Assessing the impact of Space Debris on the orbital resource in LCA

Clean Space Industrial Days 2018

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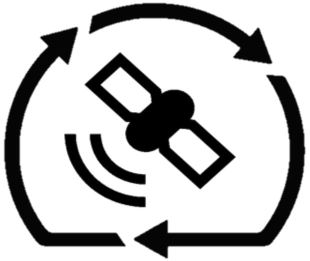
SUMMARY



1 CONTEXT

2 SCOPE AND OBJECTIVES

3 MATERIALS AND METHODS

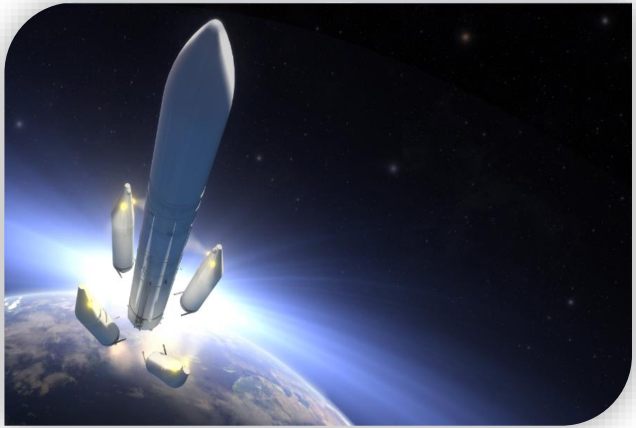
4 RESULTS

5 THEORETICAL CASE STUDY – SENTINEL-1A

6 DISCUSSIONS & OUTLOOK

01

WHY USING LCA FOR SPACE ACTIVITIES ?



GLOBAL DRIVERS LEADING TO ENVIRONMENTAL DETERIORATION

IPAT equation – (Holdren & Ehrlich, 1974)

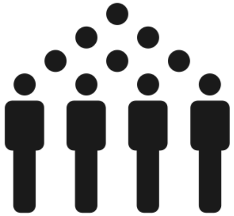
$$I = P \cdot A \cdot T$$

Impact on the environment

Ex. kg CO_2eq.

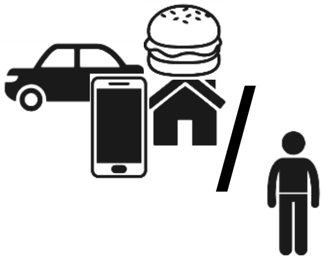
Population

number of inhabitants



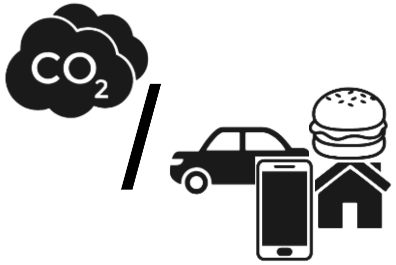
Affluence

Goods & services / inhabitants



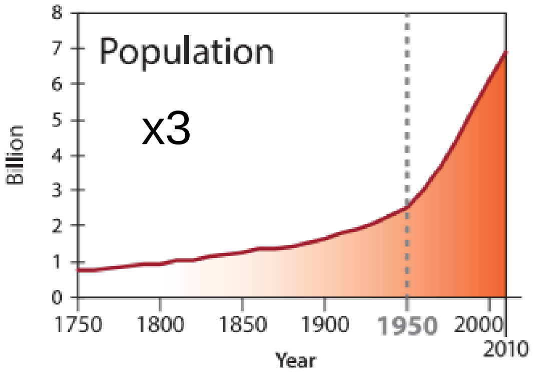
Technology

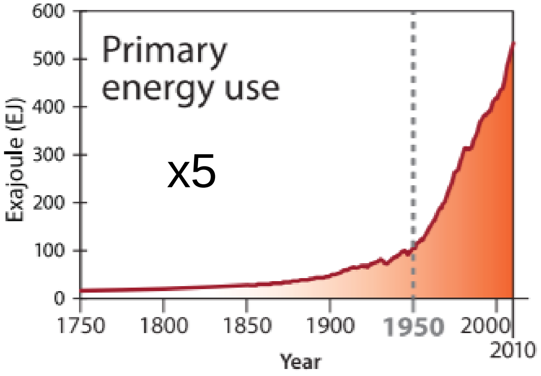
Environmental footprint / goods & services

