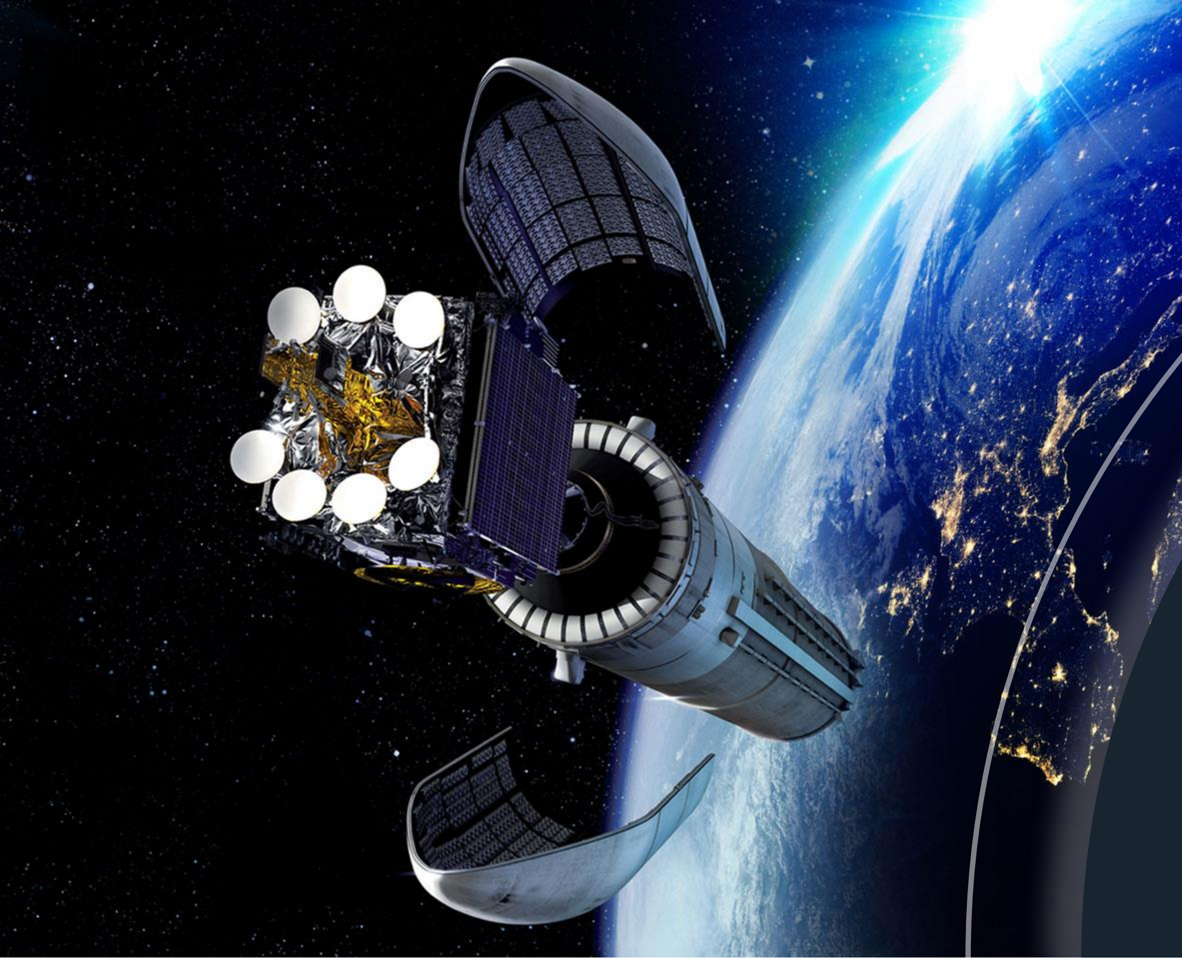

GreenSat

Nicolas Thiry (nicolas.thiry@thalesaleniaspace.com)

Augustin Chanoine (AChanoine@deloitte.fr)

Pierre-Alexis Duvernois (PDuvernois@deloitte.fr)

Jasmine Bitar (JBitar@deloitte.fr)

