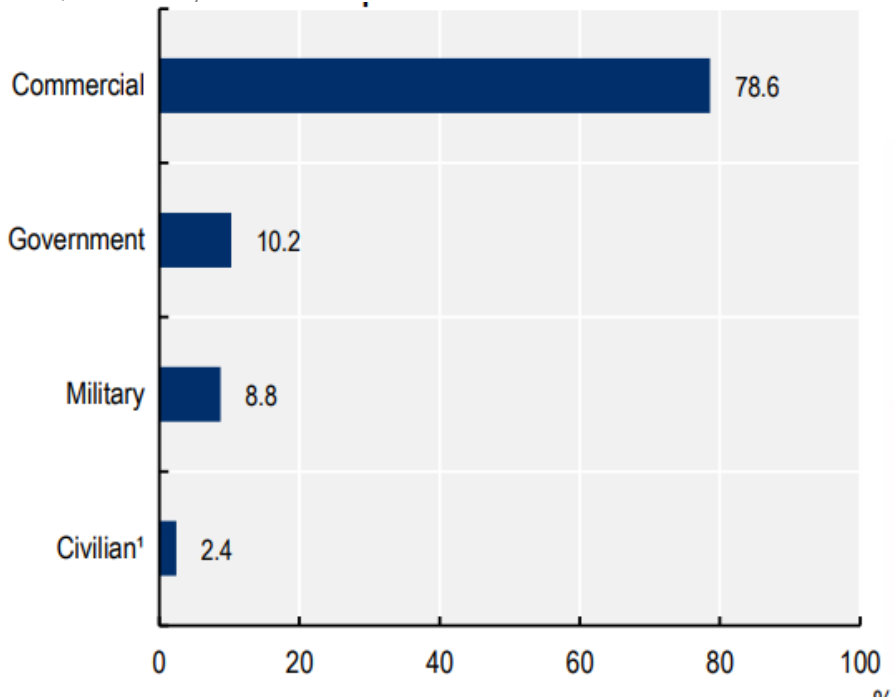


OECD (2023), The Space Economy in Figures: Responding to Global Challenges, OECD Publishing, Paris, https://doi.org/10.1787/fa5494aa-en.

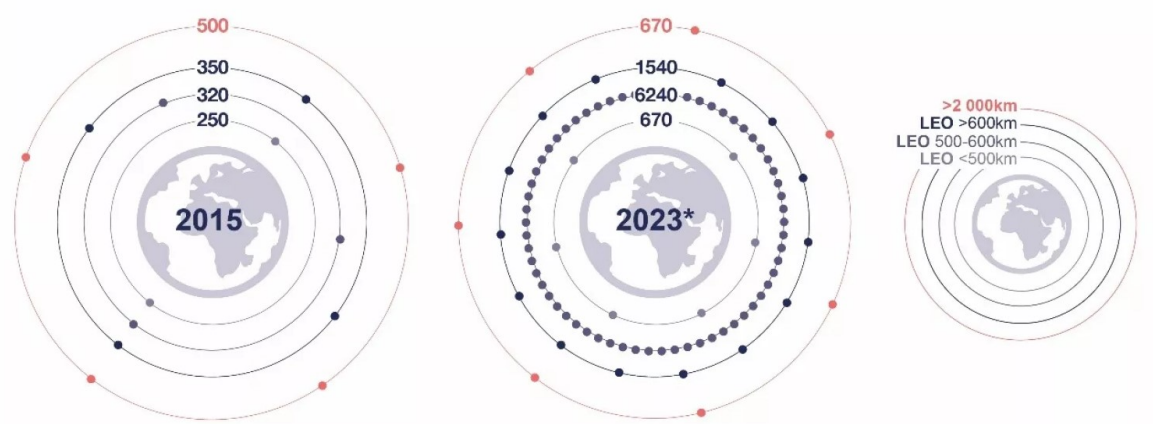
ESA (2025), Report on the space economy 2025

SPACE : APPLICATIONS

Distribution of operational satellites by type of operator in 2022



Number of operational satellites



**opérationnels au 31 octobre 2023*

Source : Euroconsult's Satellites to be built and launched 25th Edition

Commercial operations are the main

Communication (television, internet), navigation...

OECD (2023), The Space Economy in Figures: Responding to Global Challenges, OECD Publishing, Paris, https://doi.org/10.1787/fa5494aa-en.

DECARBONIZATION ROADMAP

CNES is working with various stakeholders in order to define roadmaps accordingly to the disposition to reach the net-zero greenhouse gas emissions in 2050 as part of the space activities: Scientific community, Occitanie region, French industry, etc.

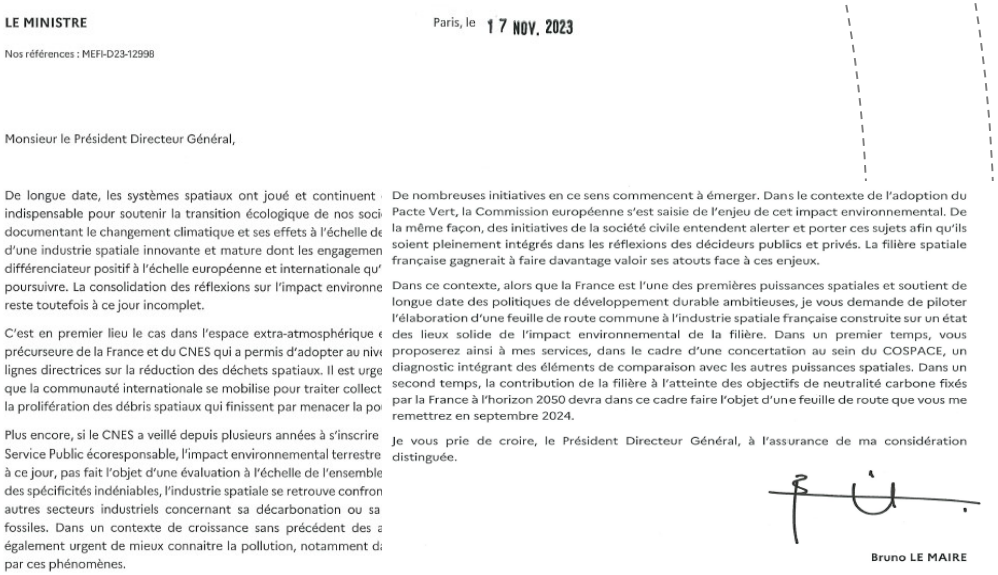
Roadmap is based on several steps:

- Environmental footprint
- Mitigation actions
- Scenarios
- Etc.