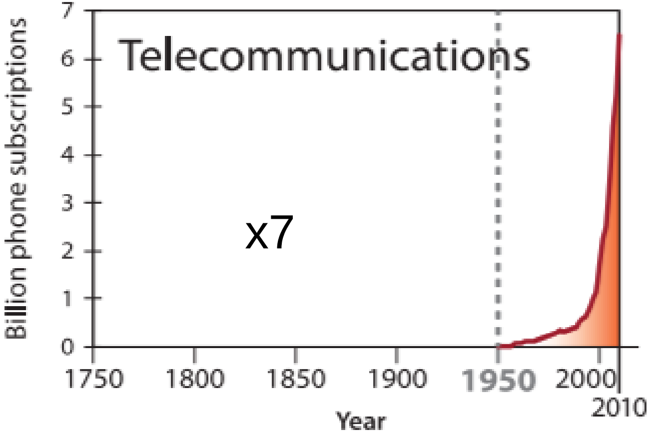


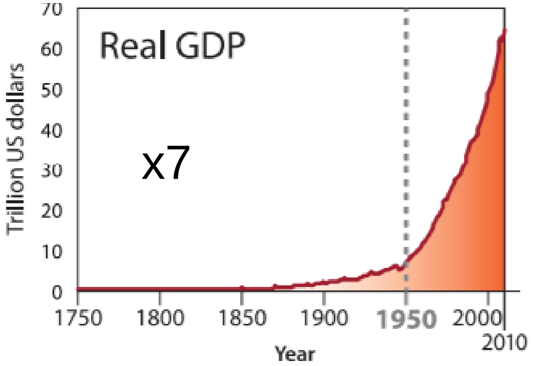
OVERVIEW OF POPULATION & AFFLUENCE FACTORS (I=PAT)

Socio-economic trends









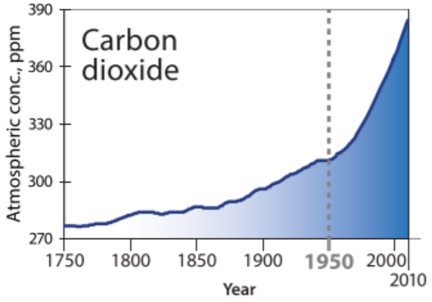
All the indicators of affluence have increased at higher rates than the world population growth…

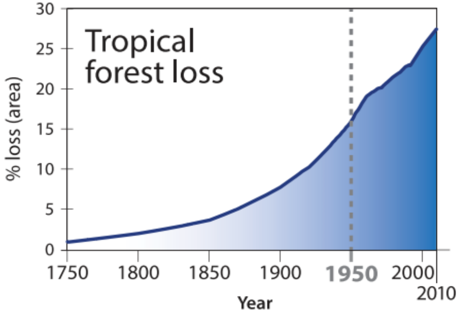
Steffen, W., et al., 2015. The trajectory of the anthropocene: The great acceleration. Anthr. Rev. 2, 81–98. doi:10.1177/2053019614564785

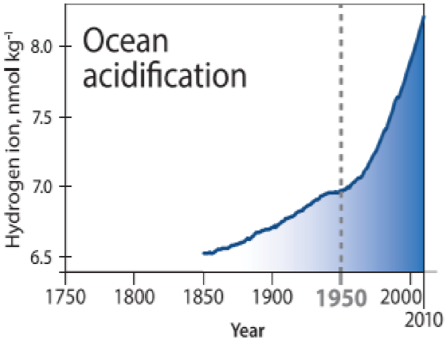
ENVIRONMENTAL DETERIORATION (I=PAT)

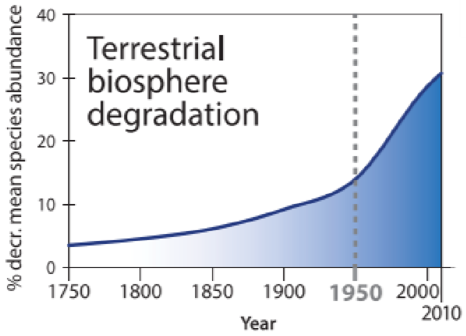
Earth system trends (Environmental stressors)

