Integrating space debris modeling to environmental impact studies via the Life Cycle Assessment framework

5th European Workshop on Space Debris Modeling and Remediation
CNES HQ, Paris - June, 25th 2018

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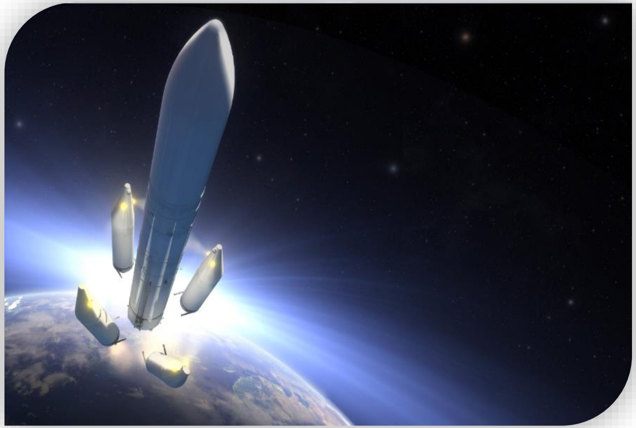
SUMMARY



01

CONTEXT & OBJECTIVES OF THE WORK

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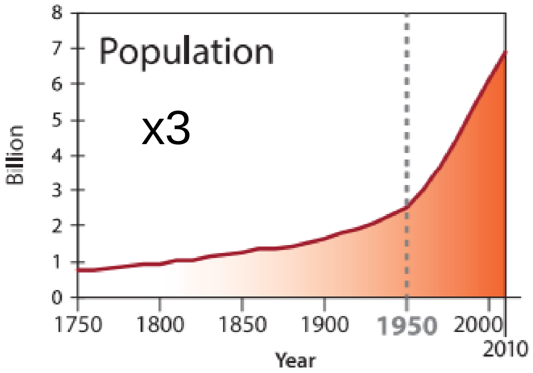
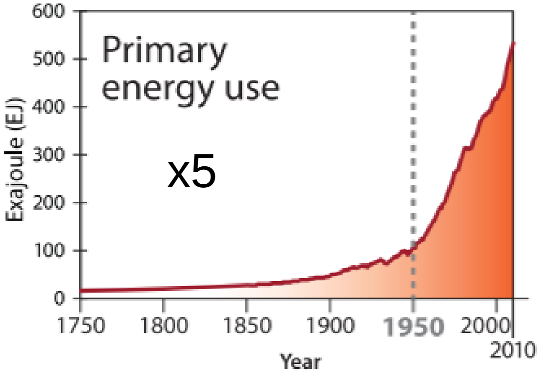
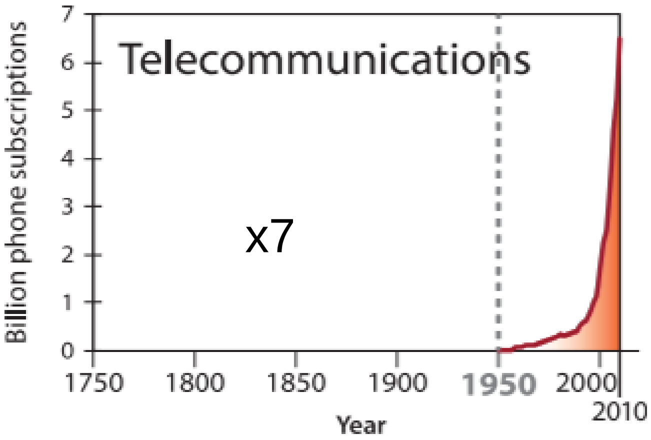
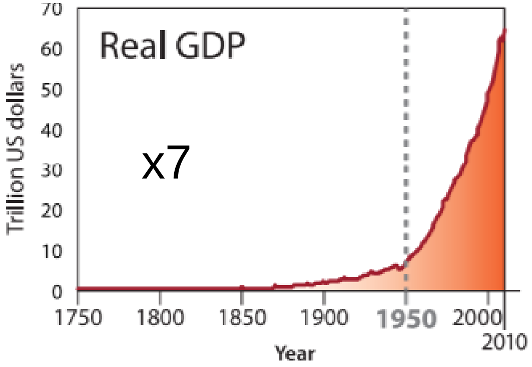
SPACE DEBRIS: PARALLEL WITH TRADITIONAL ENVIRONMENTAL DETERIORATION