The aforementioned steps requires:

- Skills
- Means
- Etc.

National roadmap is expected in the beginning of 2025



LE MINISTRE

Paris, le 17 NOV. 2023

Nos références : MEFI-D23-12998

Monsieur le Président Directeur Général,

De longue date, les systèmes spatiaux ont joué et continuent
indispensable pour soutenir la transition écologique de nos soci
documentant le changement climatique et ses effets à l'échelle de
d'une industrie spatiale innovante et mature dont les engagemen
différenciateur positif à l'échelle européenne et internationale qu'
poursuivre. La consolidation des réflexions sur l'impact environne
reste toutefois à ce jour incomplet.

C'est en premier lieu le cas dans l'espace extra-atmosphérique
précurseure de la France et du CNES qui a permis d'adopter au nive
lignes directrices sur la réduction des déchets spatiaux. Il est urge
que la communauté internationale se mobilise pour traiter collect
la prolifération des débris spatiaux qui finissent par menacer la po

Plus encore, si le CNES a veillé depuis plusieurs années à s'inscrire
Service Public écoresponsable, l'impact environnemental terrestre
à ce jour, pas fait l'objet d'une évaluation à l'échelle de l'ensemble
des spécificités indéniables, l'industrie spatiale se retrouve confron
autres secteurs industriels concernant sa décarbonation ou sa
fossiles. Dans un contexte de croissance sans précédent des a
également urgent de mieux connaitre la pollution, notamment d
par ces phénomènes.

De nombreuses initiatives en ce sens commencent à émerger. Dans le contexte de l'adoption du Pacte Vert, la Commission européenne s'est saisie de l'enjeu de cet impact environnemental. De la même façon, des initiatives de la société civile entendent alerter et porter ces sujets afin qu'ils soient pleinement intégrés dans les réflexions des décideurs publics et privés. La filière spatiale française gagnerait à faire davantage valoir ses atouts face à ces enjeux.

Dans ce contexte, alors que la France est l'une des premières puissances spatiales et soutient de longue date des politiques de développement durable ambitieuses, je vous demande de piloter l'élaboration d'une feuille de route commune à l'industrie spatiale française construite sur un état des lieux solide de l'impact environnemental de la filière. Dans un premier temps, vous proposerez ainsi à mes services, dans le cadre d'une concertation au sein du COSPACE, un diagnostic intégrant des éléments de comparaison avec les autres puissances spatiales. Dans un second temps, la contribution de la filière à l'atteinte des objectifs de neutralité carbone fixés par la France à l'horizon 2050 devra dans ce cadre faire l'objet d'une feuille de route que vous me remettrez en septembre 2024.

Je vous prie de croire, le Président Directeur Général, à l'assurance de ma considération distinguée.

Bruno LE MAIRE

French economy minister letter

DECARBONIZATION

The CNES Low Carbon Strategy defines especially a commitment (#6) dedicated to the project environmental footprint estimation:

“100% of new orbital projects will carry out an environmental footprint assessment by 2026”

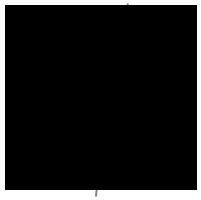
General comments:

- Orbital projects from phase B (minimum)
- Frequent commitments by some major suppliers (LCA but also ecodesign)
- The commitment has to be extended to other project phases (early phases, downstream phases, etc.)
- CNES is working tirelessly with its customers, partners and suppliers to provide a pragmatic approach to this strategy

Consequences:

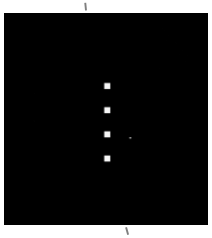
- Project teams have to estimate their project environmental footprint
- Environmental footprint joins the other criteria: resources (costs, human, means, etc.), planning, performances
- Environmental footprint contributes to the decision maker to carry out or not a space mission.

ECO-DESIGN ROADMAP



Roadmap ambitions

- Structure the eco-design approach at CNES
- Define the methodology to be applied in an eco-design approach, for all sectors
- Define the roles and responsibilities of stakeholders
- Deploy eco-design: acquire tools and databases
- Provide support for eco-design projects



Projects

- ➢ Acculturate and train employees
- ➢ Harmonize methodology
- ➢ Be able to quantify precisely space environmental footprint
- ➢ Implementing eco-design on project as far as possible
- ➢ Developp thematic guides (digital, electronic, material, laboratory…)

ECO-DESIGN APPROACH

"Systematic integration of environmental aspects from the design and development of products (goods and services, systems) with the aim of reducing negative environmental impacts throughout their whole life cycle for equivalent or better service provided."