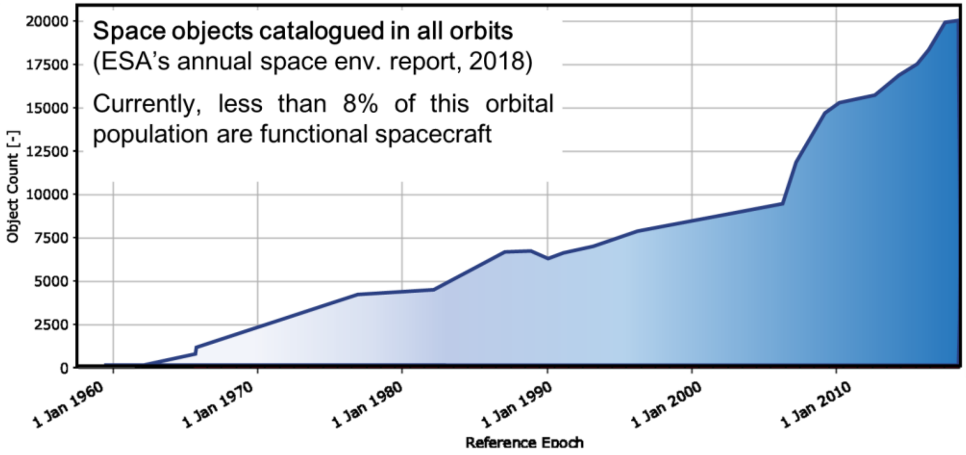
…Orbital Environment trend









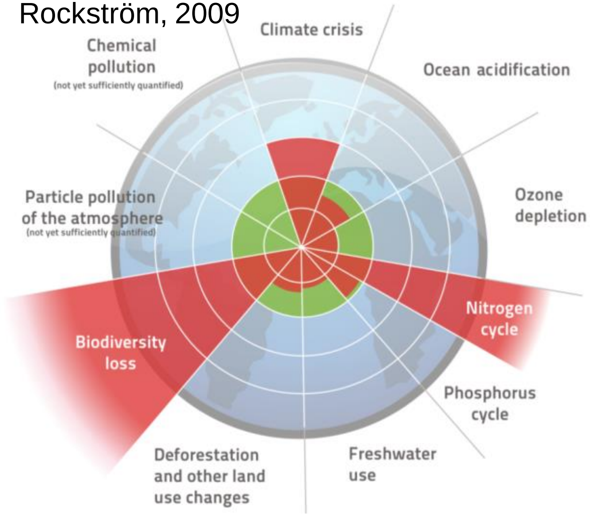


Debris → stressors of the orbital environment

Non-functional objects grow faster than functional objects

BEYOND PLANETARY BOUNDARIES ?

Rockström, 2009



*Need to decrease the technology factor **'T'** (resource intensity) to stay within the planetary boundaries*

'Space Capacity' concept (Krag et al. 2017, 2018)

Green: safe operative space for Humankind

Red: scientific observations since 2009

Role of the Life Cycle Assessment (LCA) methodology:

↘ **measure** and **minimise** the environmental footprint (T) of space activities to stay **within** the planetary boundaries

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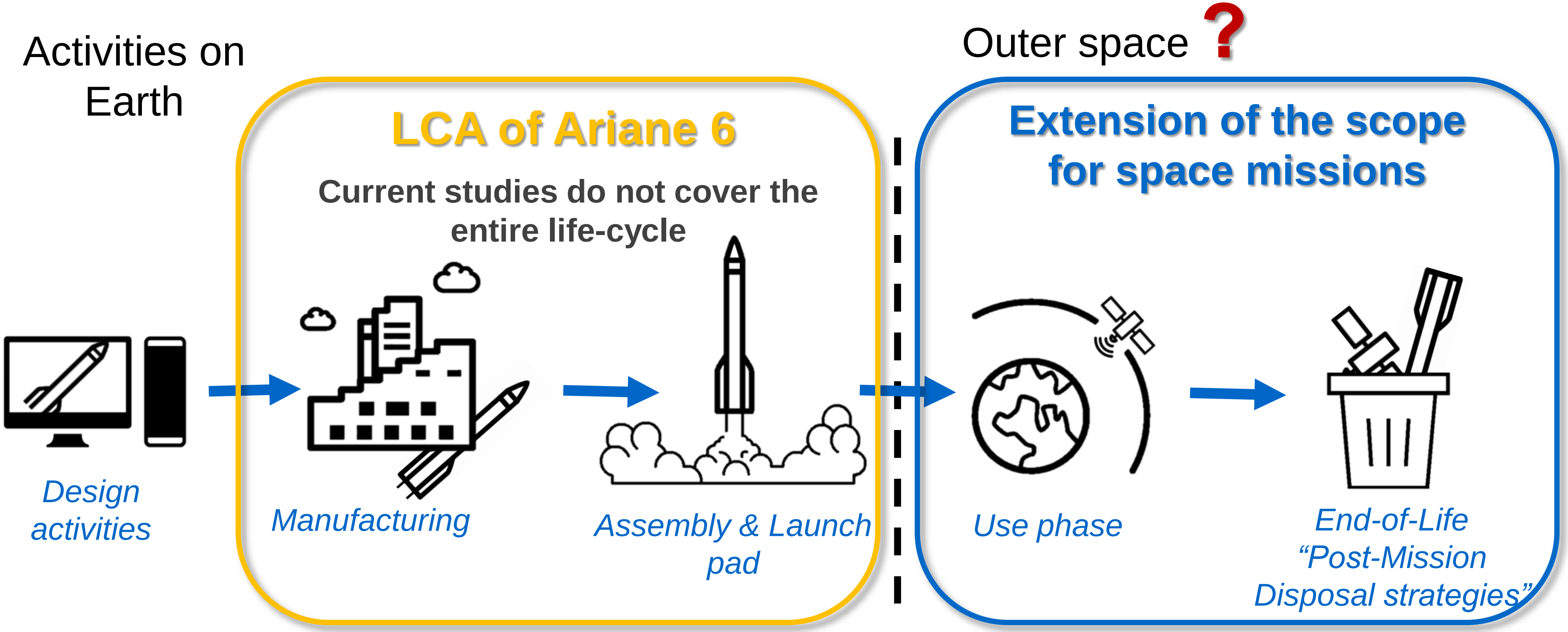
SCOPE AND OBJECTIVES