Socio-economic trends







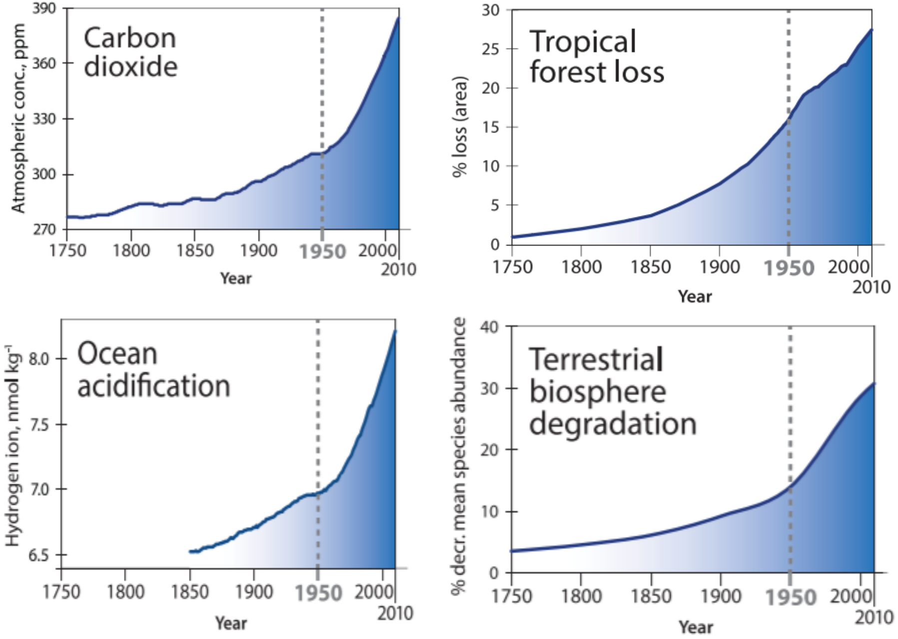


All the indicators of affluence have increased at higher rates than the world population growth…

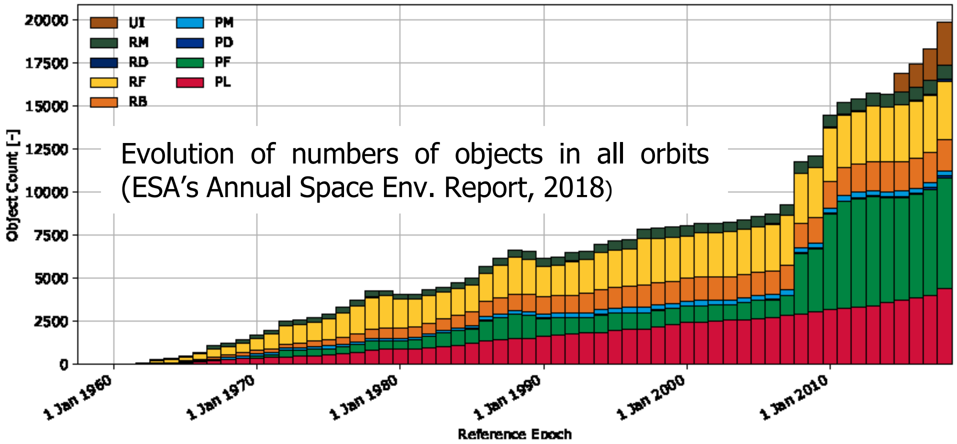
Steffen, W., et al., 2015. The trajectory of the anthropocene: The great acceleration. Anthr. Rev. 2, 81–98. doi:10.1177/2053019614564785

SPACE DEBRIS: PARALLEL WITH TRADITIONAL ENVIRONMENTAL DETERIORATION

Earth system trends (Environmental stressors)



…Orbital Environment trend



Non-functional objects grow faster than functional objects

Debris → stressors of the Orbital Environment

Steffen, W., et al., 2015. The trajectory of the anthropocene: The great acceleration. Anthr. Rev. 2, 81–98. doi:10.1177/2053019614564785

ECO-DESIGN IN EUROPEAN SPACE SECTOR

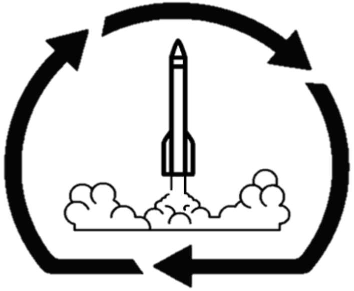
- Binding & Non specific: European regulations & directives (REACh, ROHS, CRM)
- Non binding & Specific: UNCOPUOS guidelines (Specific – non binding) for the long-term sustainability of outer space activities
- Binding & Specific: French Space Operation Act (full entry into force in 2020)

↘ How to measure and minimise its environmental footprint?

Life Cycle Assessment (ISO 14040/44) has been identified as the most appropriate tool to evaluate and reduce the environmental impact of space activities

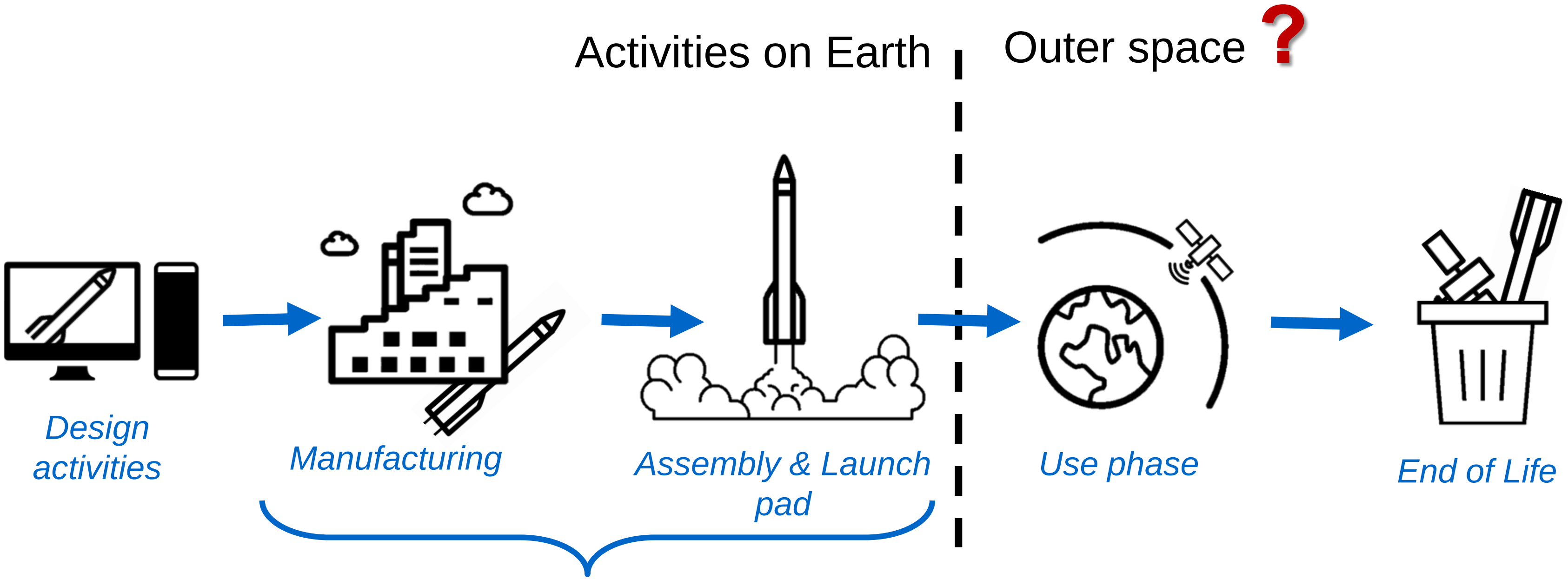
Ariane 6 development – ESA's Contractual requirement:

- Perform an LCA of Ariane 6 in exploitation phase



LIFE CYCLE OF SPACE MISSIONS

Ensuring sustainability on both Earth and orbital environment



Current LCA studies do not cover the entire life-cycle

OBJECTIVES OF THE WORK

Make the link between eco-design and Space Debris *via* LCA methodology

- Development of **Characterization Factors** (CF) assessing potential impacts of space missions on orbital environment

- Application of the CF on 3 post-mission disposal scenarios in LEO to study potential trade-off with different dwelling time
  - *No management of the End-Of-Life*
  - *Delayed Re-entry (< 25 yrs)*
  - *Direct Reentry (< 1 yr)*

- Broadening the scope of environmental study considering the complete footprint of the chosen End-of-Life scenario

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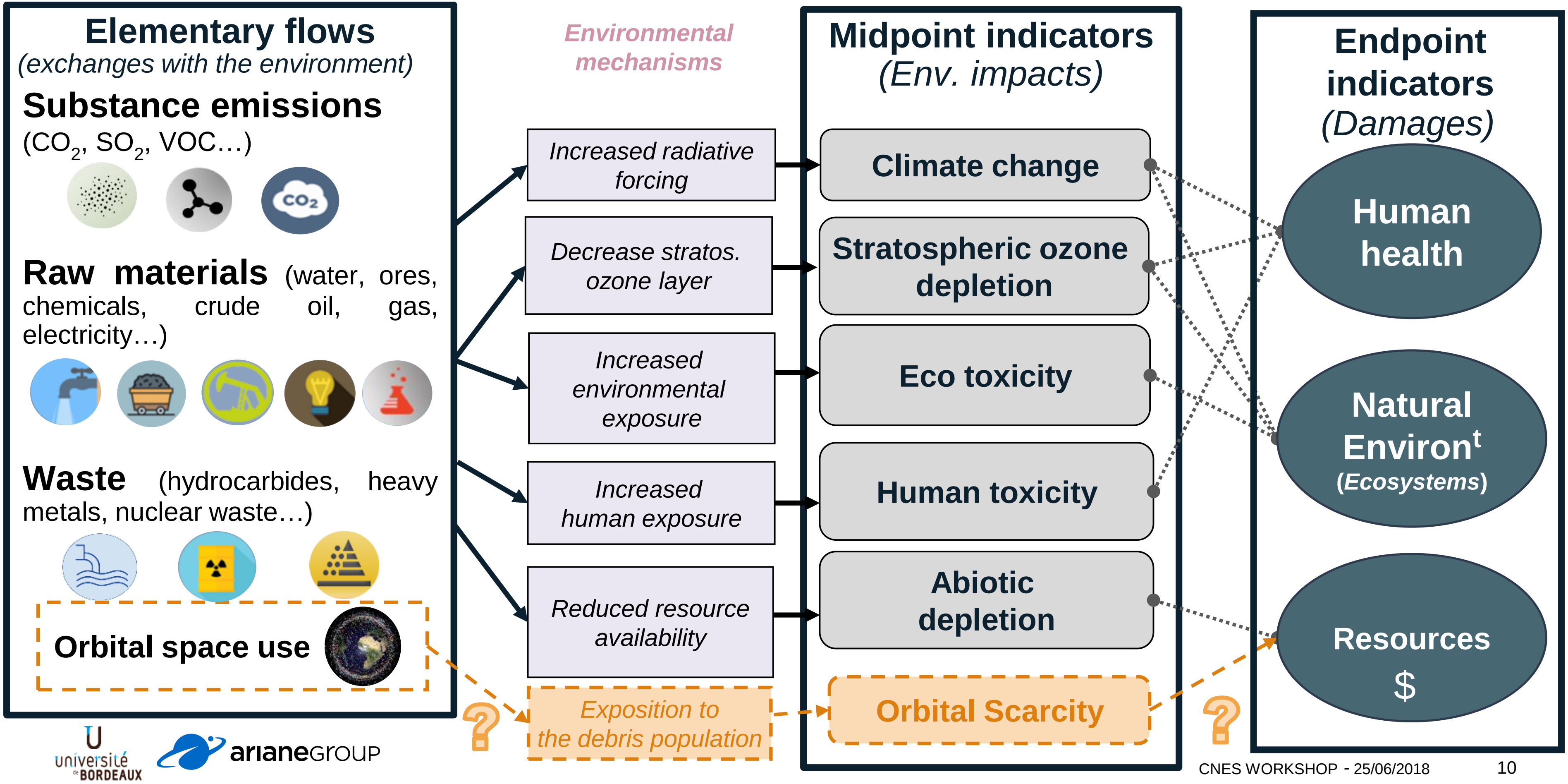
MATERIAL & METHODS

