Key learnings when applying an iterative LCA approach during the different development phases of a space mission

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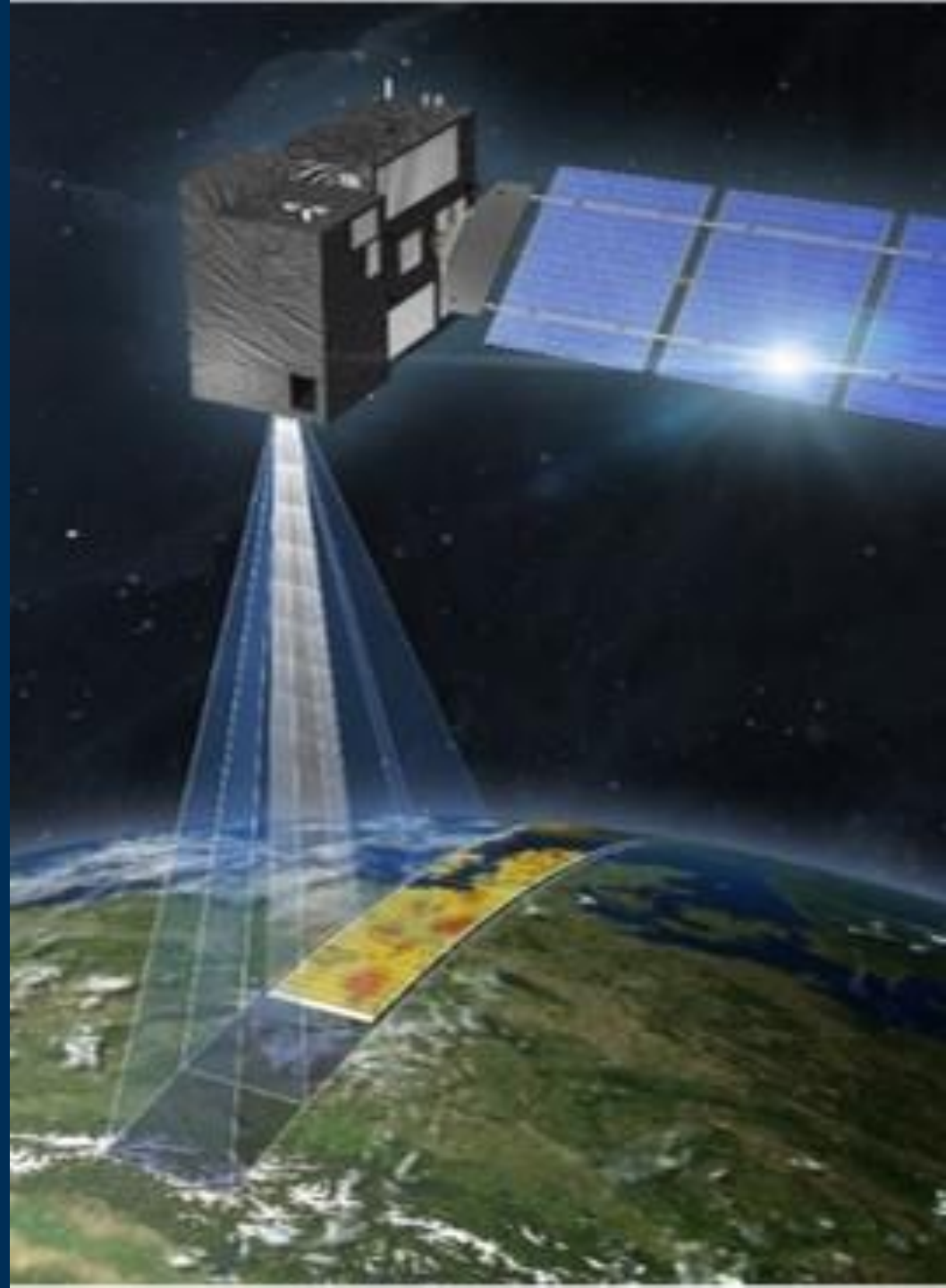
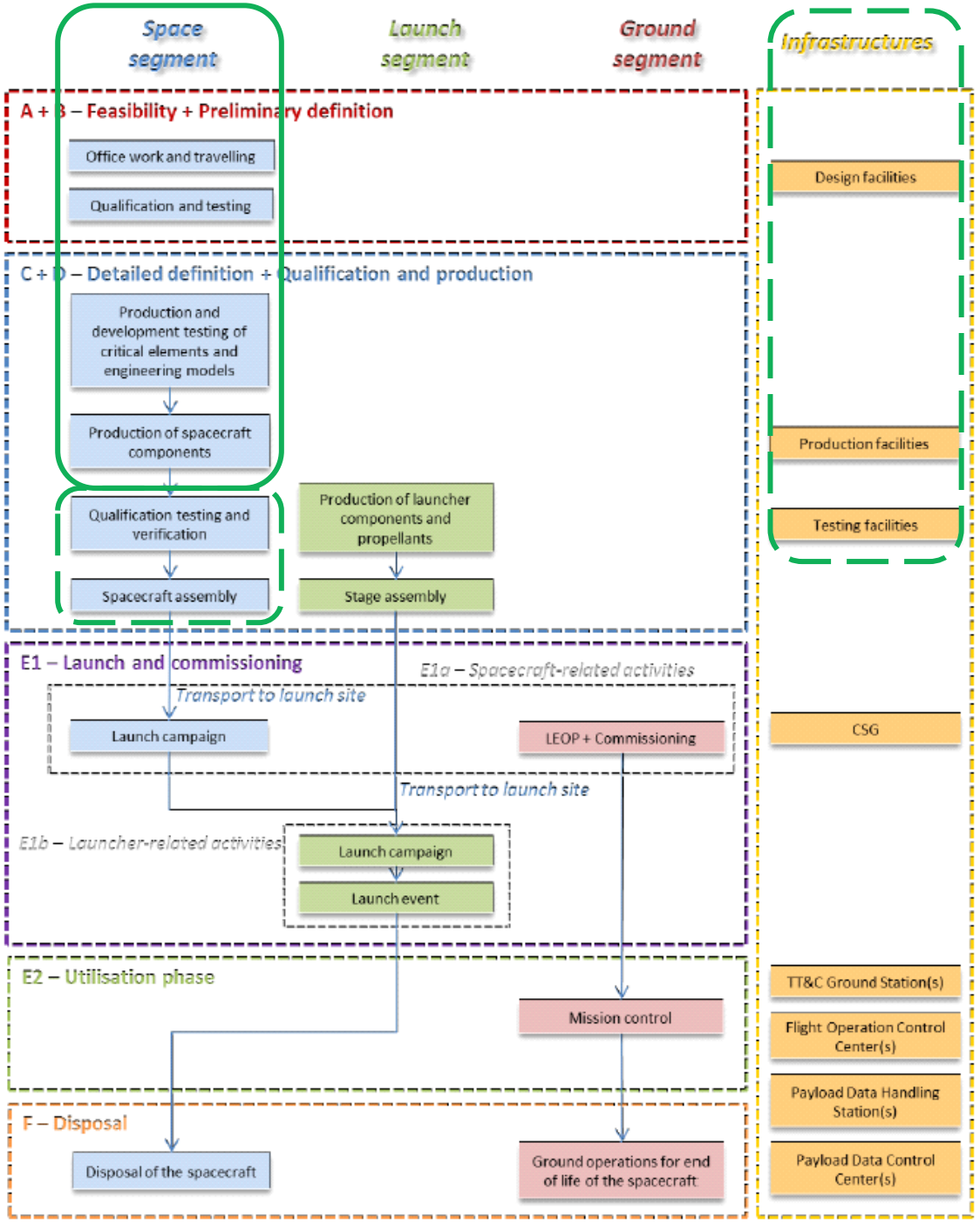