ThalesAlenia Space
a Thales / Leonardo company

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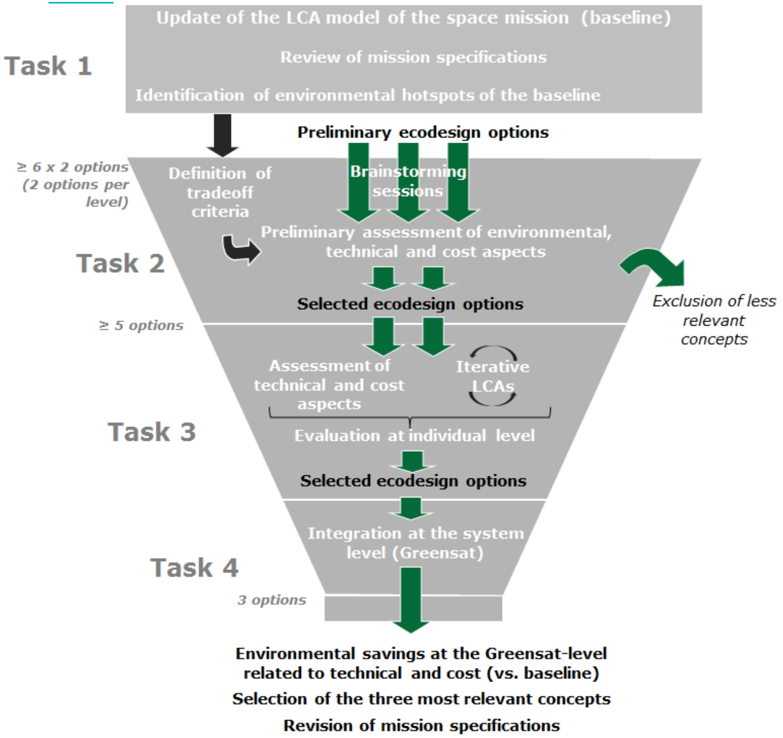
GreenSat Study Objective



The objectives of the GreenSat study are:

- To develop **ecodesign options** to higher maturity to target reductions of **50% of the environmental impact** on at least **three environmental indicators** without an increase on others;
- To demonstrate the **feasibility** of such improvements from a **technical** and **economic perspective**;
- Overall, to favor the **update of ecodesign approaches** and related tools by the European space industry.

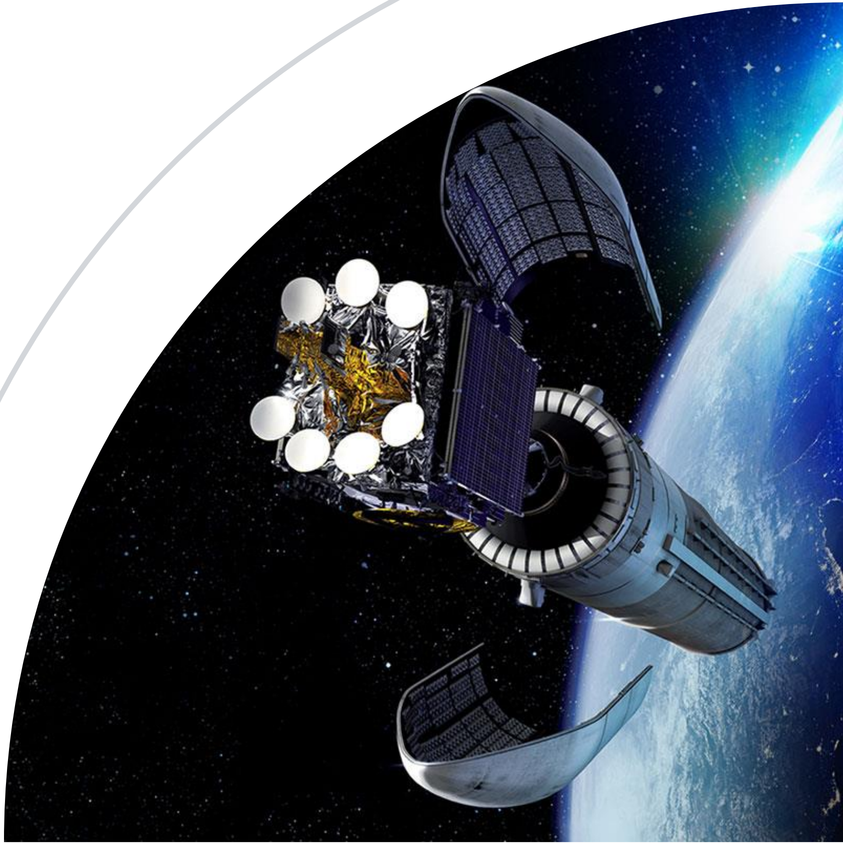
This presentation will summarize the main findings of Task 2