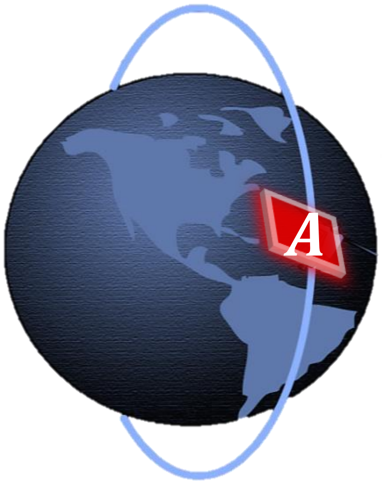
LIFE CYCLE IMPACT ASSESSMENT FRAMEWORK



PRODUCT SYSTEM INVENTORY

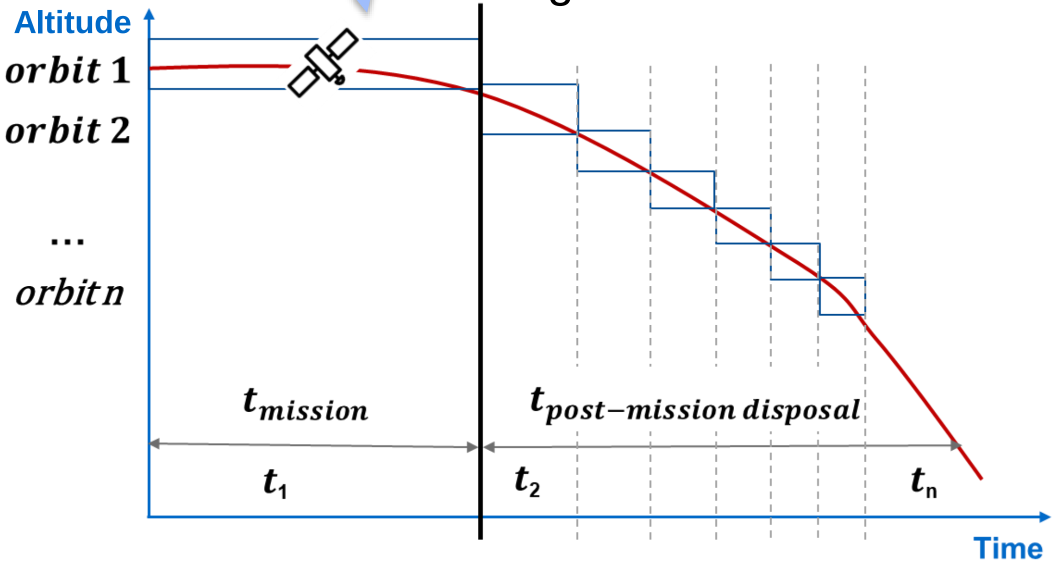
$$Accounting = A \cdot \sum_{Orbits} t_i$$

$[m^2]$ $[yr]$



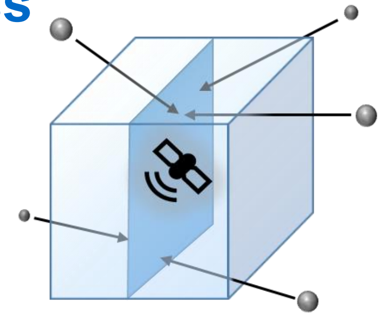
Average cross sectional area

Dwelling time



CHARACTERISATION FACTORS

Weighting the occupation of the orbit by the 'debris stress'



$$Impact = Inventory \cdot CF$$

- We decide to characterize orbital scarcity with the average **flux of debris** crossing the target orbits
- Each orbit presents a different state of **scarcity** which allows to classify and differentiate them (existing background impact not caused by the modeled product system).

$$Impact = A \cdot \sum_{i=Orbit} t_i \cdot \overline{\Phi_i}$$

$[\#_{debris}]$ $[m^2]$ $[yr]$ $[\#_{debris}.m^{-2}.yr^{-1}]$

Calculated impact: avg. number of debris crossing a shape A during the dwelling time of the spacecraft into an orbit i

CHARACTERISATION FACTORS (Φ_i)

MASTER-2009 Model – Business as usual

MASTER 2009

Meteoroid and Space Debris Terrestrial Environment Reference Model

Orbital environment

- All sources excepted Multi Layer Insulation and Cloud
- Debris Population > 1cm
- Interval Epoch [2018;2035] (35yrs)
- Flux averaged w.r.t RAAN variation of the target orbit