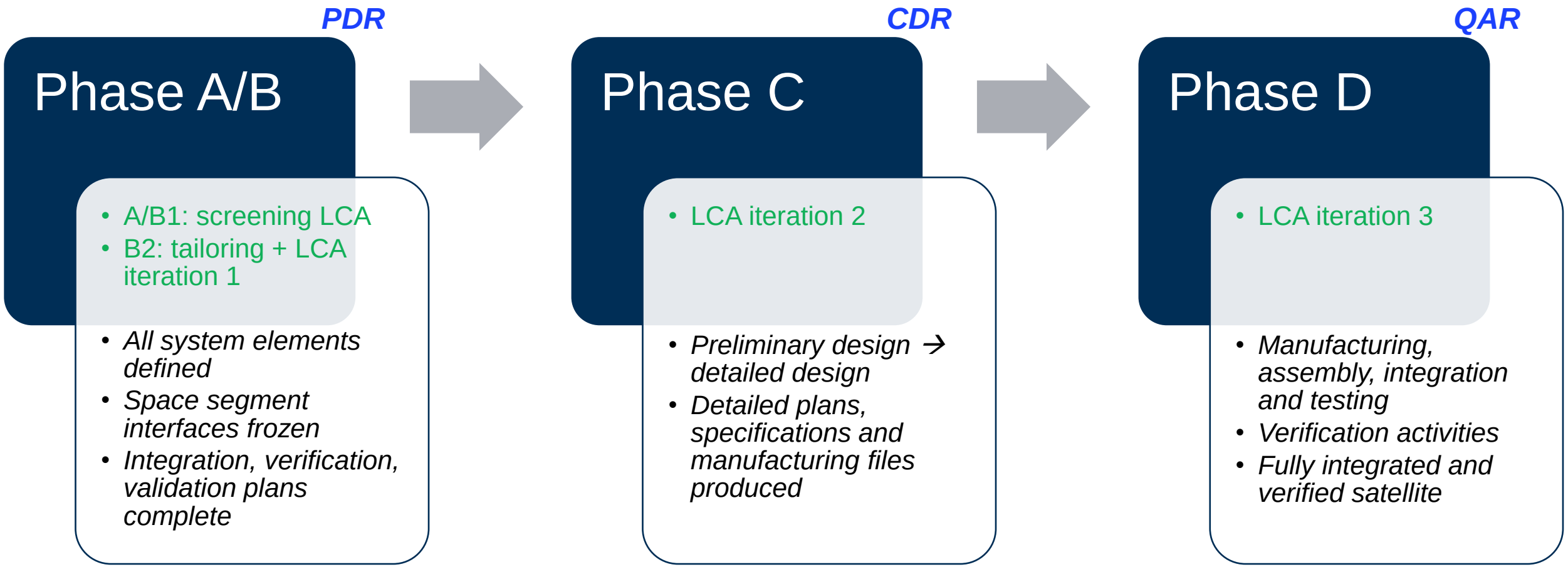
LCA following space mission development phases