LIFE CYCLE OF SPACE MISSIONS



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 mission in orbits

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

- Overview of the potential burden shifting

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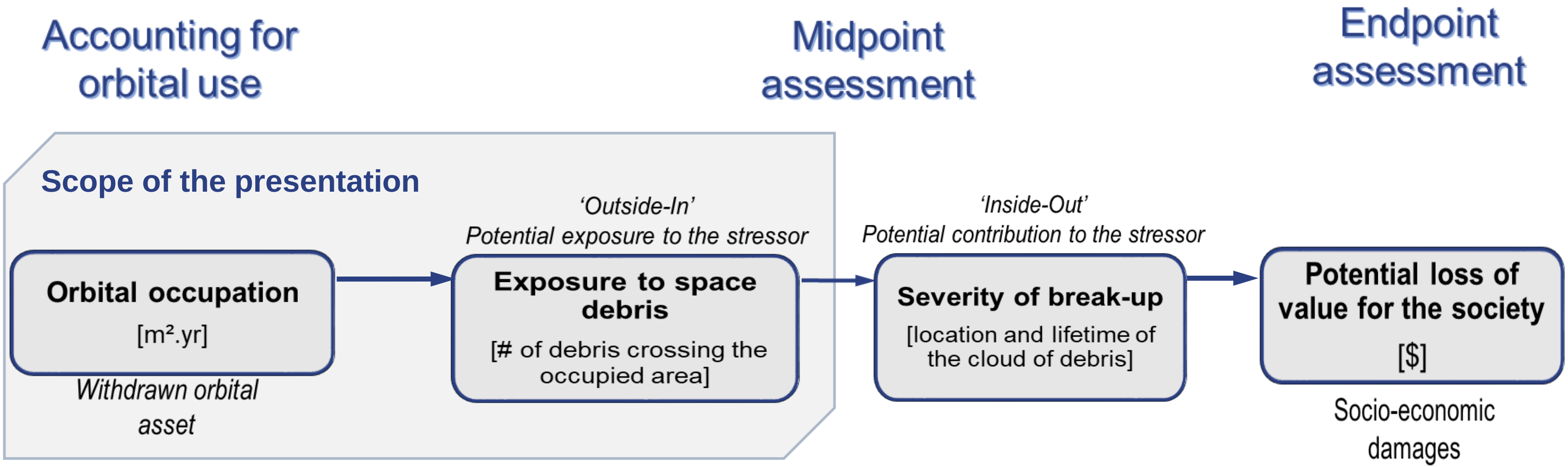
MATERIALS & METHODS

IMPACT PATHWAY – CAUSE-EFFECT CHAIN



Orbits = Resource[1]

Environmental stressor = 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.

INVENTORY

Orbital occupation

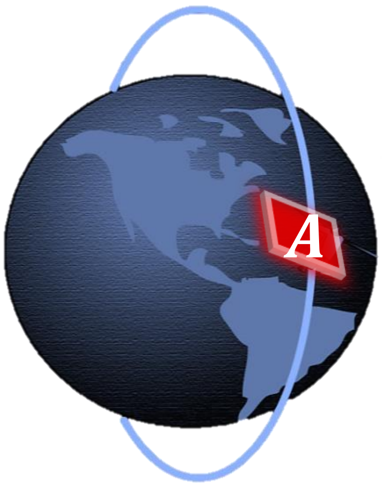
[m².yr]

Withdrawn orbital asset

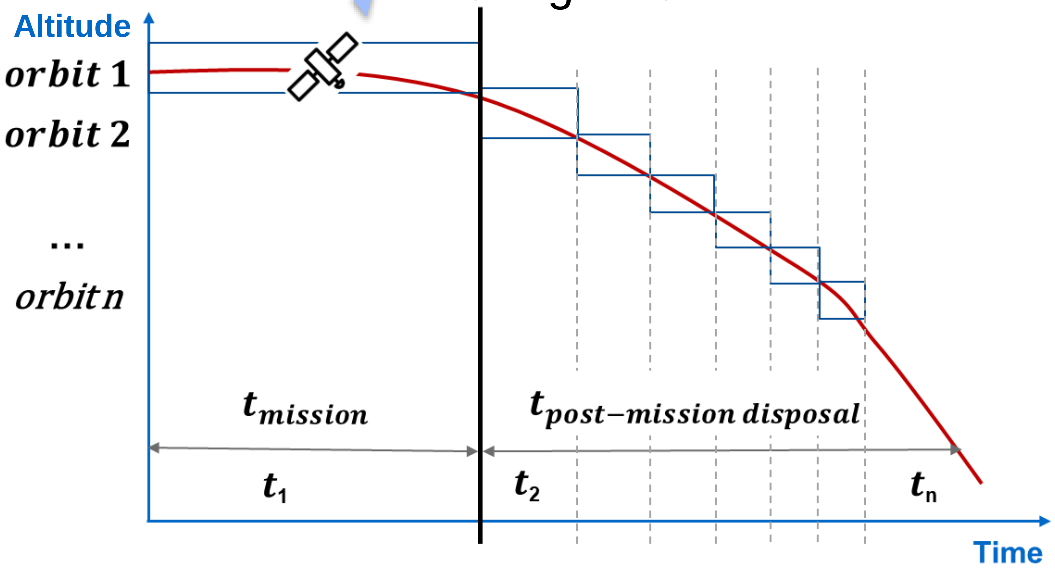
$$Inventory = A \cdot \sum_{Orbits} t_i$$

