# OUTCOMES OF LIFE CYCLE ASSESSMENT, 2ND ITERATION, APPLIED TO THE SPACE SEGMENT OF CO2M MISSION

ANDREA CALIO‘ / STEFANIE DE SMET / AN VERCALSTEREN

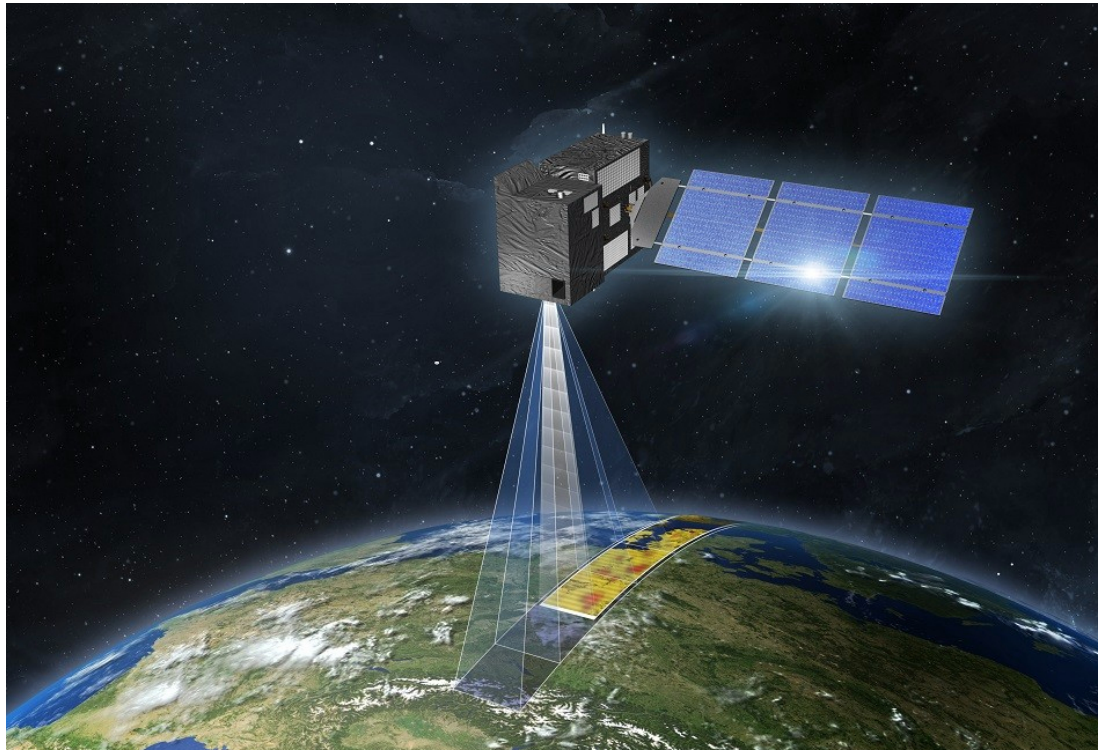
09/10/2024

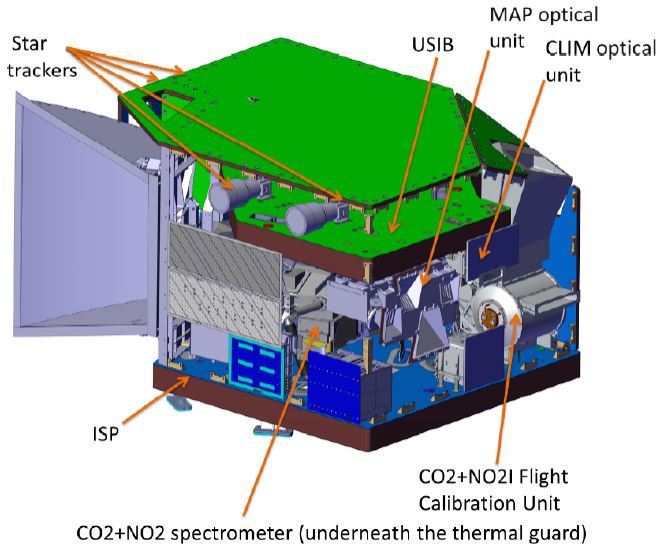
# CO2M – LCA

INTRODUCTION

## CO2M MISSION:

***Providing space-based Anthropogenic CO2 and auxiliary NO2, cloud and aerosol distribution observations***

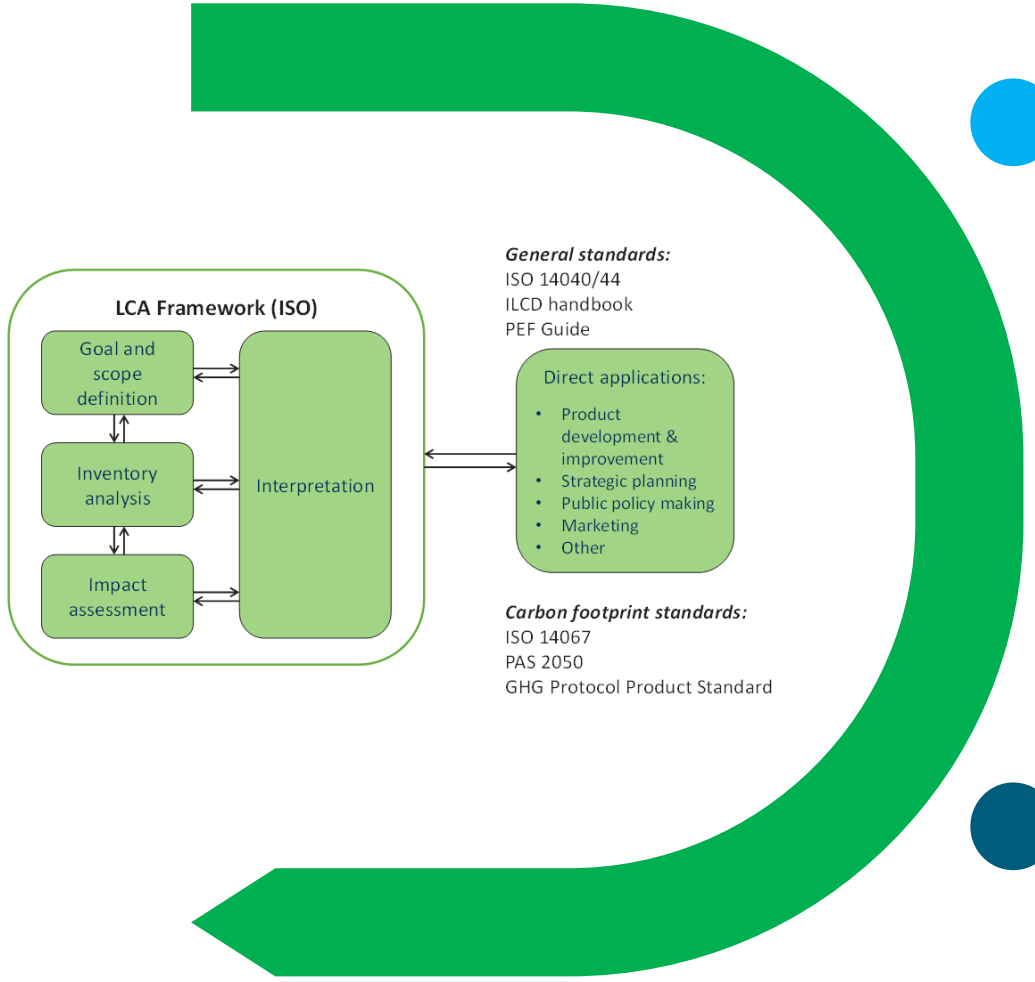





| |
|---|
| ***Mission*** |
| SSO, Earth Observation |
| ***Flight Models*** |
| PFM + FM2 (FM3 Optional) |
| ***TOTAL MASS AT LAUNCH*** |
| 1984,1 kg (including launch adapter) |
| ***MASS IN TARGET ORBIT:*** |
| 1678 kg |
| ***LIFETIME*** |
| 7.5 + 5 years |
| ***PAYLOAD*** |
| Combined CO2 and NO2 Instrument |
| Multi Angle Polarimeter (MAP) |
| Cloud Imager (CLIM) |