Standard NF X30-264

...product

Good

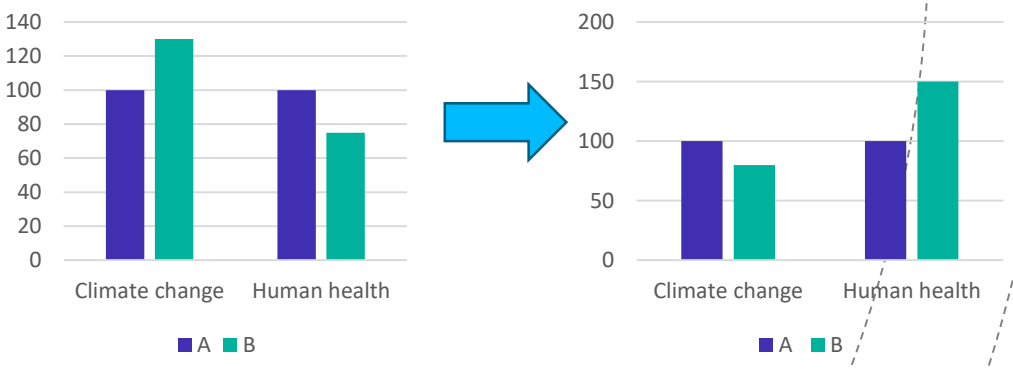
Service

...multicriteria

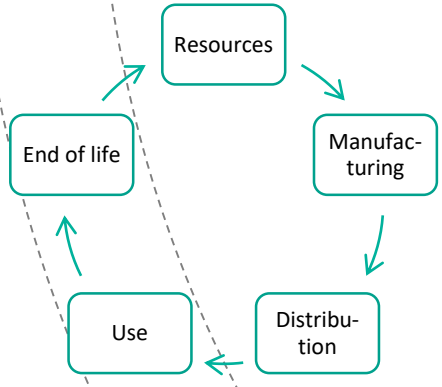
- Climate change
- Resource depletion
- Ecotoxicity
- ...

... trade-off

Ex: impact transfer



...multi-stage

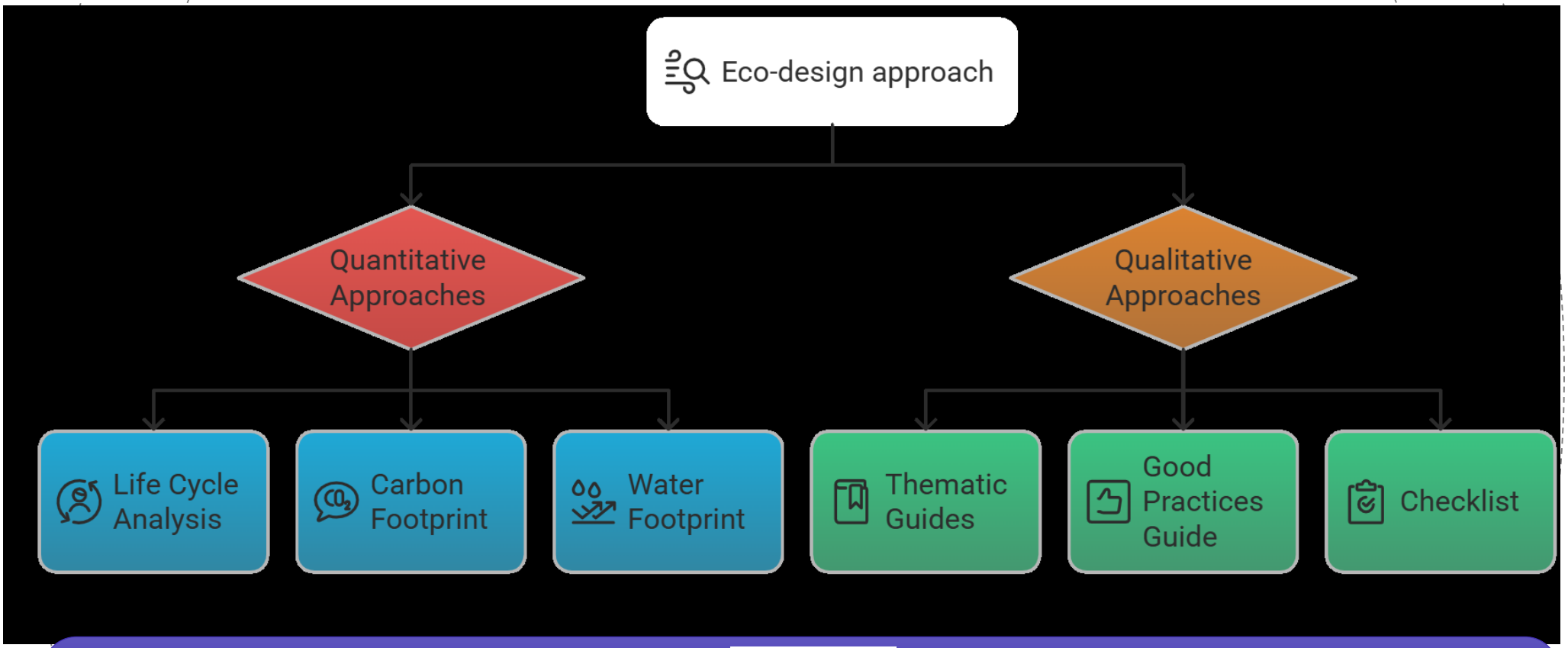


...multi-actors

- Provider
- User
- Recycler
- ...

Sources : Introduction à l'écoconception – Tatiana REYES (UTT) Projet ET-LIOS – S.mart | Pôle écoconception

ECO-DESIGN TOOLS (EXAMPLES)

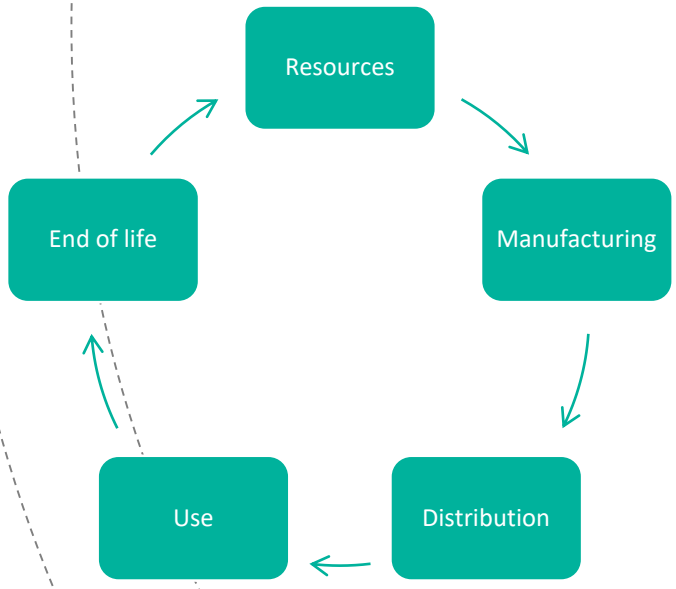


ENVIRONMENTAL IMPACT ASSESSMENT

Life Cycle Assessment (LCA) is a standardized evaluation method (ISO 14040 and 14044) used to carry out a multi-criteria, multi-stage environmental assessment of a given system (product, service, company or process) over its entire life cycle.