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

Average cross sectional area



Dwelling time



CHARACTERISATION FACTORS

'Outside-In'
Potential exposure to the stressor

Exposure to space debris

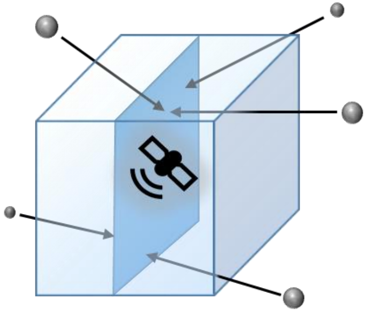
[# of debris crossing the occupied area]

$$Impact_{exposure} = Inventory \cdot CF$$

- **Characterisation Factors** (CF): average **flux of debris** crossing the target orbits
- Each orbit presents a different state which allows to classify and differentiate them (existing background impact not caused by the modeled product system).

$$Impact = A \cdot \sum_{i=Orbit} t_i \cdot \overline{\boldsymbol{\Phi}_i}$$

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



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

- Debris population >1cm
- Time interval [2018-2035] (35yrs)
- Circular orbits (e=0,001)
- Fictive spherical target of 1m² (angle of collision 90° - isentropic flux)
- All the LEO region is characterised: Δ 50km & Δ 2° inclination (3330 runs)

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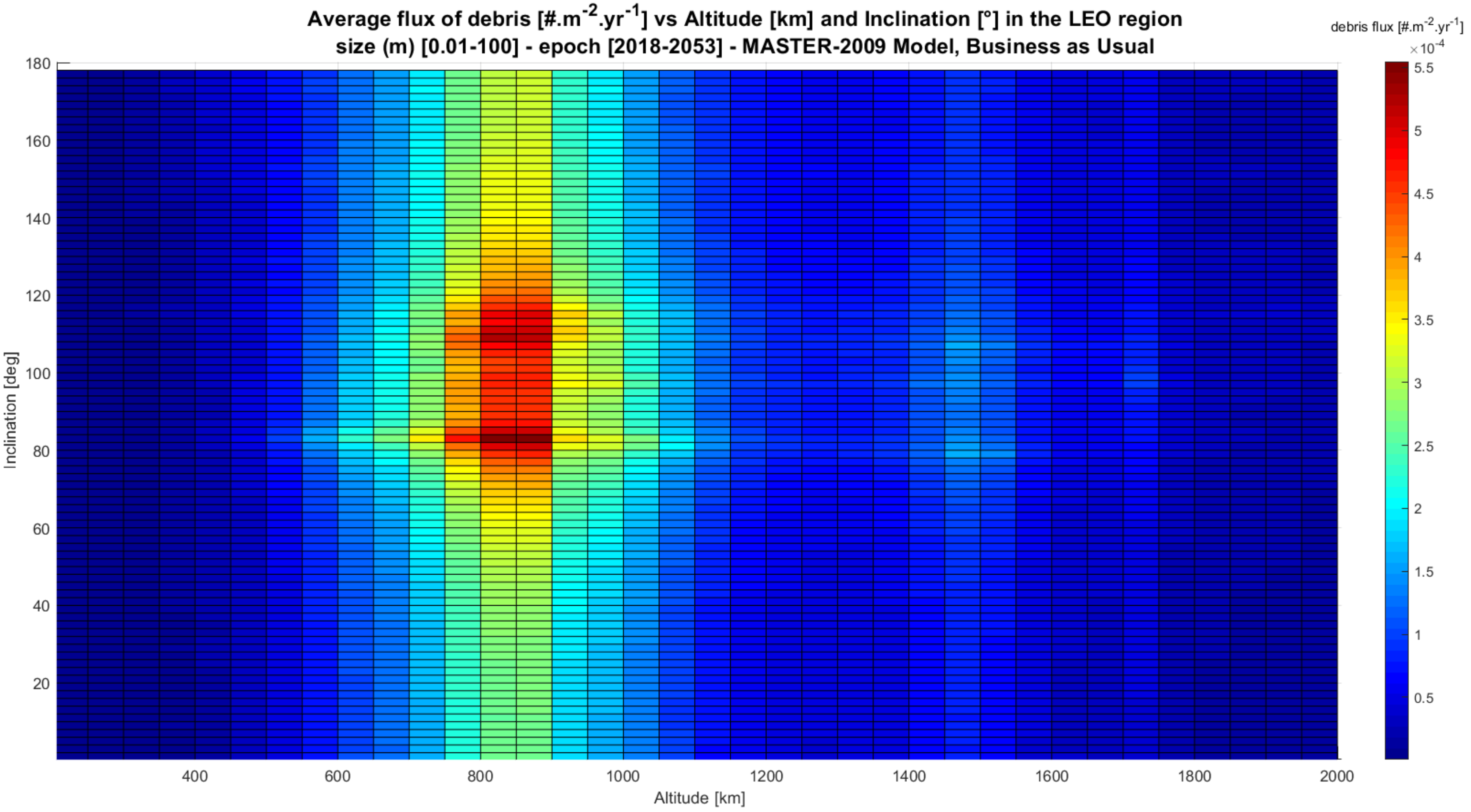
RESULTS