Target velocity

- Circular orbit: e=0,001
- Fictive spherical target (1m²)
- Angle of collision 90° → **Worst case**

$$\Delta v_{col}^2 = v_T^2 + v_F^2 - \cancel{2 v_T v_F cos\alpha}$$

D. J. Kessler, "Derivation of the collision probability between orbiting objects: the lifetimes of Jupiter's outer moons," Icarus, Vol. 48, Oct. 1981, pp. 39–48, 10.1016/0019-1035(81)90151-2.

$$\Phi_i = Density \cdot \Delta v_{col\,(max)}$$

[#.m⁻³.yr⁻¹] [#.m⁻³] [m.yr⁻¹]

$[\#.m^{-3}.yr^{-1}]$ $[\#.m^{-3}]$ $[m.yr^{-1}]$

- All the LEO region is characterised: Δ 50km & Δ 2° inclination (3240 runs)

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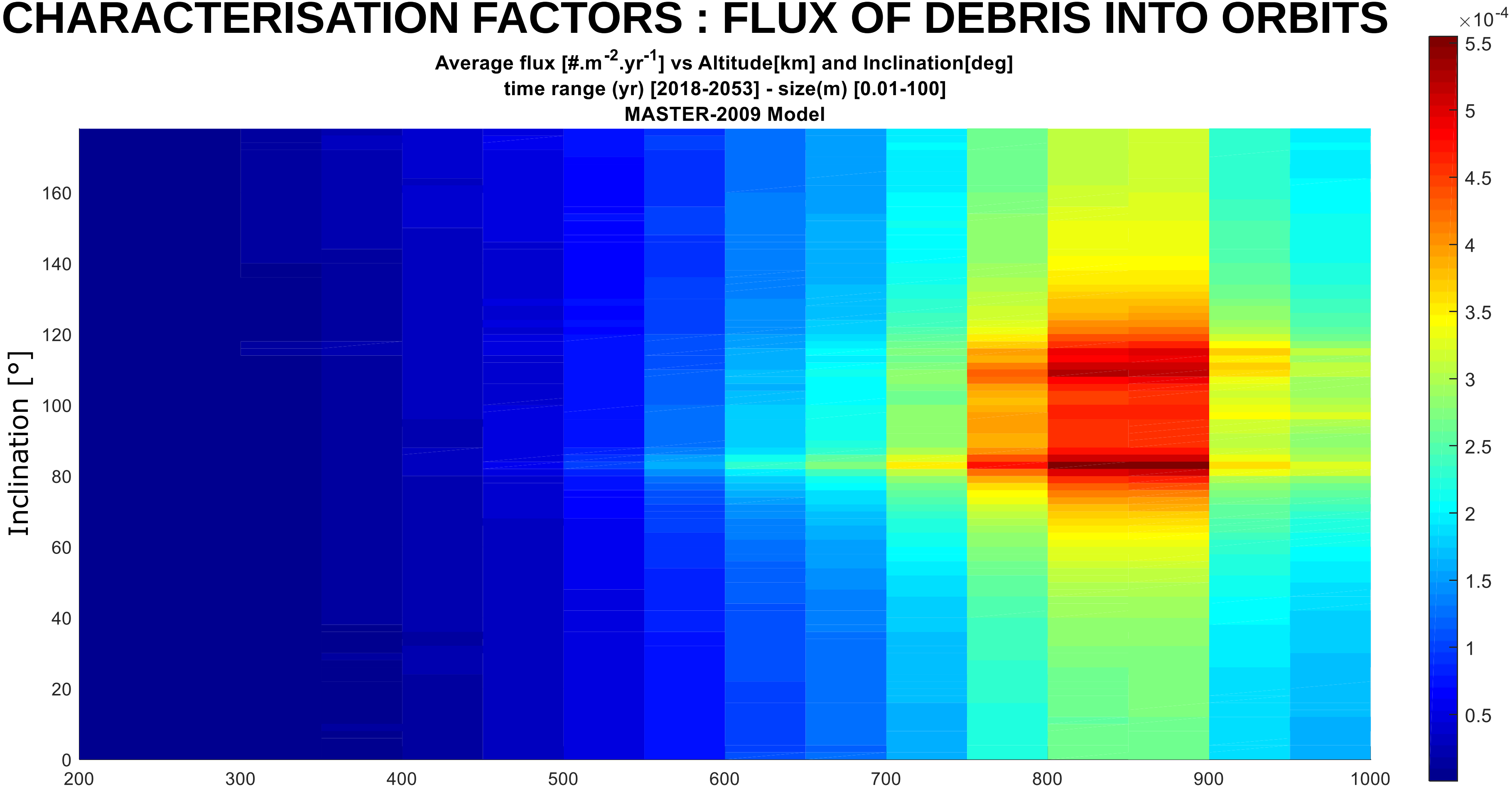
RESULTS