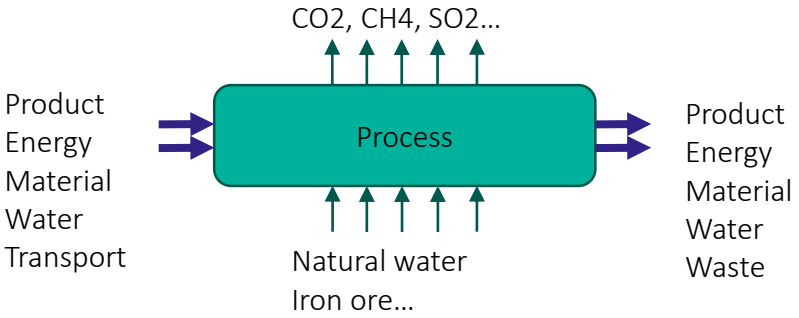
Relevant method that allows to check impact transfers and rebound effects, but also to identify main contributors all along the value chain.

Life cycle approach



Life cycle inventory

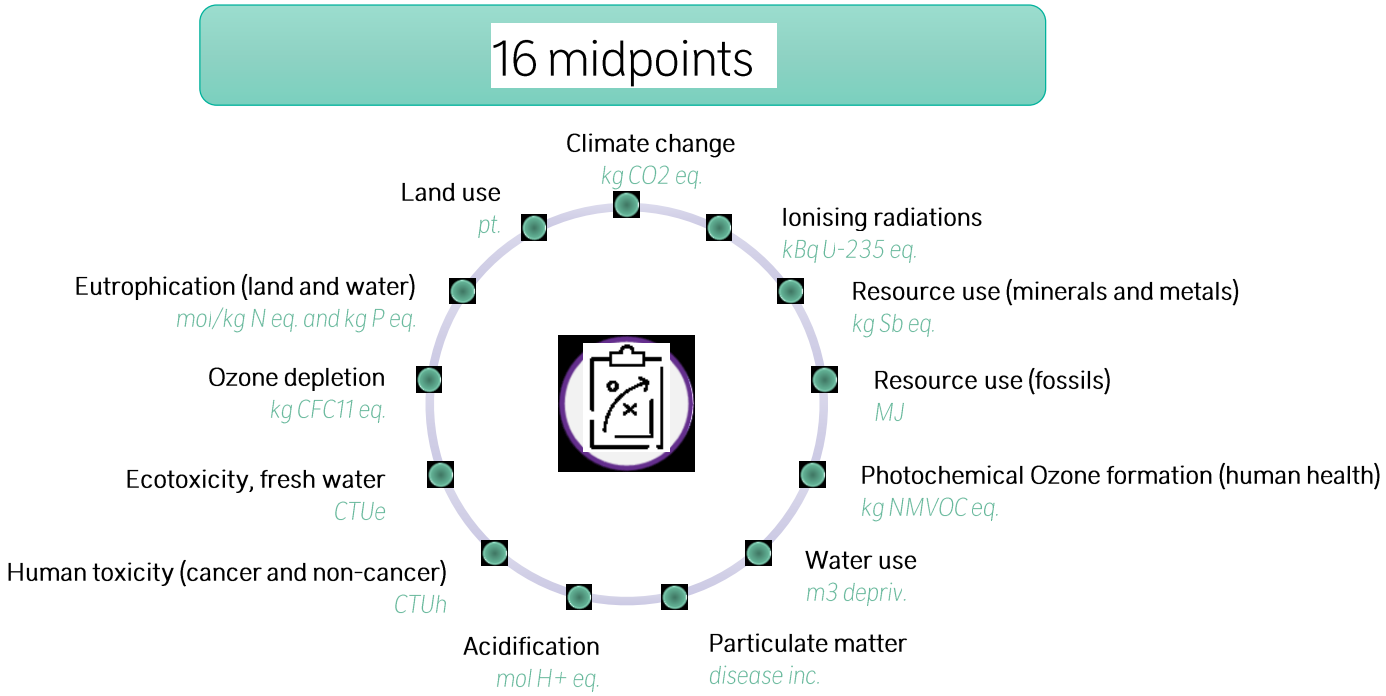
Quantify all flows (elementary or intermediate) for each of the required processes