CHARACTERISATION FACTORS : FLUX OF DEBRIS INTO ORBITS



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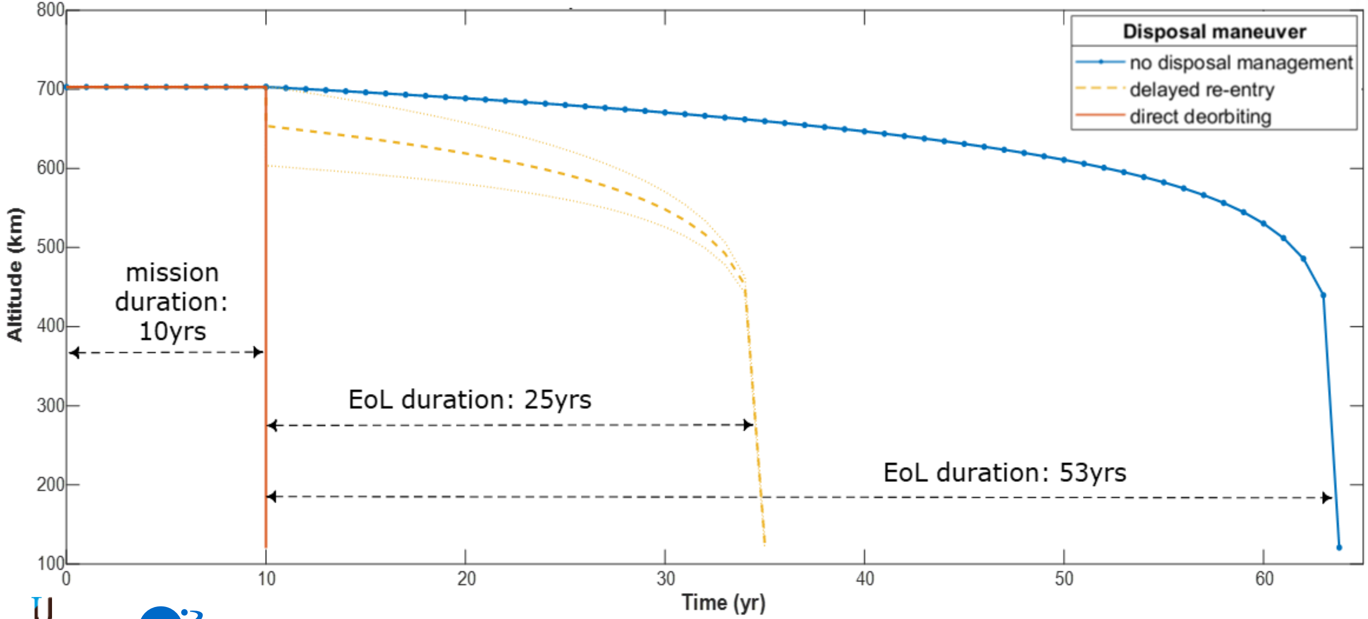
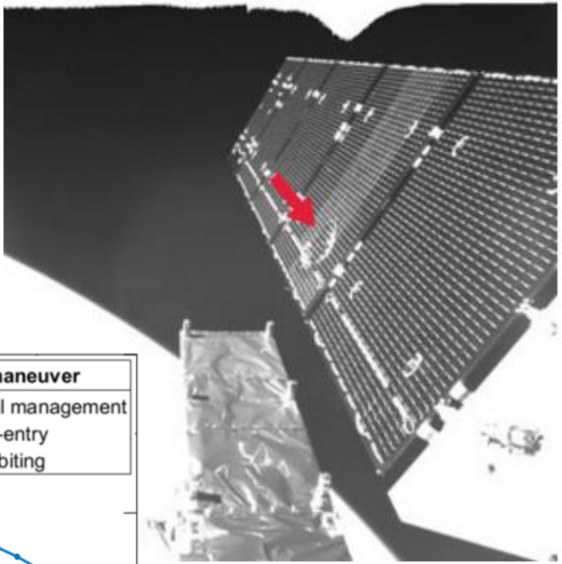
CASE STUDY