GreenSat Study Case

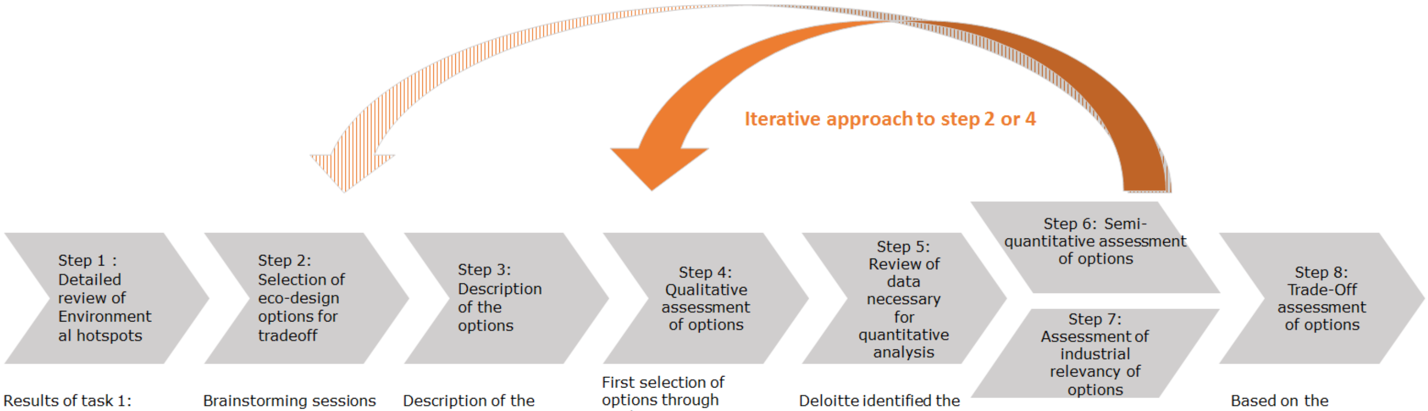
The Sentinel 3 satellite

Name	Sentinel 3
Launch date	2016 (S3A), 2018(S3B), ~2021(S3C/D)
Nominal lifetime	7 years (5 years extension provisioned)
Orbit	SSO with 814km altitude and 10:00 Mean local solar time, 98.6° inclination, 27 days repeat cycle
Mass	1150kg
Bus dimensions	3.9 m (height) x 2.2 m x 2.21 m
Structure	CFRP (Carbon Fiber Reinforced Plastics) central tube and shear webs
EPS	• Unregulated power bus, with a Li-ion battery and GaAs solar array. • Solar Array 1 wing, 3 panels , 10.5 m2, power of 2300 W EOL, SADM
Propulsion	130kg (monopropellant N2H4), 8x1N thrusters
Payload	OLCI, SLSTR, SRAL, MWR, OLCI, DORIS, GNSS, LRR

Trade-off of ecodesign Solutions



General Methodology



Results of task 1:

- Detailed review of environmental **hotspots** of the mission
- **Preliminary recommendation** for eco-design options

Brainstorming sessions to select eco-design options :

- Internal brainstorming with subsystem experts, to identify **potential eco-design options**
- Wider brainstorming: **refining of the eco-design options list**

Description of the different ecodesign options considered for the tradeoff, compiled by TAS

First selection of options through qualitative assessment, retaining:

- Options addressing identified hotspots
- Options presenting significant potential for improvement
- Options without major risk of burden shifting

Deloitte identified the **necessary inputs for a semi-quantitative analysis** of selected options :

- Whenever feasible, TAS provided the requested inputs to Deloitte, involving appropriate experts.
- In some cases, ESA was solicited if no data could be retrieved by TAS.

Deloitte performed **simplified LCA** based on available inputs, for each option.