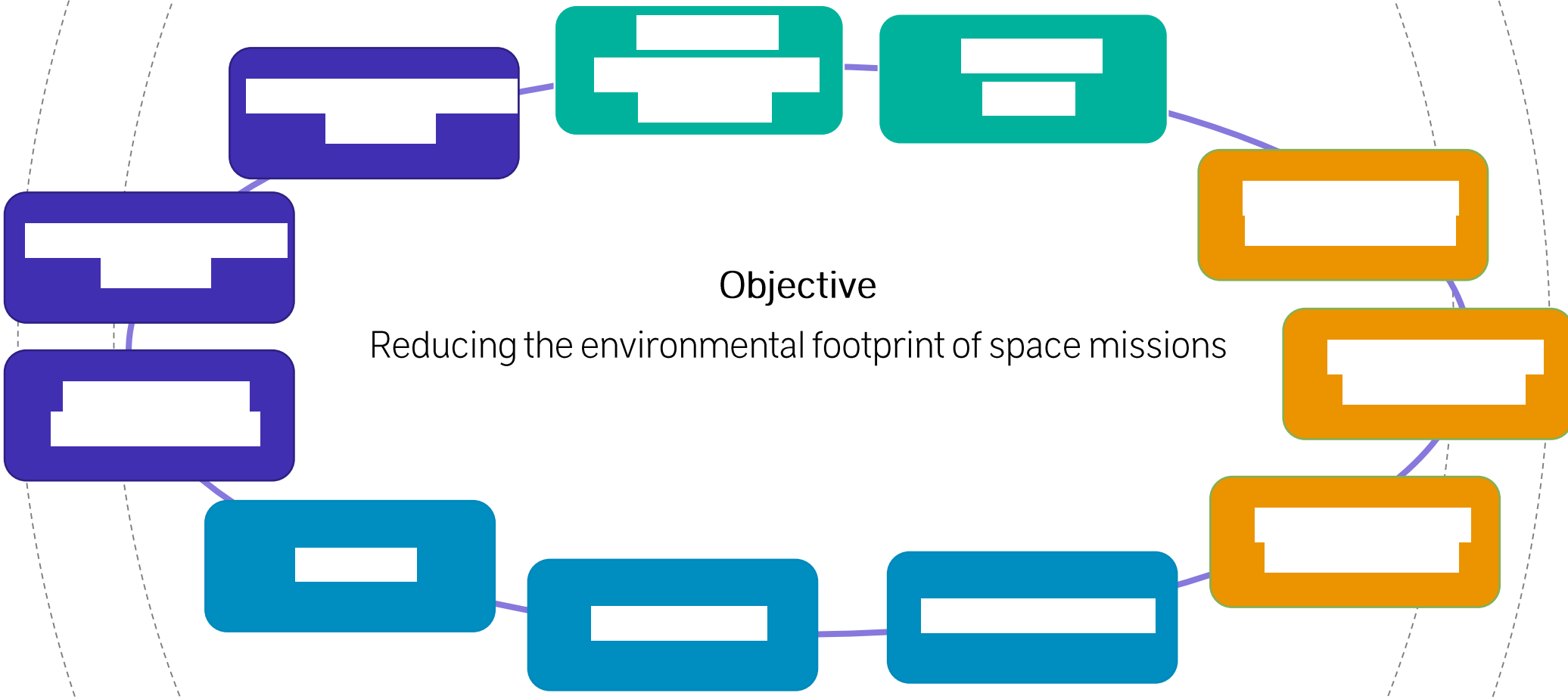
The sum of everything extracted from the environment and everything emitted to satisfy the functional unit

LCA ENVIRONMENTAL IMPACTS INDICATORS

- Environmental Footprint 3.0 method – Elaborated by European Union, a combination of several reknown methods

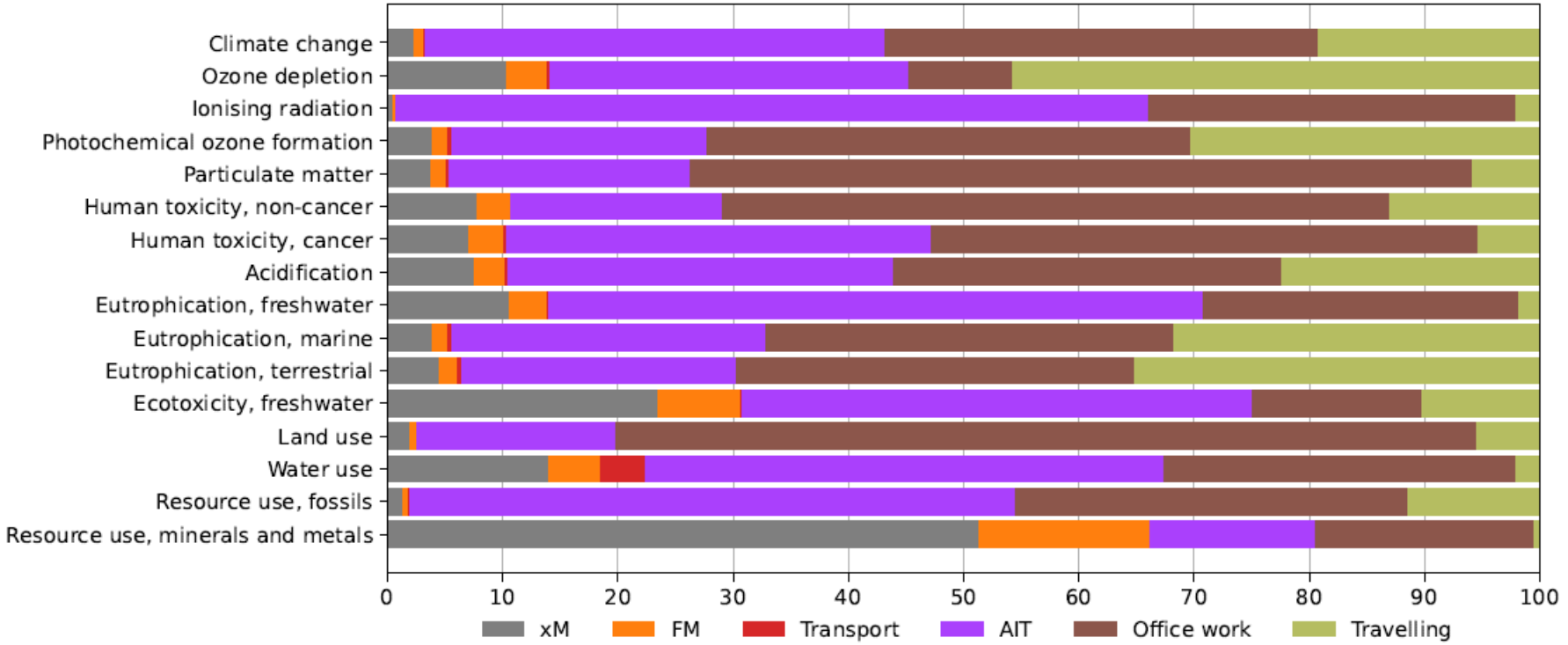


SPACE MISSION LIFE CYCLE



INSTRUMENT : ATHENA X-RAY INTEGRAL FIELD UNIT – X-RAY SPECTROMETER

Athena is a versatile facility designed to address the Hot and Energetic Universe science theme (clusters of galaxies, black holes, exploding stars)
FU: manufacture 1 Athena X-Ray IFU