SENTINEL 1-A

SENTINEL 1-A

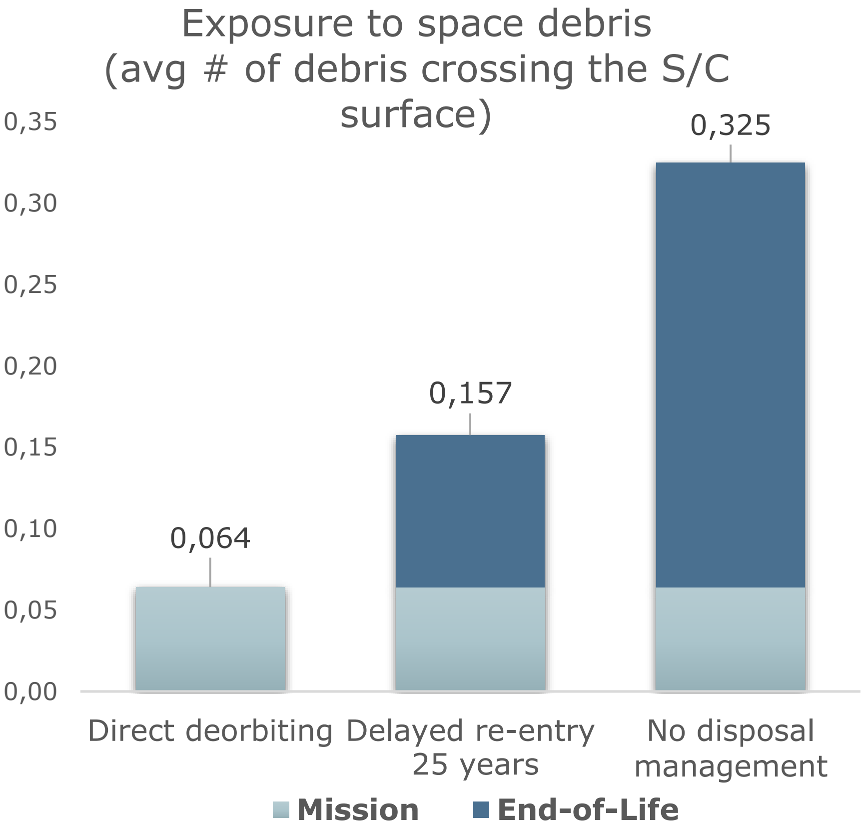
Assessing different End-of-Life scenarios





SENTINEL 1-A

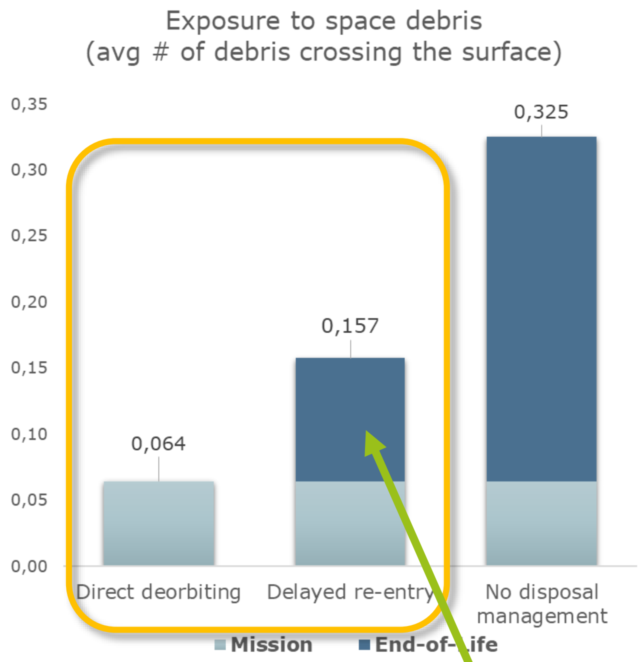
Results of the case study

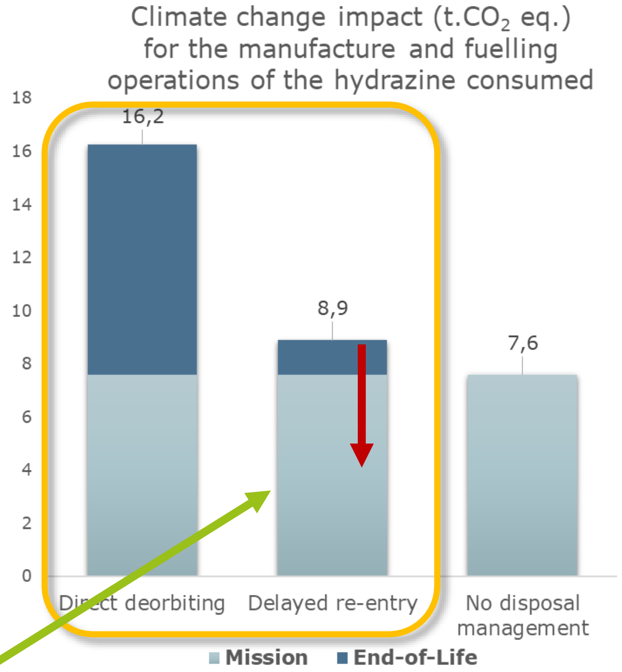


But…
Burden shifting

SENTINEL 1-A
Environmental profile

Hydrazine burned in space is out of the scope





Reduction of the Impact of the embedded propellant
(Global Warming, Tox…)

… But Hydrazine classified as SVHC by REACH regulation

➔ Need to redesign the EoL stage with a better environmental profile
(e.g. Passive Deorbiting?)

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DISCUSSIONS AND OUTLOOK

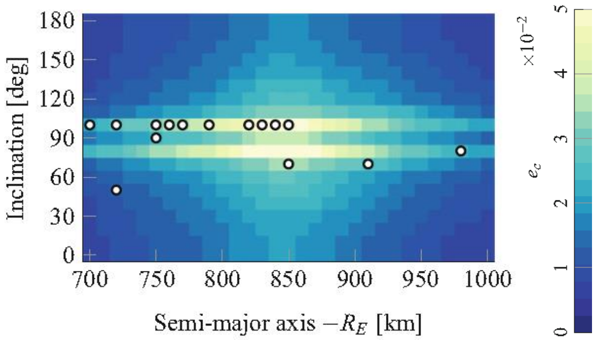
SCIENTIFIC ROBUSTNESS

- The indicator is fully compliant with the LCA Framework (ISO 14040/44)
- The numerical approach proposed here is closed to (semi)-analytical approaches already published and discussed, which both integrate the severity:
  - **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
  - **Letizia, F., Colombo, C., Lewis, H.G., Krag, H., 2018.** Development of a debris index.