In parallel, TAS internally assessed the industrial relevance of eco-design options through **an eco-design matrix**

Based on the preliminary assessment, the T/O was done in 2 steps:

a) Assessment through the eco-design matrix, to **filter options by industrial relevance**

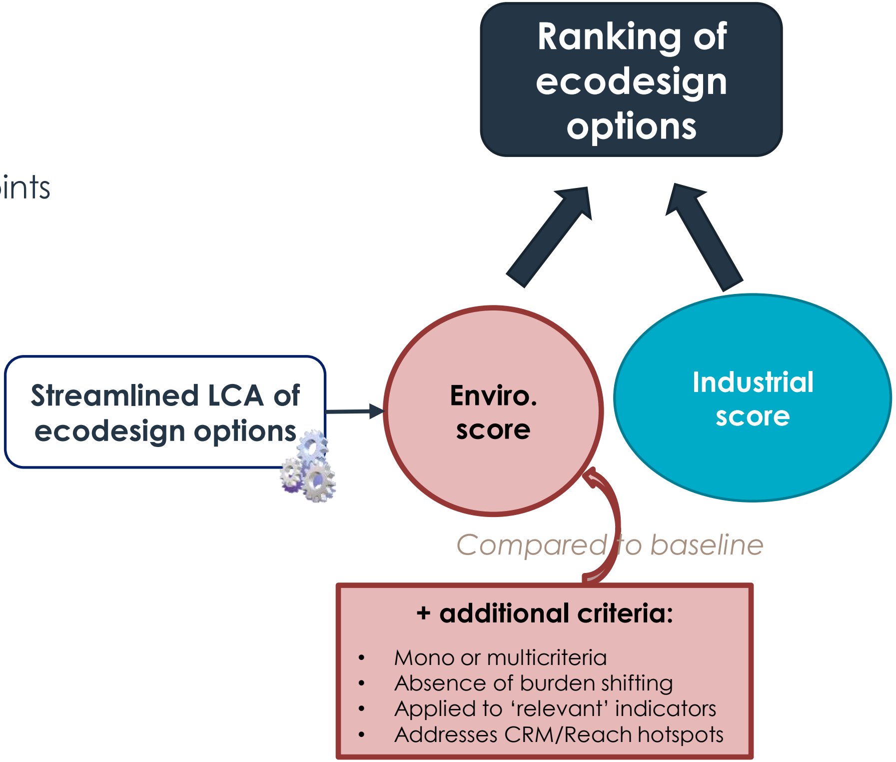
b) ESA's **T/O criteria** list was defined to retain the best options to be further investigated in task 3 and 4

Sentinel 3 hotspots analysis

Hotspot	Level	Main indicators targeted	Explanation	Eco-Design Levers	Technological options
Germanium in solar cell substrate	MATERIAL	Mineral resources depletion	Part of the CRM list with high characterization factor	• Alternative to current cells • Substrate recycling • Use less cells per m²	• Perovskite, CIGS, … • Epitaxial Liftoff • Solar concentrator
PTFE in harness coating	MATERIAL	Ozone depletion	Emission of ozone depleting substances during the manufacturing of precursors of PTFE.	• Cable types • Total cable length reduction • Derating factor (ESSC)	• Fiber braggs grating for thermistances • Decentralized avionics, SpaceFiber • High voltage power bus • Powerline communication
Electronics in Payload and PDHU	EQUIPMENT	ALL	Extraction of rare metals and manufacturing	• Greener manufacturing and materials	• 3D-printed electronics
Manpower	MANAGEMENT	ALL	• Design effort • Flight Operations • Payload data ground segment	• Heritage (Reduces Design effort) • Satellite autonomy (reduces operations) • Machine learning (automated payload data treatment)	• ALM (structure procurement) • Autonomous control of orbit • Sustainable energy source • Digital transformation
Travelling	MANAGEMENT	ALL	Design phases	• Virtual meetings	• Virtual meetings
LN2 consumption	MANAGEMENT	ALL	TVAC tests during AIT sequence at instrument and satellite level	• Use smaller vacuum chambers • Reduce test durations	-
Clean room energy consumption	MANAGEMENT	ALL	mainly due to air handling units	• Energy efficiency • AIT shortening • Hygrometry requirement (ECSS)	• Optimization of air handling units • Sustainable energy source • ALM (integration)
Hydrazine	REGULATION	-	REACH	• Green propellant • Electrical propulsion	• HPGP • Ion thrusters • Arcjet thrusters