CHARACTERISATION FACTORS : FLUX OF DEBRIS INTO ORBITS



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CASE STUDY

SENTINEL 1-A

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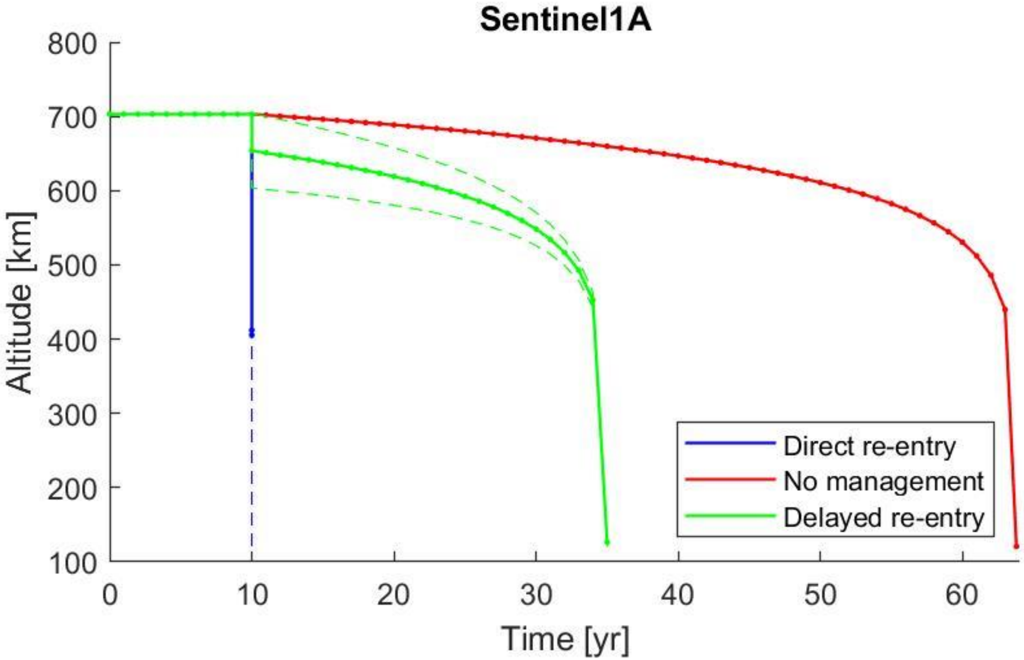
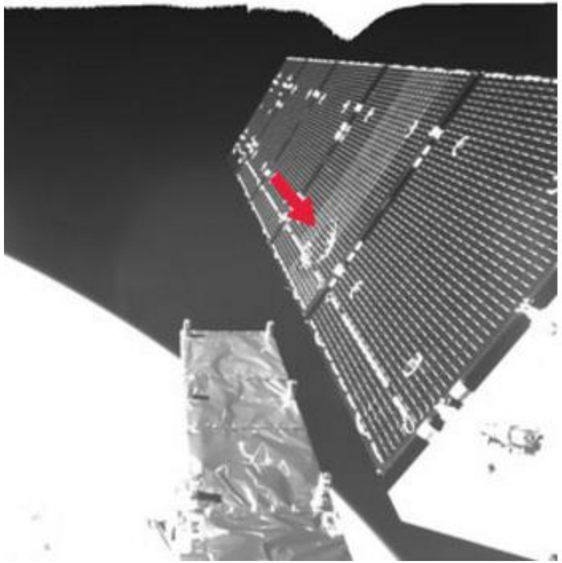
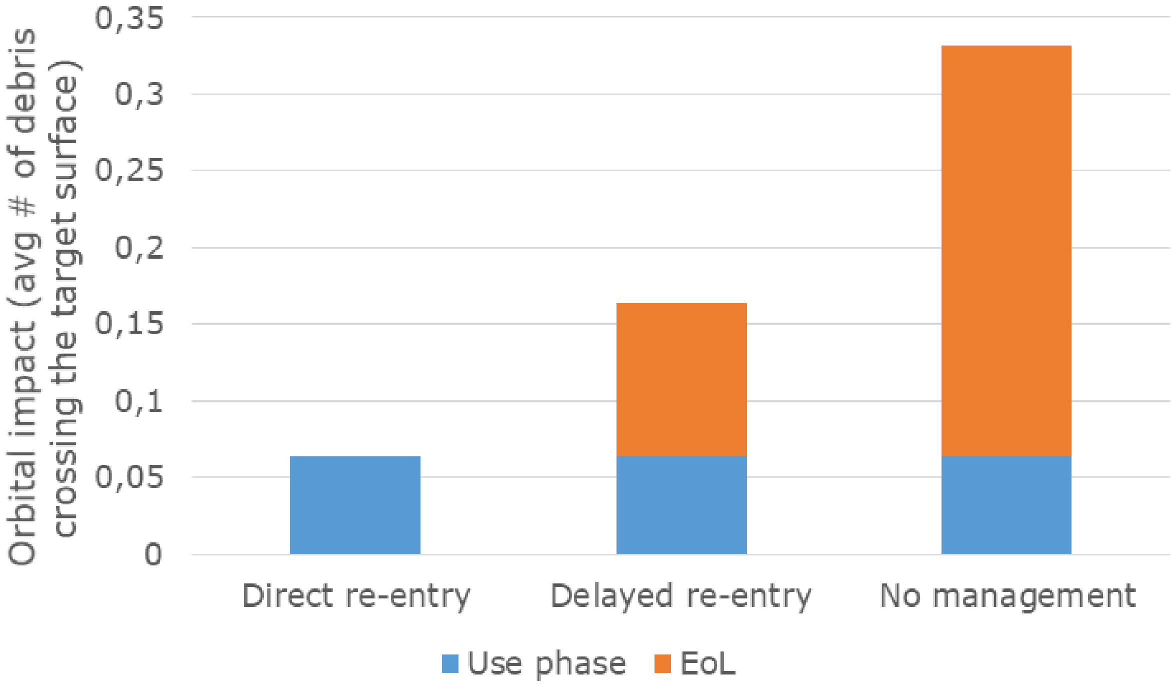