- **Iterative approach** is recommended
- From **screening** to more **detailed** LCA
  - Goal and scope
  - Data collection
    - Specific data
    - Data gaps and proxies
  - Data Quality Rating and Requirements

- Illustrated by learnings from **CO2M mission**



LCA following space mission development phases



Goal and scope

- **Tailoring** of system boundaries in specific context is required

- **Functional unit**: “Definition, production, testing and spacecraft-related launch activities of the space segment of the CO2M mission”
  - Deviation from the ESA Space system LCA guidelines: **scope** is limited to phases B2, C, D and part of E1, excluding the launch and ground segment

- **Data Quality Requirements:**
  - ESA currently requires data quality to be determined according to the method based on the Environmental Footprint (EF) initiative
  - Alternative quality ranking approach might be more feasible to be applied in first iterations

Life Cycle Inventory

- A/B Office work
- Production and testing of platform components
- Production and testing of payload instruments
- Production of GSE
- AIT
  - Cleanroom work
  - Testing
- C/D Office and cleanroom work
- E1 Fueling and storage

Office and cleanroom work

Useful to update impact per manhour for each mission?

Phase A/B

Specific data:	*Source*
• # manhours suppliers	*LSI contracts*
• # manhours LSI	*contract*
• # manhours ESA	*???*

Estimate for ratio office/cleanroom

Proxy:

• Impact per office hour	*ESA database*
• Impact per cleanroom hour	*(based on previous projects), with country-specific E-mix*

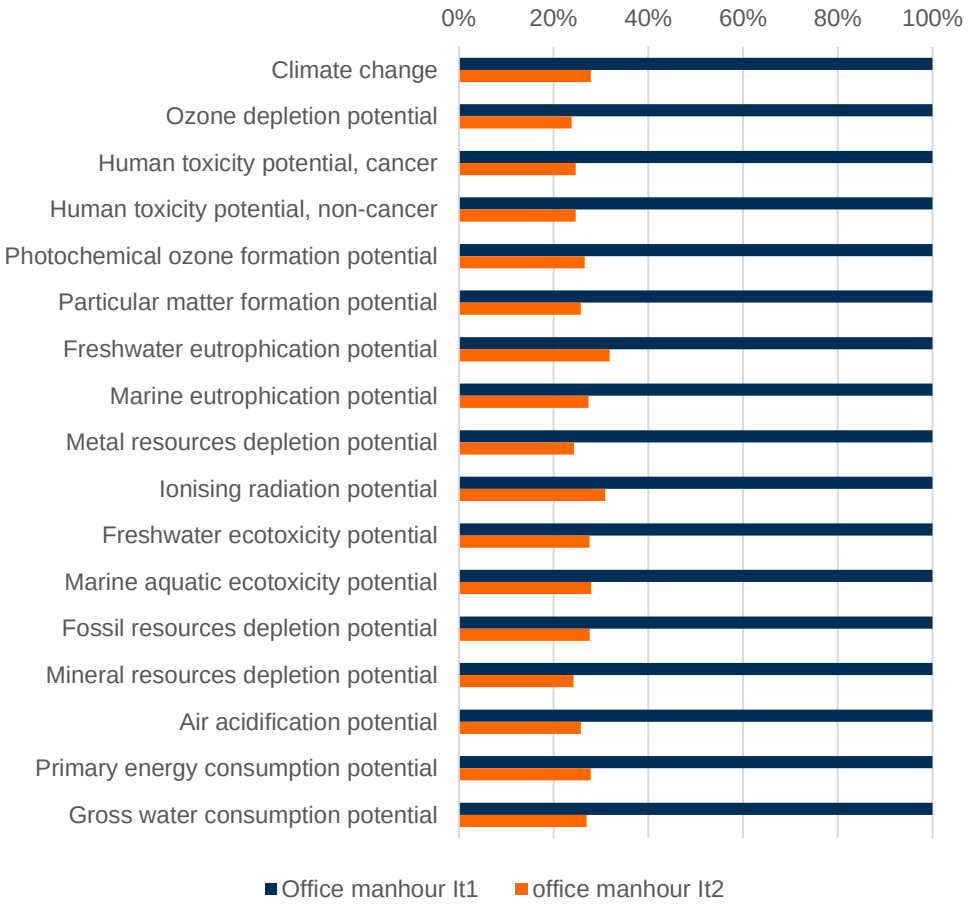
Phase C/D

Specific data:	*Source*
• # manhours suppliers	*questionnaire*
• # manhours LSI office • # manhours LSI cleanroom	*detailed estimate of departments*
• # manhours ESA	
• Impact per office hour	*LSI*
• Impact per cleanroom hour	*(measurements and sustainability reporting)*