Trade-Off Criteria

- **Environmental score: 51 points**
  - Single score (JRC meta-weighting method): 26 points
  - Absence of burden shifting: 10 points
  - Midpoint indicator relevance: 5 points
  - Mono or multiple indicators addressed: 5 points
  - Targets CRM or REACH hotspot: 5 points
- **Industrial score: 49 points**
  - Recurrent cost: 10 points
  - Development cost: 10 points
  - TRL: 5 points
  - Mass: 5 points
  - Performance: 5 points
  - System level impacts: 14 points



Trade-Off Results

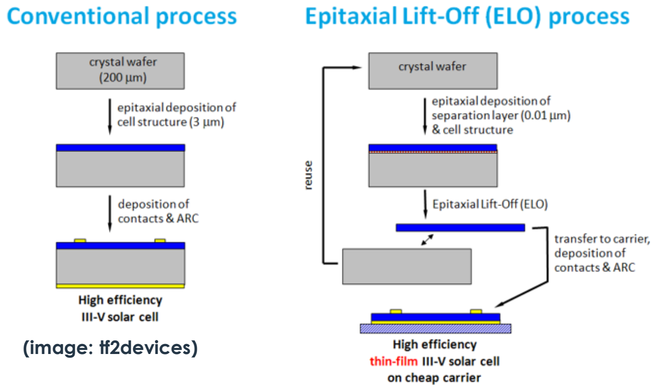
#	General information				Ruling form preliminary analysis	Total environmental score (51 pt)	Rank (environmental only)	Total technical and economic score (49 pt)	Total score (100 pt)	Rank
	Option	Level	Phase of the Space Mission (if relevant)	Sub-system (if relevant)						
1	Green propellant	Material	C+D	Propulsion	Yes	23	2	49	72	2
2	Aerogels	Material	C+D	Thermal insulation	No					
3	New thermoplastic materials	Material	C+D	NA	Yes	5	5	24,5	29,5	5
4	Additive layer manufacturing	Manufacturing	C+D	NA	Yes	36	1	49	85	1
5	Dry adhesion	Manufacturing	C+D	NA	No					
6	Friction stir welding	Manufacturing	C+D	Structure Propulsion	No					
7	Laser surface treatment	Manufacturing	C+D	NA	No					
8	Epitaxial lift off (ELO)	Manufacturing	C+D	Power	Yes	40,9	2	41,5	82,4	1
9	Hall effect thrusters	Equipment	C+D	Propulsion	Yes	23	5	29,5	52,5	5
10	Arcjet thrusters	Equipment	C+D	Propulsion	Yes	23	5	29,5	52,5	5
11	Concentrator solar arrays	Equipment	C+D	Power	Yes	35,7	3	27,5	63,2	4
12	Alternative to GaAs solar cells	Equipment	C+D	Power	Yes	46	1	29	75	2
13	Reduction of substrate thickness	Equipment	C+D	Power	Yes	25,3	4	49	74,3	3
14	Fiber Bragg Gratings	Equipment	C+D	Harness	No					
15	Inter-satellite links	System	E2	NA	No					
16	High voltage power bus	System	C+D	NA	No					
17	2 X-band stations instead of one	System	E2	NA	No					
18	Future avionics with space fibres	System	C+D	Harness	Yes	18	4	41,5	59,5	4
19	Decentralised Avionics	System	C+D	Harness	Yes	20	3	41,5	61,5	3
20	Power Line Communication	System	C+D	Harness	No					
21	Wireless avionics	System	C+D	Harness	No					
22	Autonomous orbit control	System	E2	NA	Yes, but in standby					
23	Multi-satellites	System	E2	NA	No					
24	Energy efficiency	Management	A+B, C+D, E2	Office work	Other					
25	Variable set point	Management	C+D	AIT	Other					
26	Dense GN2 circulation TCUs	Management	C+D	AIT	Other					
27	Digital transformation	Management	A+B, C+D	Travelling	Other					
28	On site sustainable energy production	Management	A+B, C+D, E2	Office work	Other					
29	Reduction of margins	Management	C+D	NA	No					