# CO2M – LCA

## LCA ITERATIONS




**1st Iteration, PDR (March 2022): use of preliminary DML, DPL, PDR mass budget, internal manpower & travels.**

**2nd Iteration, CDR (March 2024): use of data collection questionnaire, CDR-quality DML/DPL & Mass budget, incl. GSE data, primary energy data, internal & external manpower & travel, cleanroom occupation…**

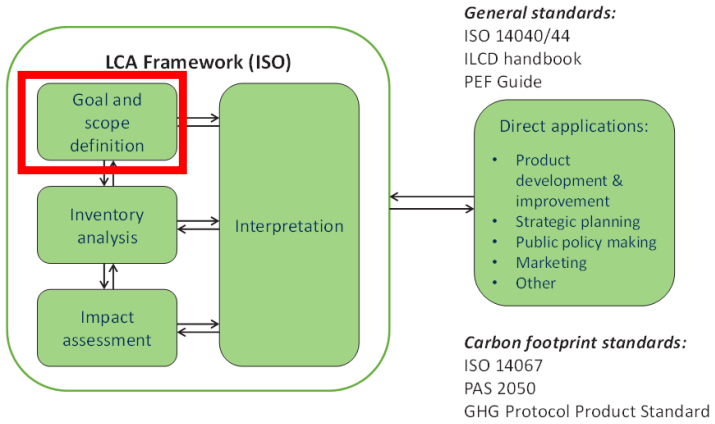
**3rd Iteration, QAR (Dec 2026): LCA improvement in specific areas: high waste (high. BTF ratio) & high energy consumption processes**

# CO2M – LCA

## GOAL AND SCOPE DEFINITION

### GOAL

- An LCA on the CO2M mission will be performed
- Reason of the LCA: identify environmental impacts of the mission, identify the hotspots and identify possible improvements to be flown down to future space programs
- The LCA is used internally and distributed to ESA. ESA will use the data collected in a confidential manner.
- No Public Disclosure, no auditor needed