- **Need to develop the Characterisation Factors for the 'Inside-out approach':**

Distance-to-Target normalisation

$$Contribution = \frac{Potential\ debris\ emitted\ by\ the\ mission}{Overall\ space\ capacity}$$



TAKE-HOME MESSAGE

- A dedicated set of characterisation factors to describe the orbital environment in the LEO region has been calculated

- The exposure to the flux of debris is characterized for several Post-Mission Disposal scenarios

- This indicator can be used to assess the on-orbit stages of the Launchers Ariane 5 / Ariane 6

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

- Towards a complete assessment of the trade-offs occurring between the Earth & the orbital environment…

Thanks for your attention

Bordeaux de nuit, vue depuis l'ISS. © Twitter/@Thom_astro – ESA/NASA

Acknowledgement

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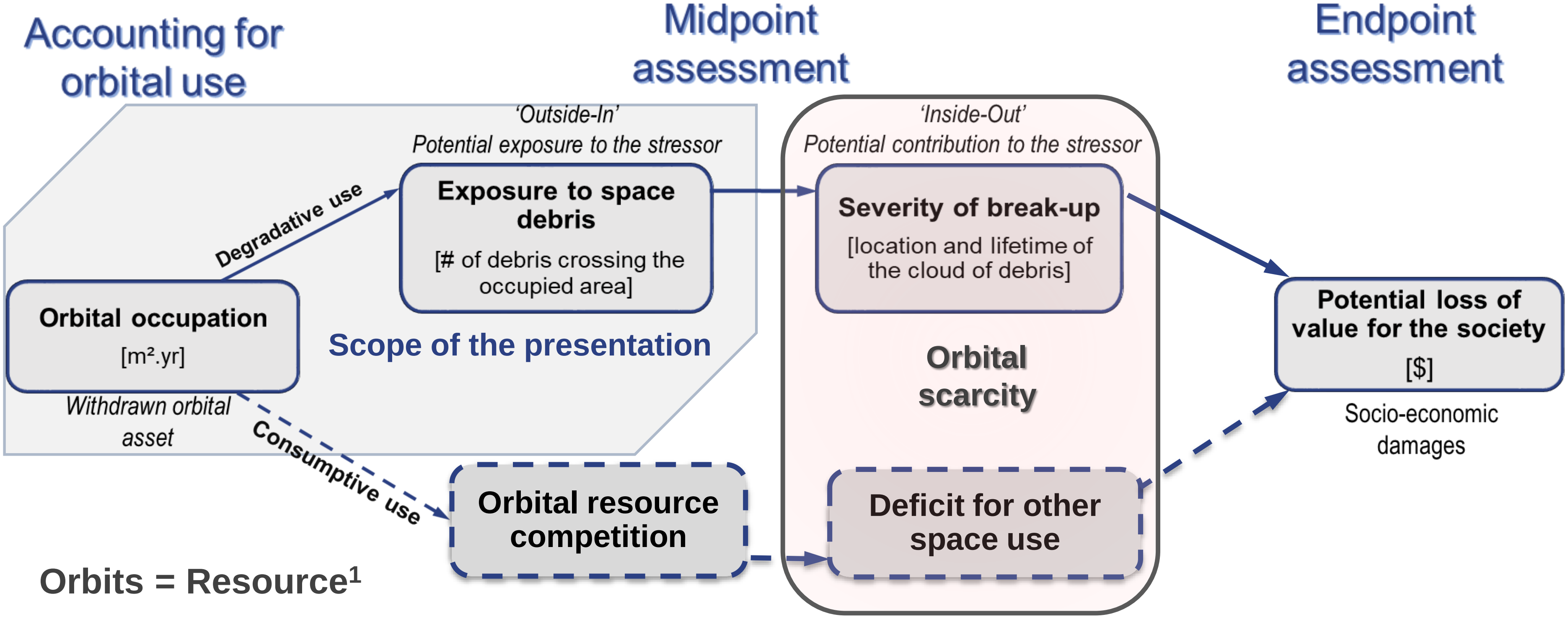
06

BACK-UP

IMPACT PATHWAY – CAUSAL CHAIN



Orbits = Resource[1]

Environmental stressor = debris

Stressor = Orbital resource depleted by S/C

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.

CHARACTERISATION FACTORS (Φ_i)

MASTER-2009 Model – Business as usual

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 at given altitude, inclination & eccentricity

Target velocity

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

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

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.

$$\boldsymbol{\Phi_i = Density \cdot \Delta v_{col}}$$

[#.m-2.yr-1] [#.m-3] [m.yr-1]

- All the LEO region is characterised: Δ 50km & Δ 2° inclination (3330 runs)