Focus on selected ecodesign options

Eco-Design Options Retained for the Solar Arrays

- **Epitaxial Liftoff (ELO)** for Inverted Metamorphic 3J solar cells:
  - **Mass reduction** due to thinner cell thickness (<50µm)
  - **Simultaneous Environmental and Cost savings** thanks to recycling of the Germanium wafer (>100 recycling for wet chemical etching process)
  - **Higher cell efficiency** thanks to higher bandgap of bottom cell
  - **Already commercialized** by US-based company

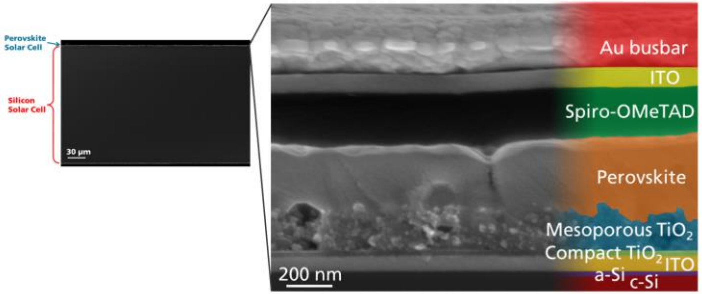
http://www.arpae-summit.com/paperclip/exhibitor_docs/14AE/MicroLink_Devices_212.pdf



(image: ff2devices)

- **Perovskite Solar Cells:**
  - Made of **abundant material** and **cheap manufacturing** process
  - **Radiation testing done** by independent **NASA** and **JAXA** teams
  - **BUT** low TRL, stability issues and sensitivity to moisture are an issue
  - Possible to coat Silicon cells with Perovskite before Lamination

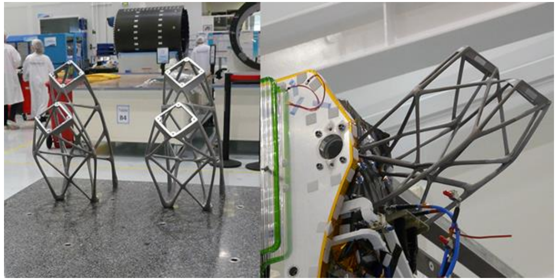
    → Increased Yield on the same footprint



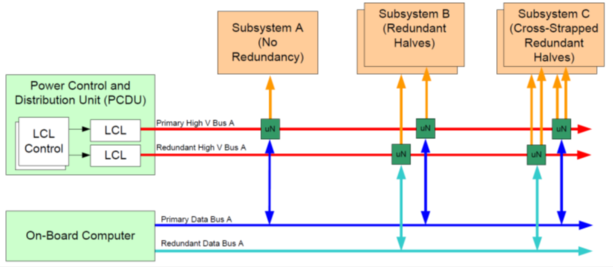
(image: Fraunhofer ISE)

Eco-Design Options Retained unrelated to the Solar Arrays

- **Additive Manufacturing:**
  - Reduction potential ~30% for spacecraft structure mass and reduction of waste (« buy to fly » ratio estimated at 1.15)
  - Shortening of procurement (limiting design iterations between PDR and CDR) and integration (reduction in the number of interfaces)
  - Increase in power consumption to be monitored