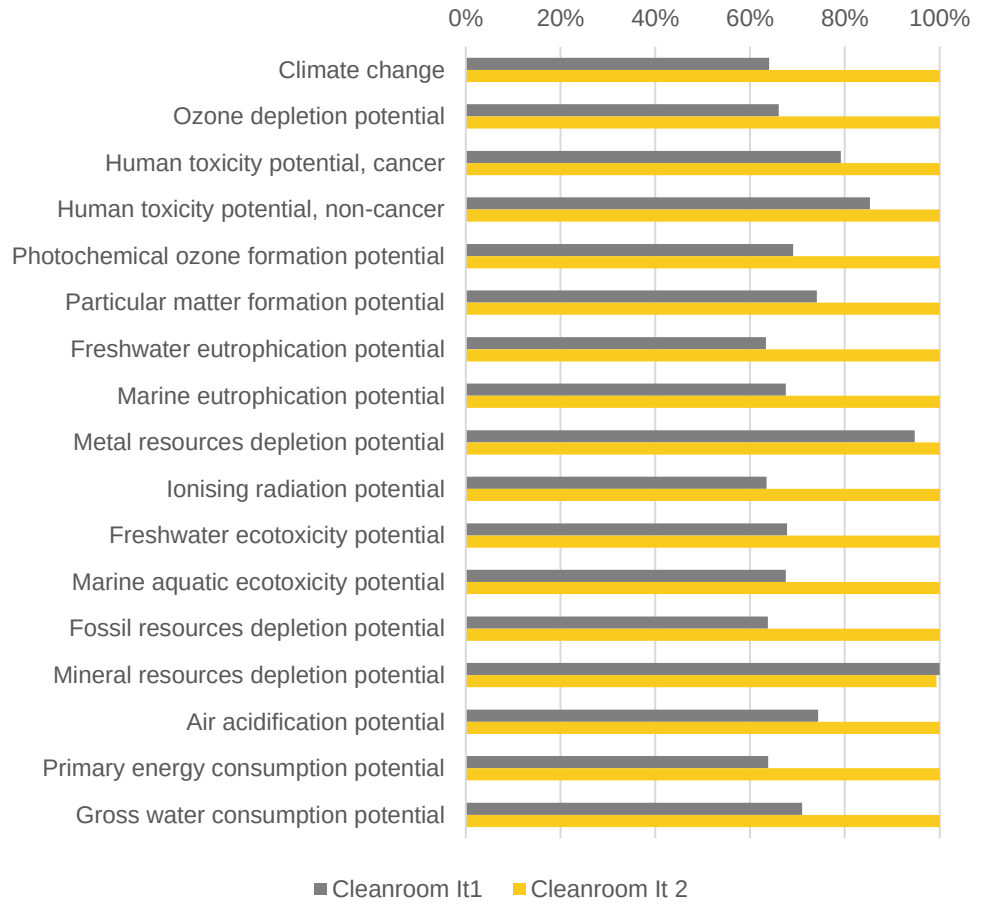
Proxy:

• Ratio office/cleanroom suppliers	*LSI data*
• Impact per office/cleanroom hour suppliers	*LSI data with country-specific E-mix*

Comparison of old proxy with LSI data for 1h office work*



1m² use of cleanroom*



*Including infrastructure

Production and testing of platform

- Include requirement for data collection in **suppliers' contract**?
  → In return: LCA profile?
- Update/elaborate of **ESA DB** with better background data?
- Point of attention:
  - Data for **equipment manufacturing** processes! (mechanical vs electronic products)
  - Data for **equipment testing**

Phase A/B

Specific data: *from DML, DPL, LSI questionnaire*

- Mass budget platform and subsystems (incl margins and test models)
- Mass ranges for equipment
- Qualitative info for manufacturing processes

Estimate for suppliers' location

Proxy: *from ESA database*

- Equipment model approximated with materials/components
- For some manufacturing processes

Data gap:

- Testing on equipment level

Phase C

Specific data: *from detailed DML, suppliers' questionnaire, internal LSI investigations (MAIT department), energy provider*

- More specific mass budget
- Suppliers' location
- Equipment test (incl. cleanroom) for one electronic unit (OBC)

Proxy:

- Improved background data for manufacturing of some equipment (e.g. electronic boards)
- Proxy for some manufacturing processes
- Equipment tests for E-units approximated by OBC data

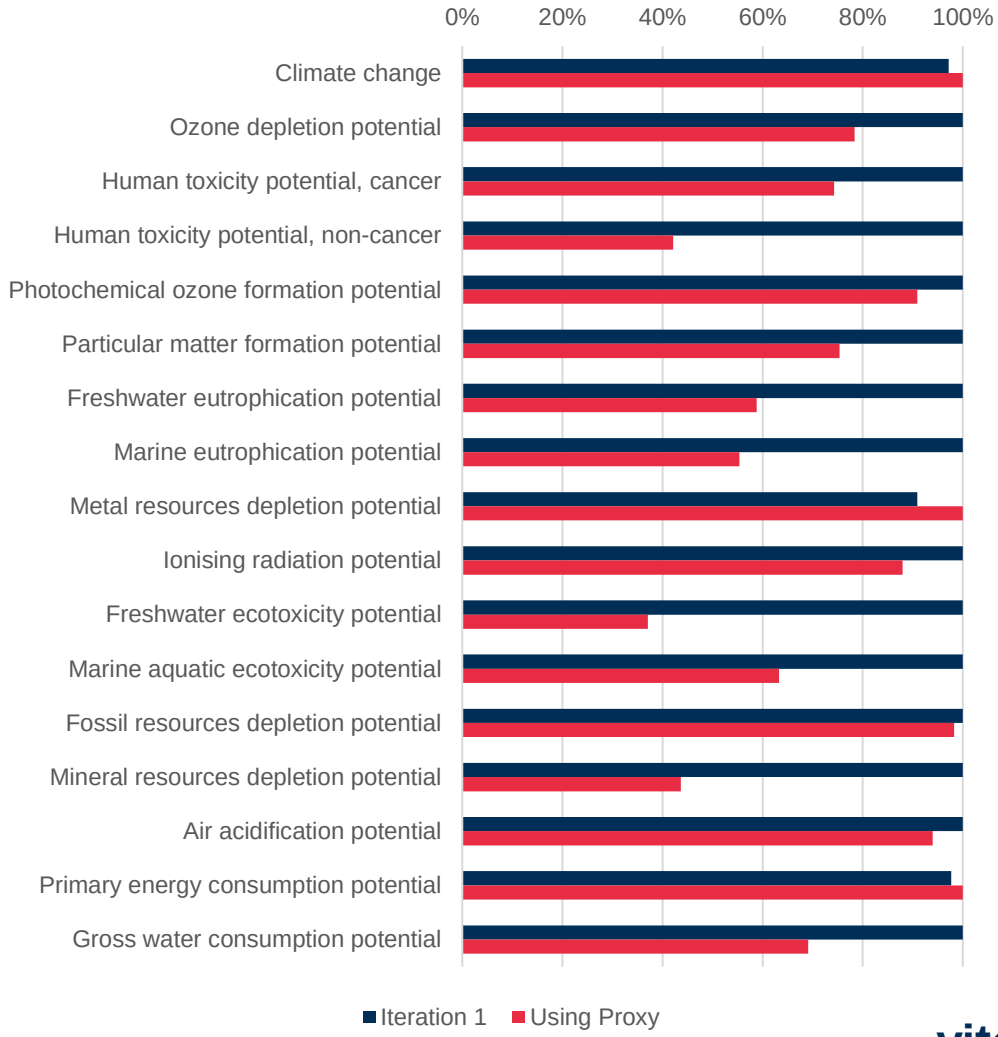
Data gap:

- Limited data for few manufacturing processes where most impact is assumed (E-use, waste) → challenge!

Phase D: If LCA iteration 2 would bring the need to investigate more in depth some hotspots → additional data collection

Production and testing of platform

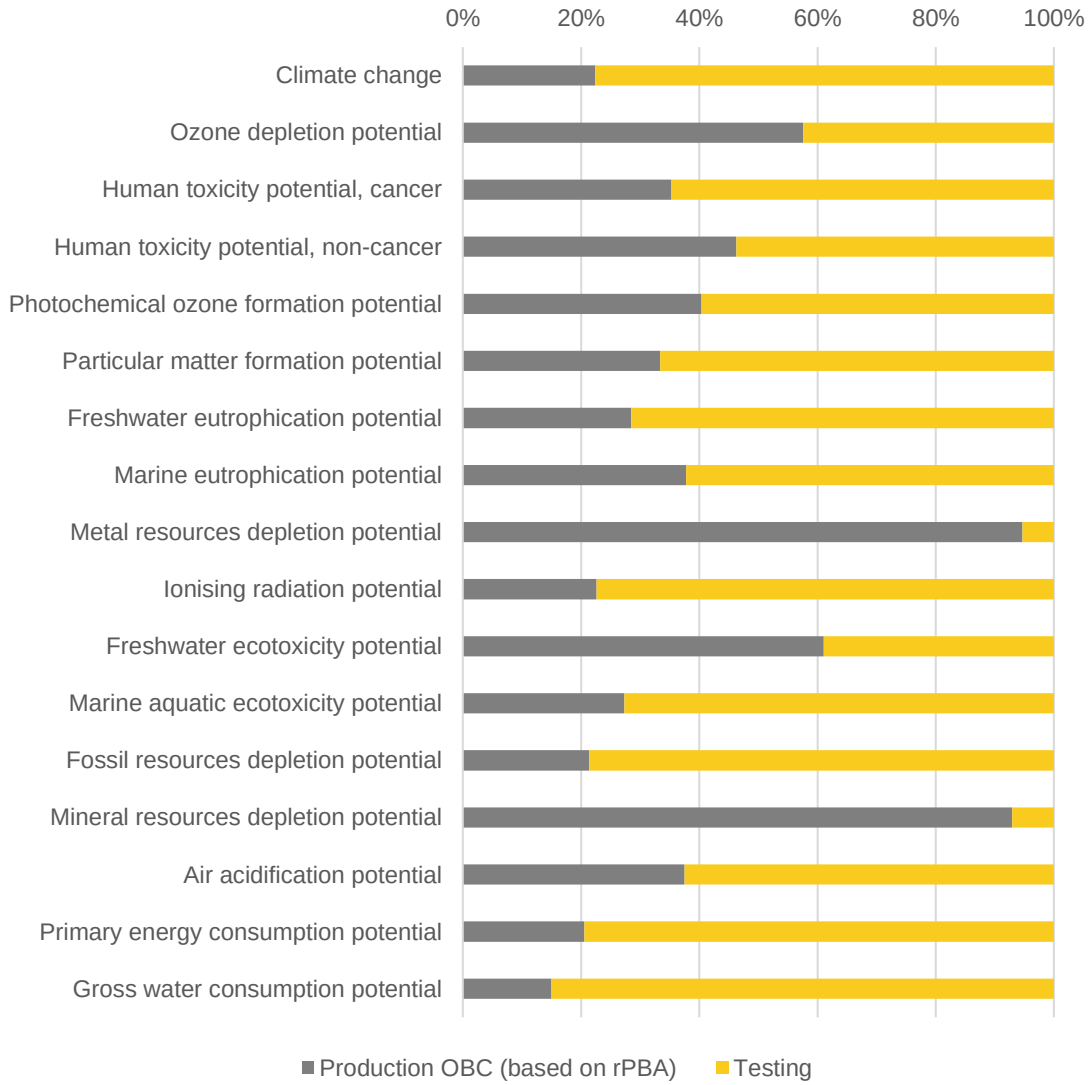
- Production of on-board computer, based on:
  - Material breakdown from DML (Iteration 1)
  - Using an elaborate electronic proxy (rPBA)