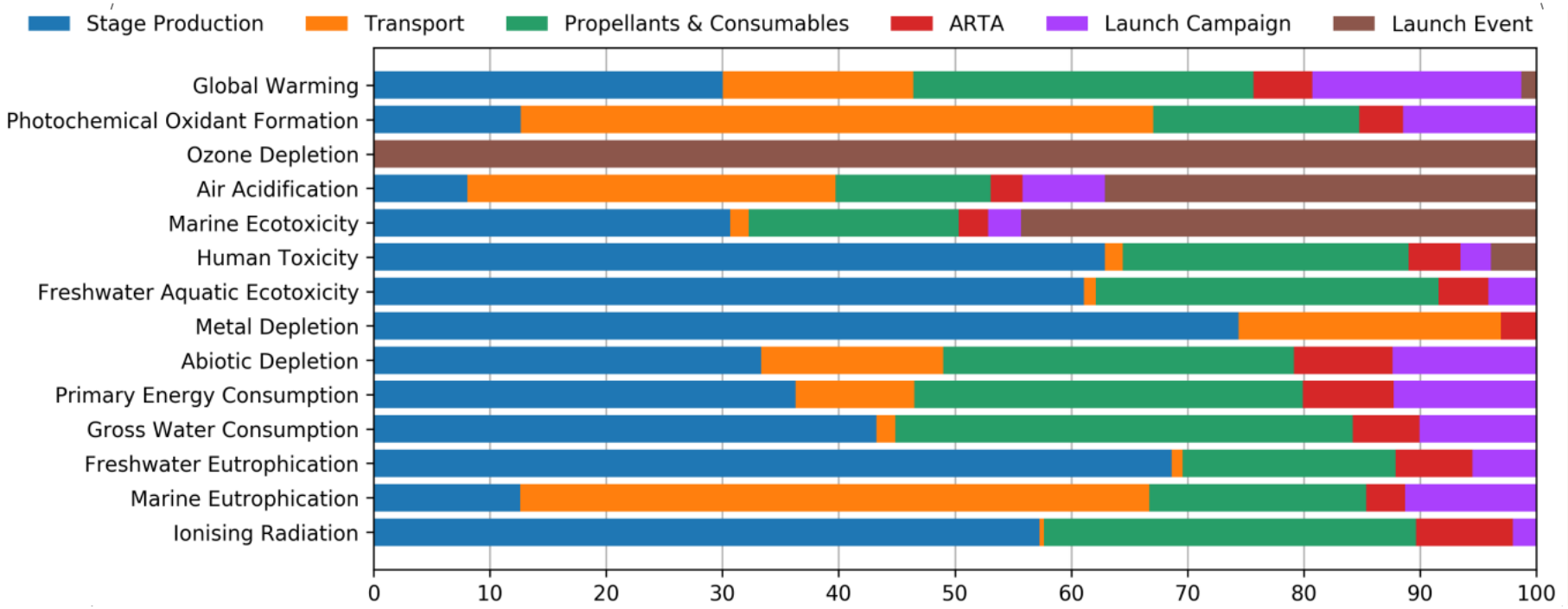
Global warming potential : 25 536 TCO2eq → 3300 europeans –> AIT, office work and travelling.

Resource use, minerals and metal : 746 kgSbeq → 13 000 europeans → Qualification models, flight model, AIT and office work.

Barret, D., Albouys, V., Knödlseder, J., Loizillon, X., d'Andrea, M., Ardellier, F., ... & Webb, N. (2024). Life cycle assessment of the Athena X-ray integral field unit. *Experimental Astronomy*, *57*(3),

LAUNCHERS

EXEMPLE : 1 LAUNCH OF ARIANE 5 ECA IN 2017



Global Warming Potential :

Stage production : EAP : 45%, EPC 40% (energy consumption)

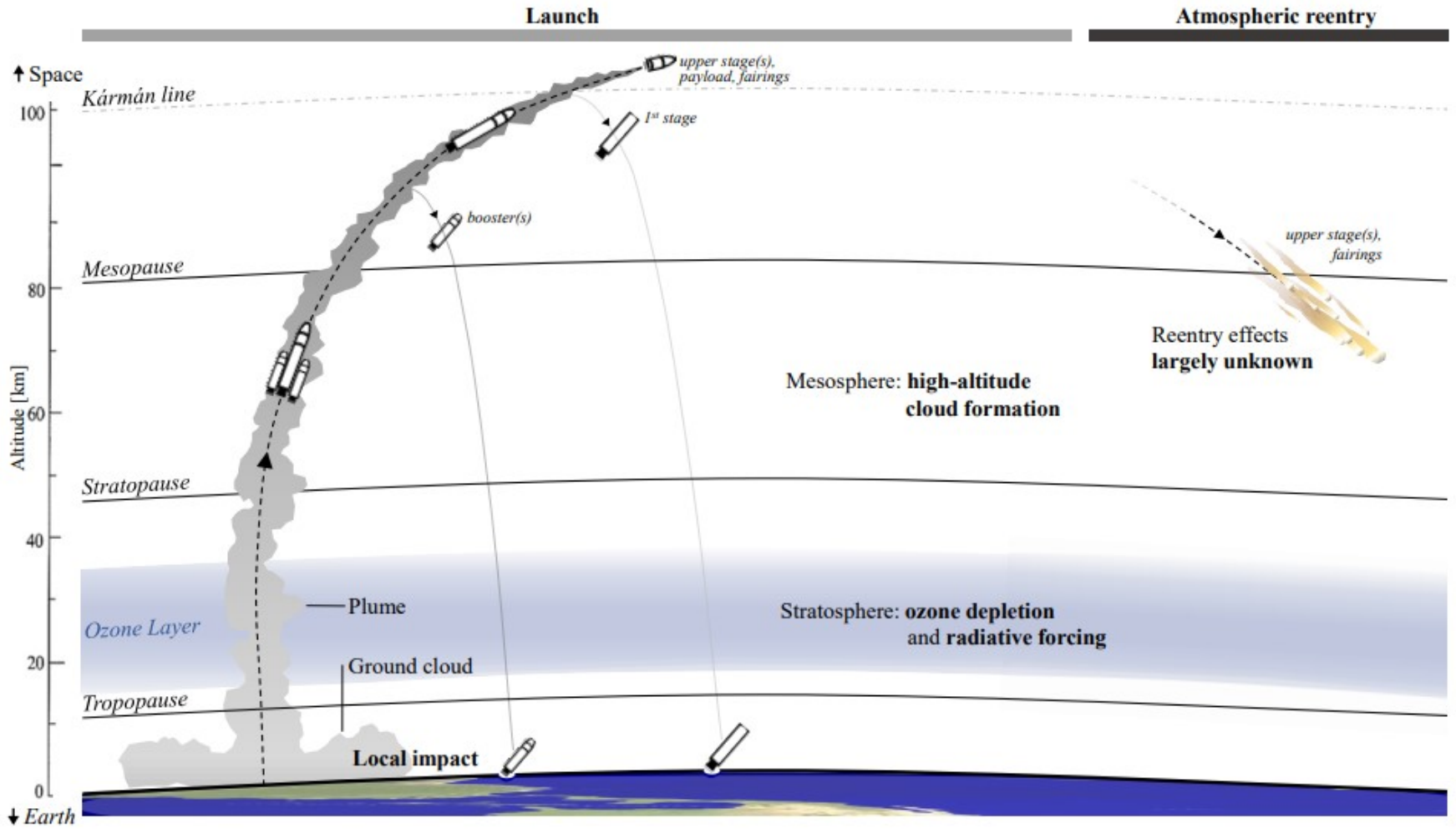
Propellants & Consumables : Solid propellant production 65%, LH2 13%, consumables 15% (electricity consumption)