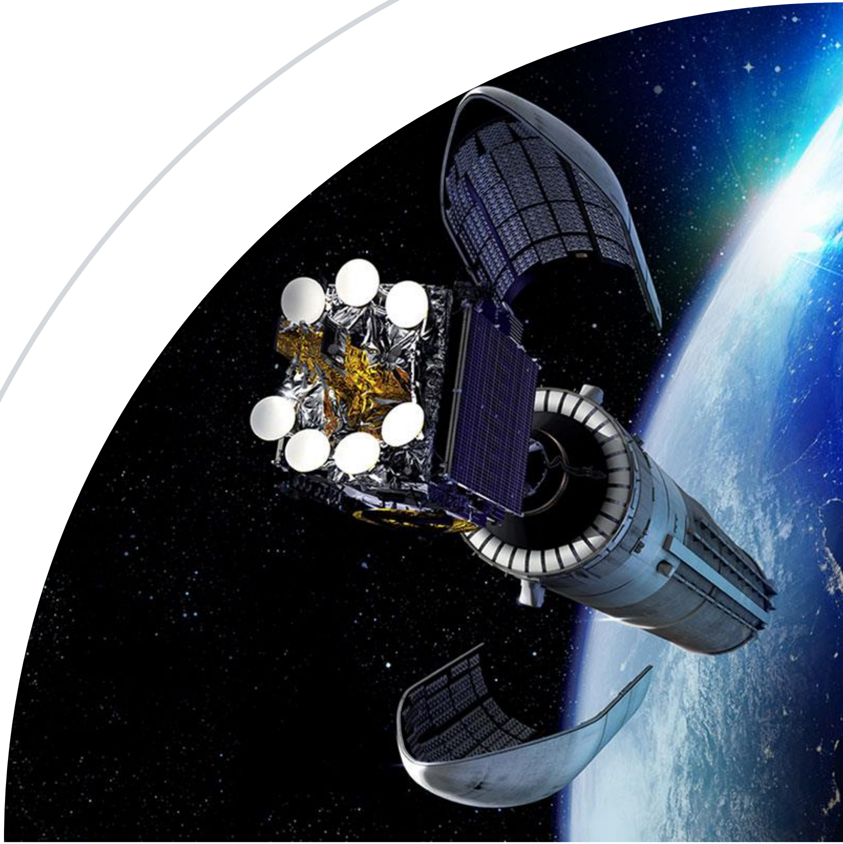


- **Green Propellant:**
  - Overall S/C mass reduction thanks to higher density impulse compared to hydrazine
  - Simplification of propellant loading operations
  - Addresses the REACH/Regulation dimension
- **Decentralized Avionics:**
  - Direct reduction on PTFE hotspot and Ozone depletion indicator thanks to overall reduction in cable length (up to 70% in some research projects)
  - Possible simplification/shortening of AIT operations to be explored in further phase
  - Possible burden shifting (due to addition of electronics) to be re-assessed in next project phase



(Micronode concept)

Conclusions and next steps



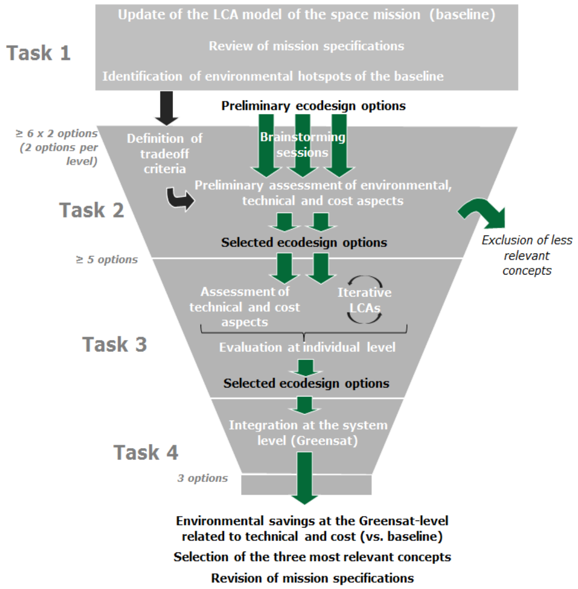
Conclusions

- The **LCA** conducted allowed to **identify** the main **hotspots of Sentinel 3 and appropriate mitigation measures for most of them**
- Out of the 5 options selected:
  - **2 concern the solar cells** and “Germanium hostpot”
  - the **remaining 3** options target impacts that are **related to the spacecraft**
- The technological **options selected** can target **significant reduction on 2 indicators** (ozone depletion and mineral depletion). **Reduction on GHG emissions** possible through optimized **facility management**

- **Development of a methodology** for identification and progressive selection of ecodesign options for a given space mission with:
  - Definition of main terms related to ecodesign and ideal requirements of a “good” ecodesign option
  - Implementation of an iterative approach
  - Combination between technical and environmental criteria

Next steps

- Next steps of the project are:
  - 2nd iteration on technical and environmental data of the 5 selected eco-design options
  - Selection of the 3 out of 5 most interesting options
  - **Combination** at system-level of the three options to design the **Final Greensat**
  - Elaboration of recommendations **for deployment of eco-design** in the European space sector



- First return of experience highlights the **need for**:
  - **Complementary section of ESA LCA guidelines on eco-design during early design studies**
  - A formal **definition of environmental hotspots**
  - A standard methodology or **single score adapted** to the space sector