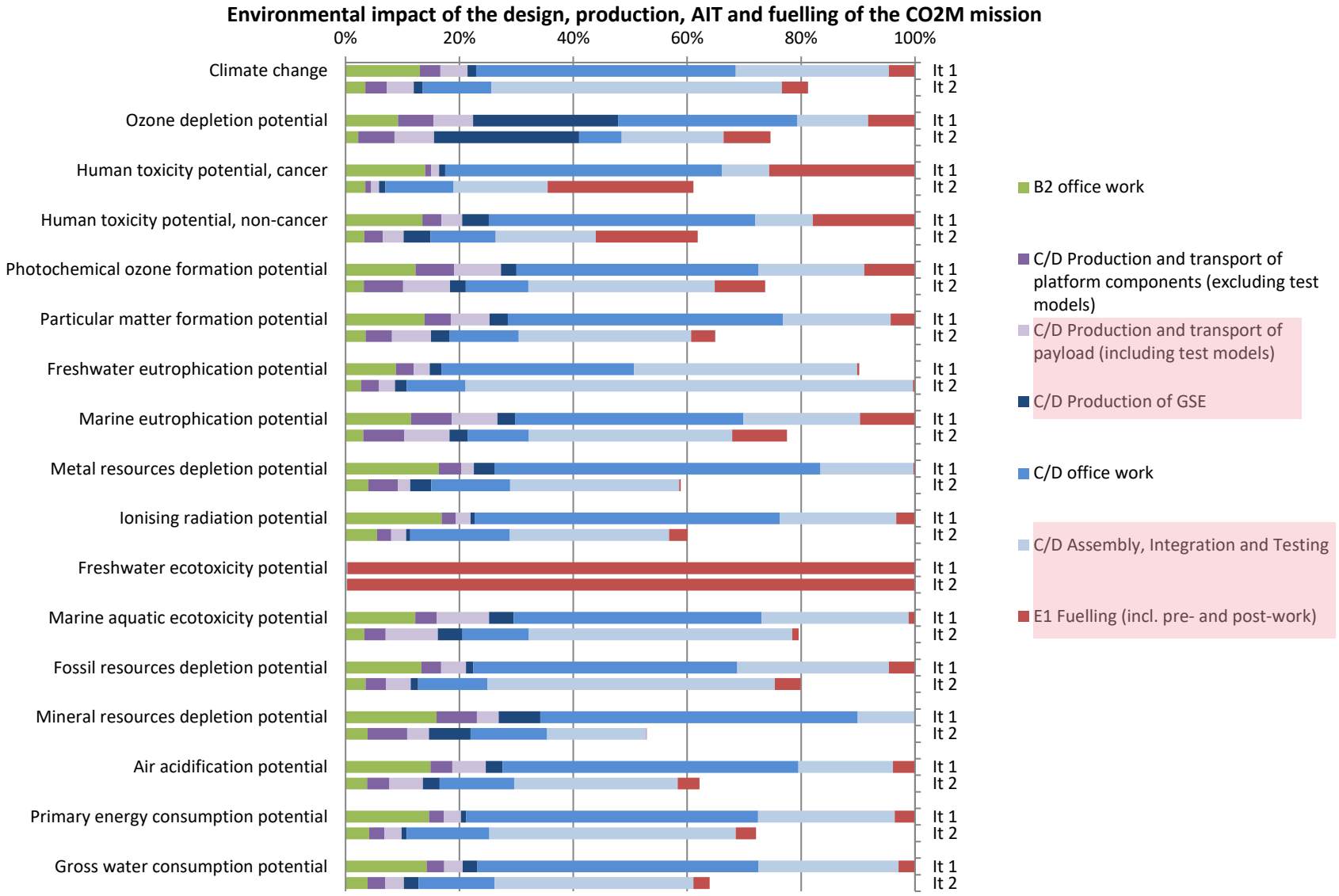
Production and testing of platform

- Production of on-board computer, based on:
  - Material breakdown from DML (Iteration 1)
  - Using an elaborate electronic proxy (rPBA)

- Testing of equipment has an important impact



Total effect on missions' impact



- Using specific data for office hours and cleanroom consumption
- Using elaborate proxy for all electronic equipment
- Testing of electronic equipment not included in this graph!

- Data for payload, GSE, AIT and E1 unchanged between iteration 1 and 2

➔ Overall impacts are decreased

➔ Office work has decreased drastically (was a hot-spot in It 1)

➔ Impact of GSE ≈ Satellite

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Production and testing of payload

Less heritage, so difficult to reuse information from other missions or from DB.

Phase A/B

Specific data: *No DML/DPL available*

- Rough mass budget for instruments including margins and test models

Proxy: *from ESA database*

- Instruments modelled with materials and components
- Proxy for some manufacturing processes

Data gaps:

- Manufacturing processes
- Testing

Phase C

Specific data: *from DML/DPL, questionnaire*

- More specific mass budget

Proxy: *from ESA database*

- Instruments modelled with materials and components

Data gaps:

- Manufacturing processes
- Testing

Production of GSE

- What happens with GSE at **end of phase D**? (reuse, storage, recycle, …)
- How to **allocate** over # missions?
- **Relevant!** → Impact of GSE is comparable to impact of satellite!