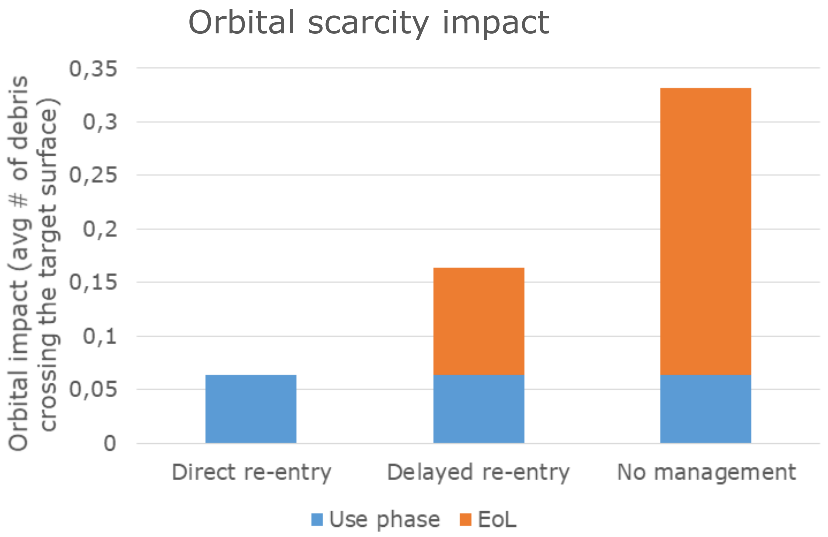
Assessing different End Of Life scenarios

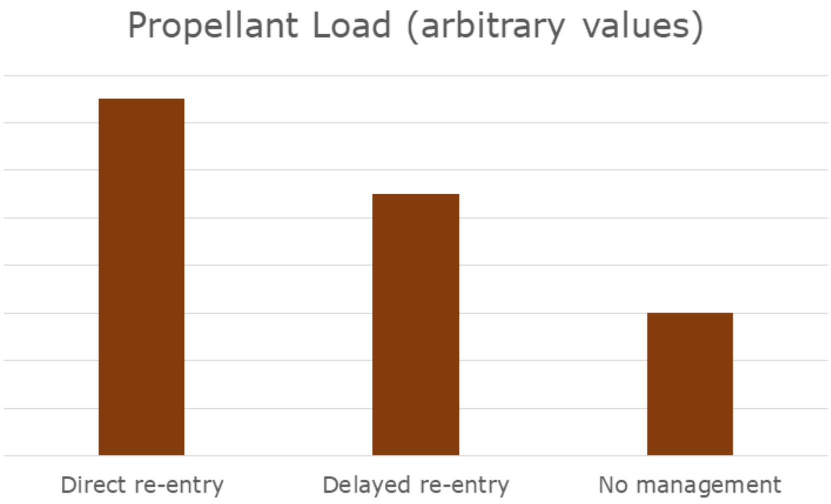
SENTINEL 1-A
Results of the case study



But…
Burden shifting

SENTINEL 1-A
Results of the case study

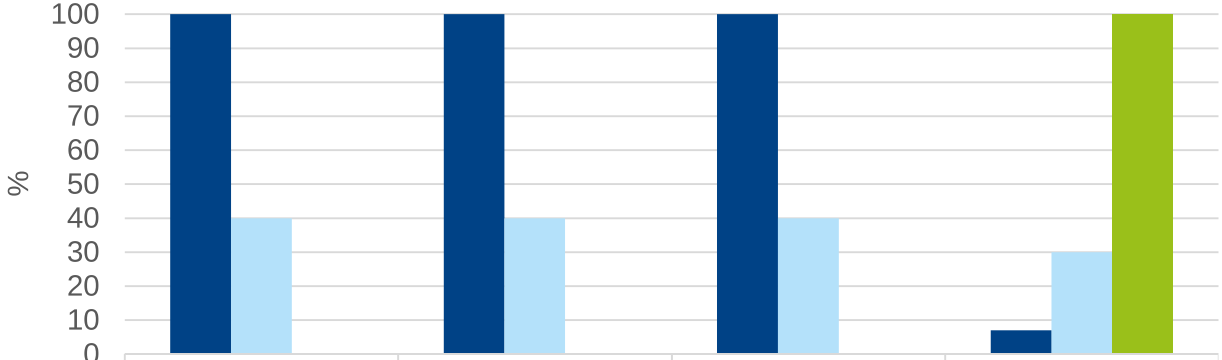




ENVIRONMENTAL IMPACTS

Environmental profile of End of Life Management

Relative additional environmental impact regarding End of life management (arbitrary value)



	Climate change	Ozone depletion	Toxicity	Orbital Scarcity
direct reentry	100	100	100	7
delayed re-entry	40	40	40	30
no management	0	0	0	100

- Atmospheric re-entry and fall down into ocean shall be included to address overall footprint of the End of Life