# CO2M – LCA

## GOAL AND SCOPE DEFINITION

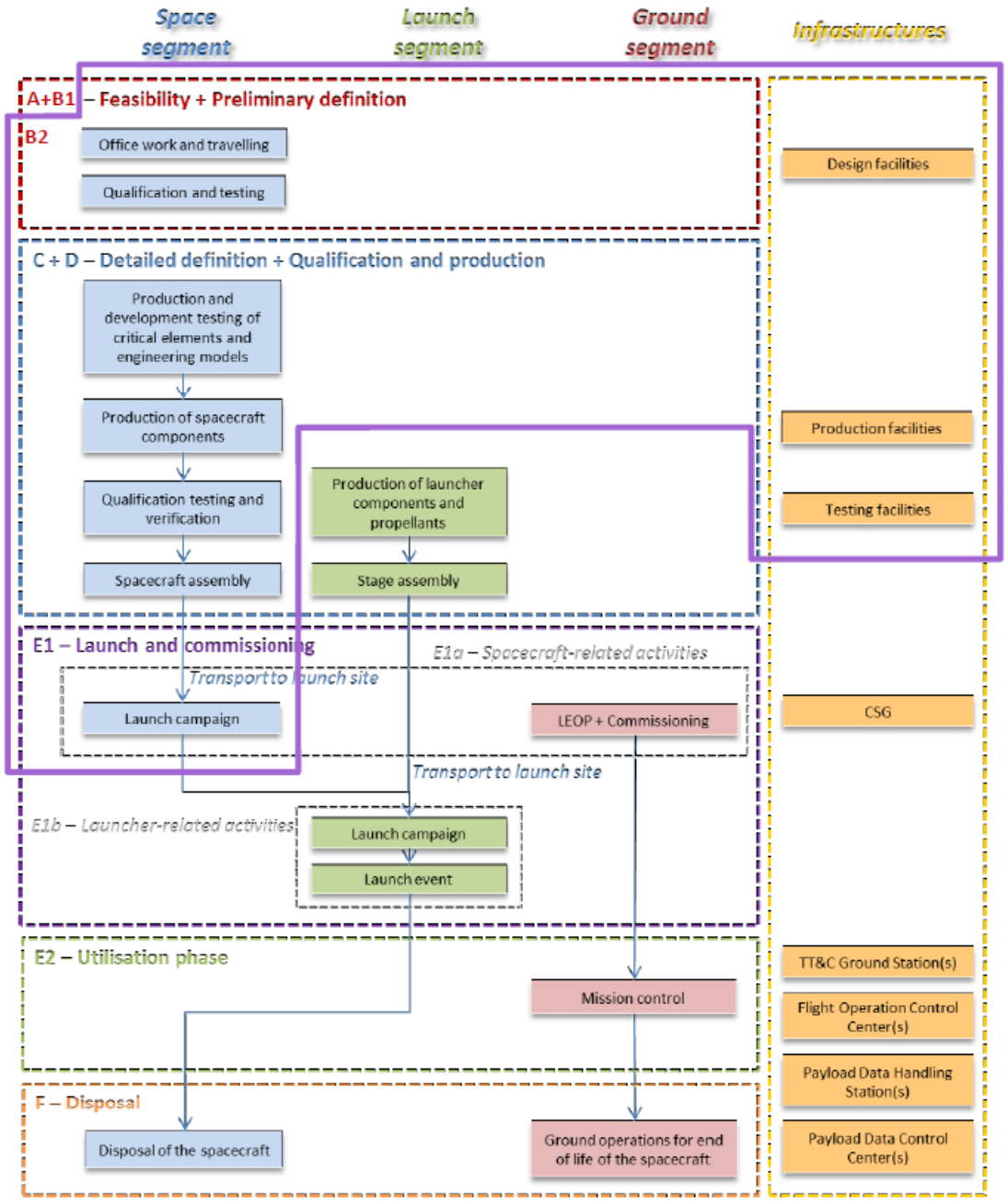
**FUNCTIONAL UNIT:**

Definition, production, testing and spacecraft-related launch activities of the space segment of the CO2M mission

*(Reference Flow is equivalent to FU)*

**SYSTEM BOUNDARIES & LIFE CYCLE STAGES:**

- ***Space segment***: phase B2 to E1, up to fuelling activities at CSG