Phase A/B

No specific data available

Estimates

- for mass, based on type of GSE and previous studies

Assumption:

- If known: allocation over # missions
- For other: no reuse or recycling of GSE

Proxy:

- GSE modelled with materials available in ESA DB

Phase C

Specific data: *suppliers' documentation: technical descriptions, mass budgets/BoM, drawings*

- More specific mass budget

Proxy: *from ESA database*

- Equipment modelled with materials and components

Assembly, integration and testing

- **AIT test** data (vibration, TVAC, acoustic) are available in ESA DB (per unit of time)
- What about **unit/subsystem and platform tests**? → useful to develop comparable records

Phase A/B

Specific data: *LSI*

- Occupation of cleanroom (time, area)
- Transport (if relevant)

Proxy: *ESA database*

- Energy use of cleanroom
- # manhours (see before)

Data gaps:

- Energy and auxiliary consumption of tests during test campaign

Phase C

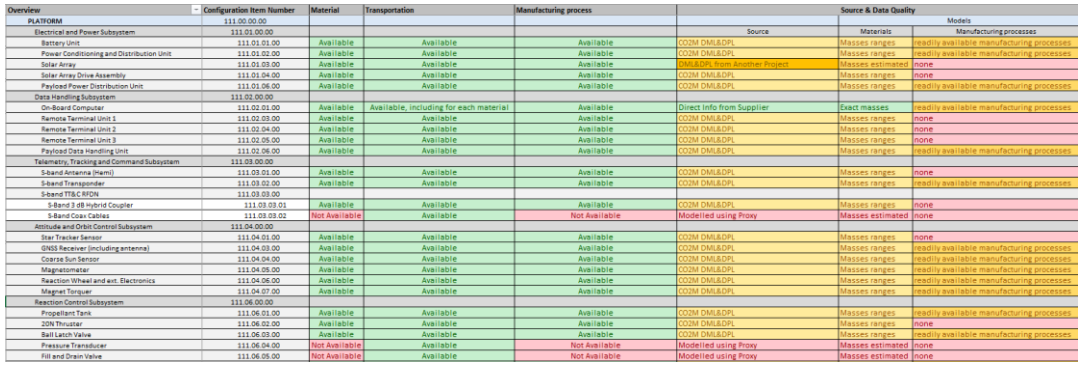
Specific data: *LSI: MAIT plans and internal investigation; energy provider; ESA*

- Energy and auxiliary use of tests on unit/subsystem, platform and satellite level
- Duration (preparation and runs) of tests
- Energy use of cleanroom (specific for LSI resp. ESA)
- # manhours and impact of office resp. cleanroom hour

Data Quality Rating and Requirements

- **Relevance** of DQR during iterative approach
  - To steer data collection and focus on where it matters most
  - e.g. for CO2M: manhours, electronic units, manufacturing processes (?), AIT

- Balance **effort versus gain**
  - Iteration 1:
    - No DQR according to ‘pedigree matrix’
    - Color coding on data availability matrix to identify data gaps and weak data
  - Iteration 2 and 3:
    - DQR according to ‘pedigree matrix’
    - Minimum requirements set by ESA



Overview	Configuration Item Number	Material	Transportation	Manufacturing process		Source & Data Quality	
						Models	
					Source	Materials	Manufacturing processes
PLATFORM	111.00.00.00						
Electrical and Power Subsystem	111.01.00.00						
Battery Unit	111.01.01.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	readily available manufacturing processes
Power Conditioning and Distribution Unit	111.01.02.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	readily available manufacturing processes
Solar Array	111.01.03.00	Available	Available	Available	DML&DPL from Another Project	Masses estimated	none
Solar Array Drive Assembly	111.01.04.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	none
Payload Power Distribution Unit	111.01.06.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	readily available manufacturing processes
Data Handling Subsystem	111.02.00.00						
On-Board Computer	111.02.01.00	Available	Available, including for each material	Available	Direct info from Supplier	Exact masses	readily available manufacturing processes
Remote Terminal Unit 1	111.02.03.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	none
Remote Terminal Unit 2	111.02.04.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	none
Remote Terminal Unit 3	111.02.05.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	none
Payload Data Handling Unit	111.02.06.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	readily available manufacturing processes
Telemetry, Tracking and Command Subsystem	111.03.00.00						
S-band Antenna (Horn)	111.03.01.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	none
S-band Transponder	111.03.02.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	readily available manufacturing processes
S-band TT&C RFDN	111.03.03.00						
S-Band 3 dB Hybrid Coupler	111.03.03.01	Available	Available	Available	CO2M DML&DPL	Masses ranges	none
S-Band Coax Cables	111.03.03.02	Not Available	Available	Not Available	Modelled using Proxy	Masses estimated	none
Attitude and Orbit Control Subsystem	111.04.00.00						
Star Tracker Sensor	111.04.01.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	none
GNSS Receiver (including antenna)	111.04.03.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	readily available manufacturing processes
Coarse Sun Sensor	111.04.04.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	readily available manufacturing processes
Magnetometer	111.04.05.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	readily available manufacturing processes
Reaction Wheel and ext. Electronics	111.04.06.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	readily available manufacturing processes
Magnet Torquer	111.04.07.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	readily available manufacturing processes
Reaction Control Subsystem	111.06.00.00						
Propellant Tank	111.06.01.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	readily available manufacturing processes
20N Thruster	111.06.02.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	none
Ball Latch Valve	111.06.03.00	Available	Available	Available	CO2M DML&DPL	Masses ranges	readily available manufacturing processes
Pressure Transducer	111.06.04.00	Not Available	Available	Not Available	Modelled using Proxy	Masses estimated	none
Fill and Drain Valve	111.06.05.00	Not Available	Available	Not Available	Modelled using Proxy	Masses estimated	none

How to focus data collection and modelling improvement?