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DISCUSSIONS

SCIENTIFIC ROBUSTNESS

- The indicator is fully compliant with the LCA Framework (ISO 14040)
  - **Orbital scarcity:** $A_c \cdot \Delta t \cdot \overline{\phi}_{h,inc} = \boldsymbol{c}$ → $P_c = 1 - e^{-\boldsymbol{c}}$
- Analytical approaches based on physical and mechanical laws already proposed and discussed:
  - **Anselmo, L., Pardini, C., 2015.** Compliance of the Italian satellites […] and ranking of their long-term criticality for the environment. Acta Astronaut. 114, 93–100. doi:10.1016/j.actaastro.2015.04.024

$$f \equiv F(h, i, M) \cdot l(h) \cdot M^{1.75} \sim P_c \cdot M^{0.75}$$

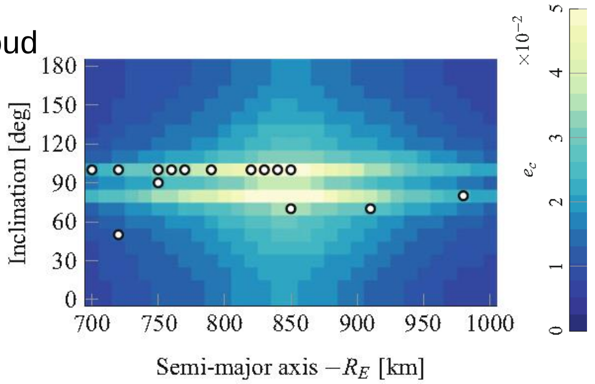
→ Index = $f \cdot g$

  - **Letizia, F., Colombo, C., Lewis, H.G., Krag, H., 2018.** Development of a debris index.

Semi-analytical method based on the continuity equation for spatial density of the cloud

<u>Combining:</u>
Collision probability for a spacecraft
Effect of a possible fragmentation on the whole debris population.

} Use of MASTER to compute relative velocity & density



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CONCLUSION

TAKE-HOME MESSAGE

- Orbital area supporting satellite activities is a resource stressed by the presence of Space objects

- A dedicated set of characterisation factors has been developed to characterize the orbital scarcity into the LEO region

- However, severity of the collision shall be included in a further step, as already proposed by several studies

- This indicator can be used to assess the End of Life of the Launchers Ariane 5 / Ariane 6

Thanks for your attention

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Acknowledgement

The French National Association of Research and Technology – CIFRE Convention 2015/1269 –

Design for Environment, ArianeGroup
Eco-space 2020 R&T project, ArianeGroup

ERC COMPASS, Politecnico Di Milano

Bordeaux de nuit, vue depuis l'ISS.

07

BACK UP

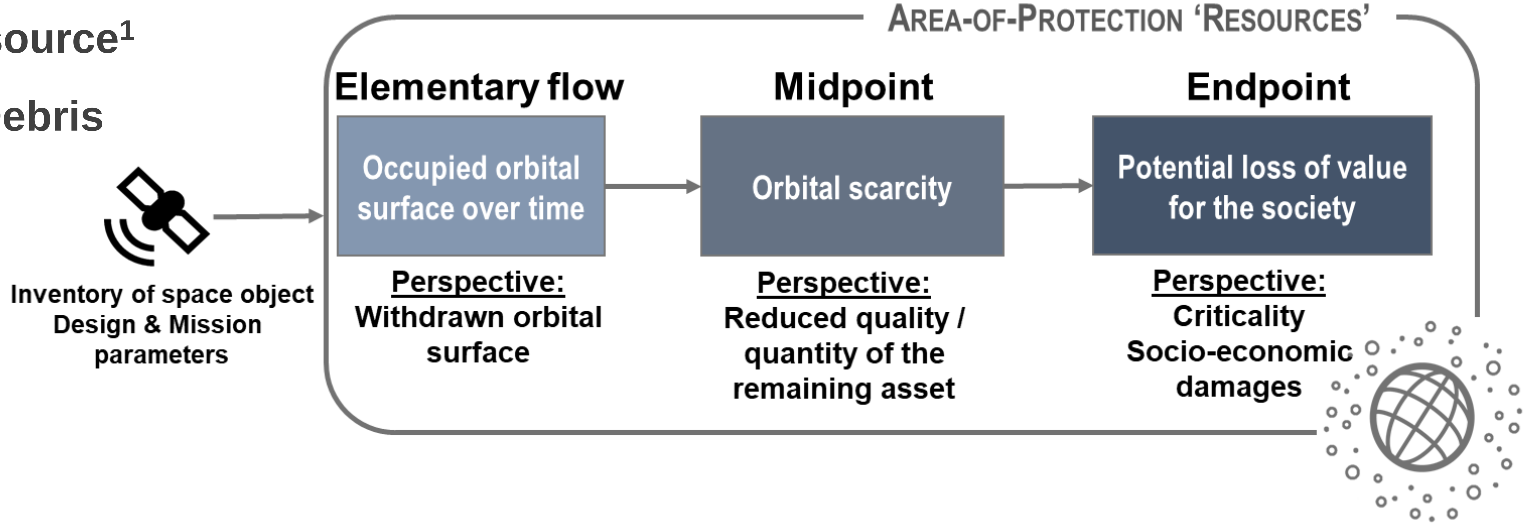
RESOURCE APPROACH FOR SPACE DEBRIS RELATED IMPACTS

Definition of Resource use in LCA

- Resource is seen as a asset providing services to man-made environment and economy
  *- JRC vision on **provisioning capacity** based on Dewulf et al. 2015 -*

Orbits = Resource[1]

Stressors=Debris



1. Maury T, Loubet P, Ouziel J, Saint-Amand M, Dariol L, Sonnemann G. Towards the integration of orbital space use in Life Cycle Impact Assessment. *Sci Total Environ*. 2017;595:642-650. doi:10.1016/j.scitotenv.2017.04.008.