Ozone layer depletion :

100% from launch event with high uncertainties

Chanoine, A. (2017). Environmental impacts of launchers and space missions. *Clean Sp. Ind. Days, ESTEC, Noordwijk*.

TRAJECTORY OF LAUNCH VEHICLE



Sirieys, E., Gentgen, C., Jain, A., Milton, J., & de Weck, O. (2022). Space sustainability isn't just about space debris: On the atmospheric impact of space launches. *MIT Science Policy Review*, *3*(29), 143-151.

HIGH ATMOSPHERE EMISSIONS : ENVIRONMENTAL IMPACTS

Emissions of particles in high atmosphere could increase impacts compared to ground emissions

Impact categories : Air Acidification , Particulate Matter, Ozone Depletion, Photochemical Oxidation , Climate Change

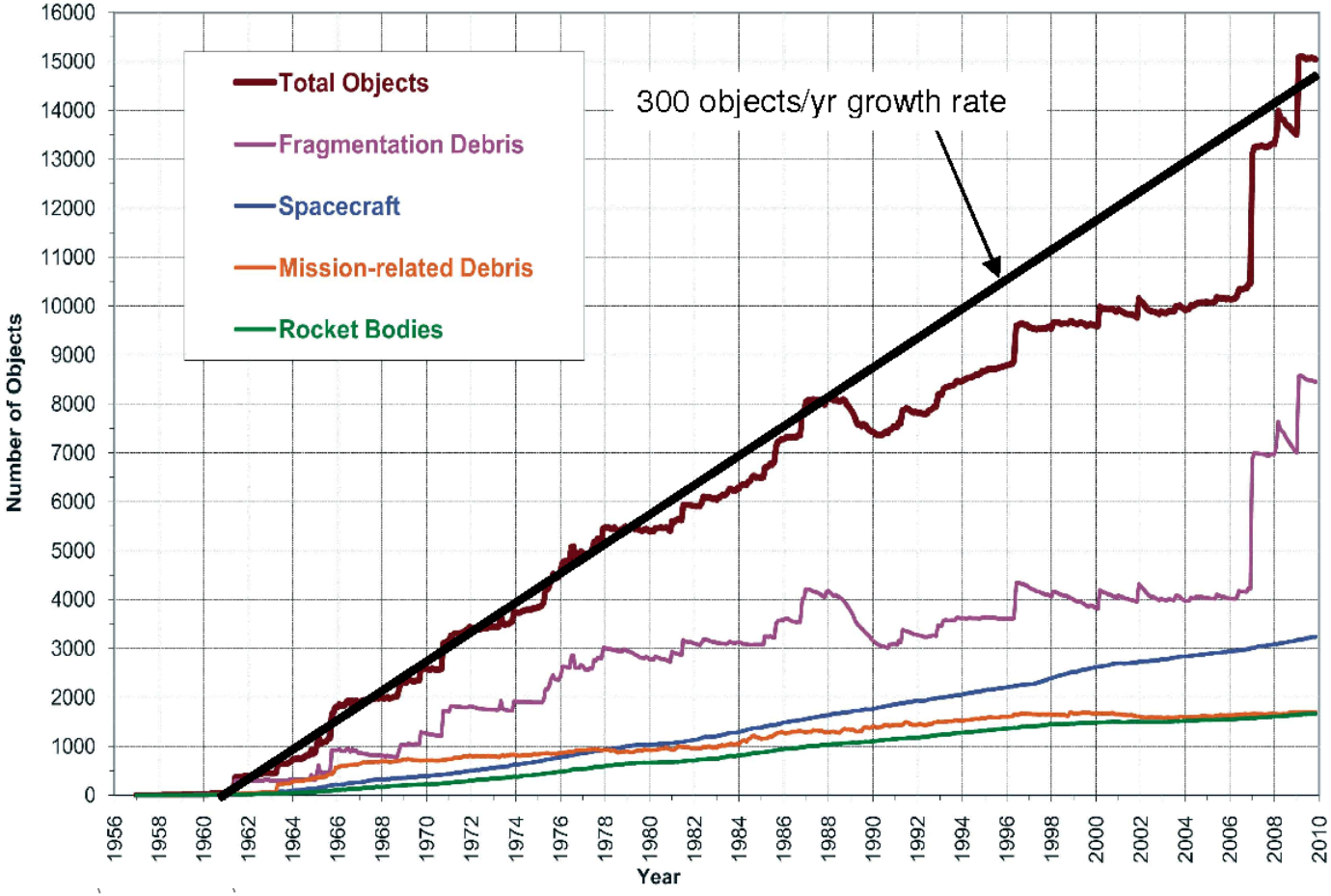
	Launch event	Reentry	Potential severity	Environmental impacts
NOx	X	x	Moderate High (OD)	React with ozone
Black carbon	X		High (CC)	Absorb ground radiation and slight reduce Earth albedo
Chlorine	x		High (OD)	React with ozone
Alumina	X	x	High (CC)	Increase earth albedo but absorb outgoing terrestrial longwave radiation
N2, CO2, H2	x		Low	
H2O	x		Moderate	