Based on:

- **Hot spots** identified in previous iteration
  - !!! Risk: this depends on how good or bad proxies are
  - E.g. manhour impacts

- **DQR** results → missing or weak data (completeness)
  - E.g. electronics

- Complemented with **expert judgement**

→ **Added value of questionnaire?**

- Can we start in 1st iteration with available DML and DPL info?
- When is best time to send this questionnaire, and which focus?
- How to overcome the limited data availability of equipment manufacturing processes?
  - Only ask for data about energy use, materials use and waste?
  - To think about: ask for data on company-level (from reporting) and define allocation rules for allocating these to product level

→ **Which data become available during space mission development phases?**

Lessons learned – Guidance & support of ESA

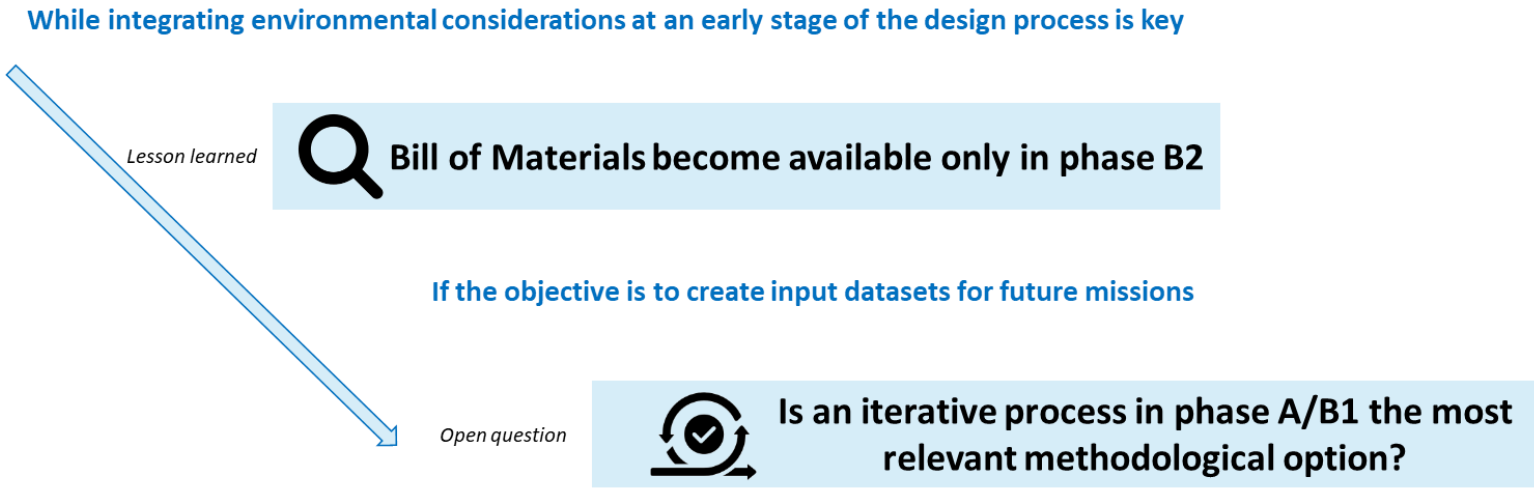
- LCA studies in space context are supported by guidance documents and database developed by ESA → Need to continuously update and elaborate

- Performing a LCA is a valuable assessment to understand the environmental hotspots of the satellite development and manufacturing.

- Keep in mind the **objective of the LCA-work** during development phases
  - For ecodesign
  - For ‘green claims’
  - For elaborating ESA database
  - …

Lessons learned – Guidance & support of ESA

- **ESA space system LCA guidelines (ESA LCA Handbook):**
  - **Tailor/distinguish** guidelines in ESA Handbook specific for G&S and LCI to
    - Development phase of space mission (A, B1/2, C/D)
    - System level, subsystem level, component level, …
    - Objective of the LCA
  - Clear guidance required for **DQR** (requirements and method) distinguishing space mission development phases
  - How to deal with **missing data** → proxies?
  - **Data collection**: how to set focus and priorities, how and when to involve suppliers?



Lessons learned – Guidance & support of ESA

- **LCA Data questionnaire :**
  - Harmonization of questionnaire is important
  - Helpful for prime, but still data and time intensive for suppliers → **prioritization** is needed
  - Link with DML and DPL
  - When is best ‘time’ to use questionnaire → phase B2 or C?

- **ESA Database:**
  - Supports for some equipment, but not for all
  - Lacks (default) data for tests on different levels (equipment, unit/subsystem, platform, satellite), manhours, manufacturing processes, infrastructure

    → this is exactly type of (background) data which is difficult/impossible to collect
  - Should be considered as a proxy that matches DQR if no detailed supplier data are available

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