Launch event → important impact of the propellant nature

Ross, M. N., & Sheaffer, P. M. (2014). Radiative forcing caused by rocket engine emissions. Earth's Future, 2(4), 177-196.

Miraux, L., Wilson, A. R., & Calabuig, G. J. D. (2022). Environmental sustainability of future proposed space activities. Acta Astronautica, 200, 329-346.

END OF LIFE : DEBRIS

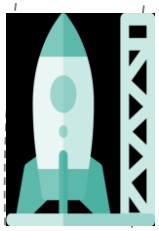


→ **Kessler syndrome** : fragments from random collisions between catalogued objects in low Earth orbit would become an important source of small debris beginning in about the year 2000, and that afterwards, "…the debris flux will increase exponentially with time, even though a zero net input may be maintained"

Kessler, D. J., Johnson, N. L., Liou, J. C., & Matney, M. (2010). The kessler syndrome: implications to future space operations. *Advances in the Astronautical Sciences, 137*(8), 2010.

CURRENT COVERAGE

Launch segment



Ecodesign roadmap for launch segment

Simplified LCA tool : MIEL

Scope : Manufacturing and launch (to be completed)

Projects

- Build a new MIEL version
- Realize LCA on launchers (ex: Vega-C…)
- Make LCA and eco-design on ground means
- H2 tank eco-designed
- …

Instruments, technique and digital

Projects

LCA

- Laboratories
- Instruments
- Supply OASIS tool

Guides

- Make a good practice guide
- Make thematic guides (software, digital, electronic, labs…)

CURRENT COVERAGE

Space missions

Environmental assessment tool : OASIS

Scope

Launch segment based on MIEL results

Spatial segment : based on ESA and CNES data

Ground segment : based on ESA and CNES data

Adapted to balloons

Including HR and business travel

Projects

- Complete OASIS scope
- Measure 23 projects in 2025
- **Measure 100% projects environmental footprint in 2026**

ENVIRONMENTAL FOOTPRINT TRAJECTORY

Environmental footprint is individually estimated for each project

This footprint is limited to CO_2

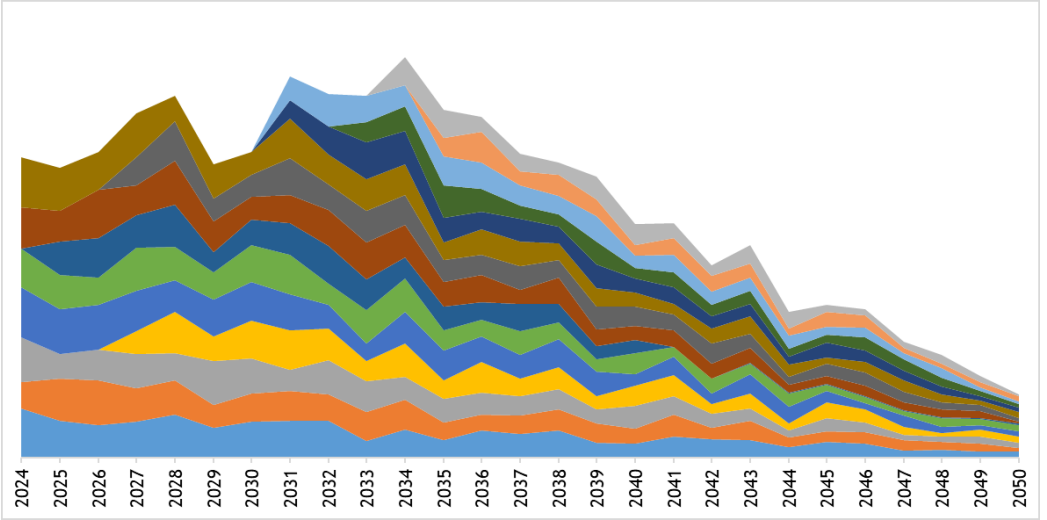
The project CO_2 footprint is time-profiled (similarity with the cost profile)

The time-profiled CO_2 footprint of all CNES projects are cumulated, giving a global CO_2 trajectory

This trajectory is compared to the "net-zero greenhouse gas emissions in 2050 trajectory"

Such an approach:

- Is comparable with the financial management (including the requested decreasing)
- Requires skills and means
- Will ensure no rebound effect and no impact transfer



CONCLUSION

Be an eco-design actor !

- To ensure a sustainable future for the space sector, at local, regional, national and international levels
- We are players, at all levels, with our stakeholders all along the value chain
- CNES has a duty to set an example and to show the way forward
- Remember that eco-design is just one lever

Education :

- Fresque du climat
- CNES training on eco-design
- Future MOOC (end of 2025)

Events

Clean Space Days (Oct. 2025 ?)
COMET
Management Cycle de Vie (Novembre 2025 Bordeaux)

Resources

→ Feuille de route décarbonation CNES in 2025
→ Mental map of space eco-design in 2025
→ Rapport CNES du séminaire de prospective scientifique 2024
→ Other papers (Ross, Miraux…)