- ***Launch Segment*** (Vega-C + CSG) is **fully excluded**
- ***Ground Segment*** (Operations) is **fully excluded**
- *Feasibility Study, Utilization and Disposal* phases are excluded



# CO2M – LCA

## GOAL AND SCOPE DEFINITION

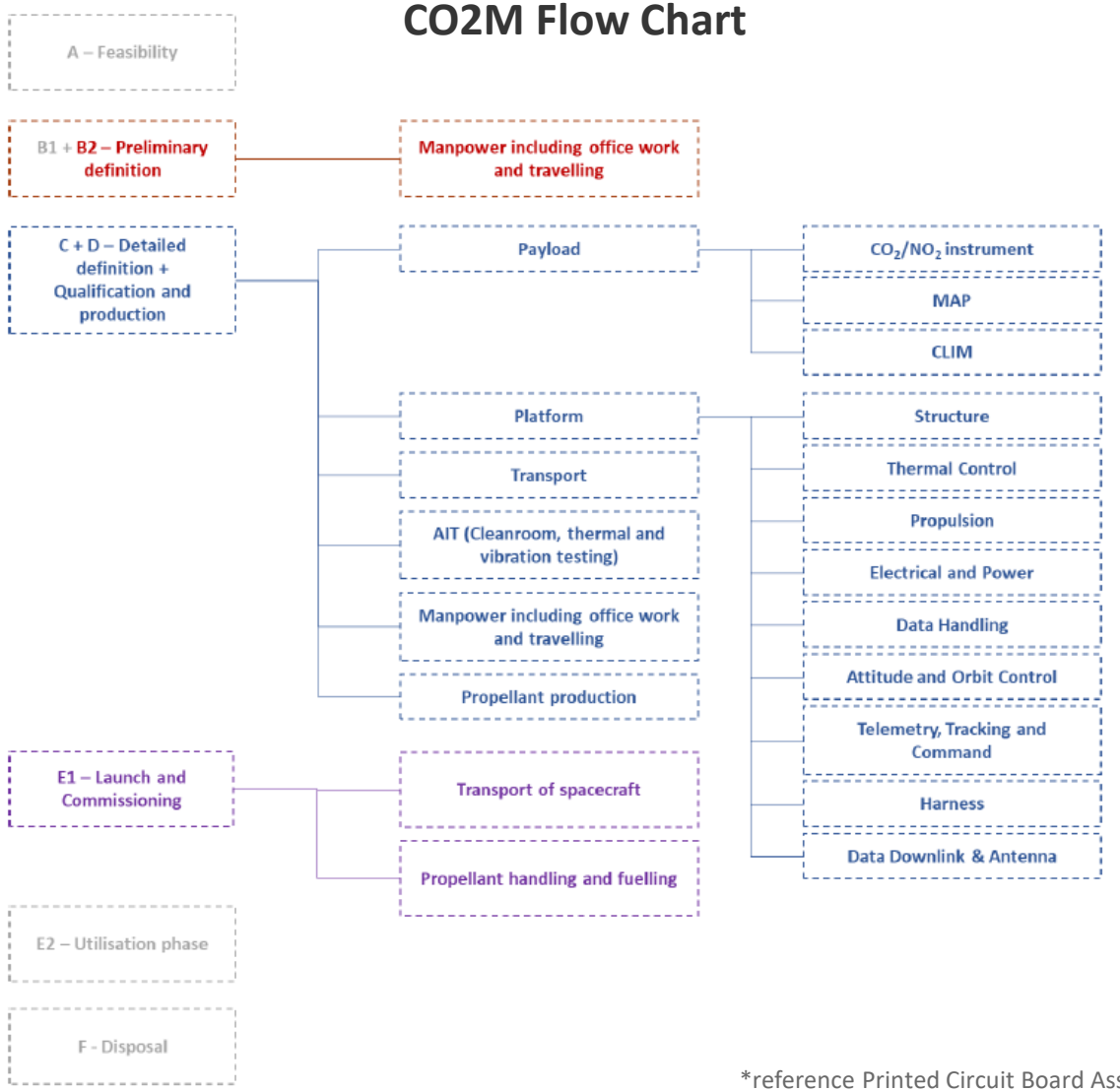
## CUT-OFF CRITERIA:

- material/sub-assembly inputs constituting all together less than 5% of the total mass of the component, subsystem or system are excluded from the scope of the assessment.
- Modelled impacts need to account for at least 90% of the overall environmental impact in each of the environmental impact categories considered.
- Only instrument units for which a mass and (main) material composition was given, have been modelled. For instrument units for which the (main) material composition was not available, cut-off was applied.

## rPBA MODEL (for Electronic Units)

- Since not enough data was possible to collect for some Electronic Units (i.e. manufacturing processes, detailed EEE composition), the rPBA* model has been used as elaborate e-units proxy
- rPBA divided into a PWB plate, a group of EEE components, the manufacturing processes and the testing and inspection processes.
- PWB plate scaled to the e-box mass reported by the supplier
- EEE components and manufacturing processes scaled to PWB size
- Testing and inspection tests applied without scaling

### CO2M Flow Chart



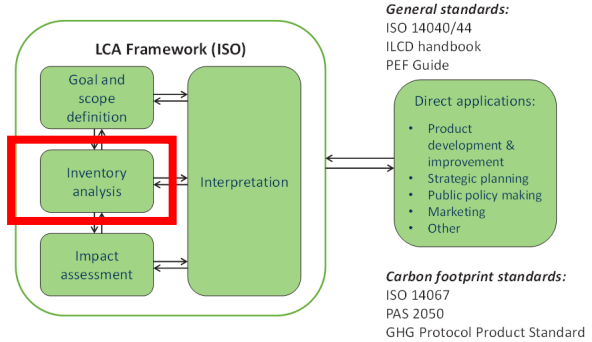

*reference Printed Circuit Board Assembly

# CO2M – LCA

## LIFE CYCLE INVENTORY ANALYSIS (LCI)

| Equipment | | Mass | Margins | Mass with margins | Materials used | Mass balance/Materials breakdown |
|---|---|---|---|---|---|---|
| Type | Configuration Item Nur | (kg) | (%) | (kg) | Type | (%) |
| Propellant Tank | 111.06.01.00 | 15.5 | 5 | 16.2 | | |
| | | A2 | | | Aluminium grade 99.5 | 0% component replaced |
| | | A4, A3, A2 | | 13.75 | Titanium Ti6Al 4V | |
| | | A2 | | | Titanium Ti3Al 2.5V | |
| | | A2 | | | ARALDITE 2 Part adhesive | 0.049382716 |
| | | A2 | | 0.0001 | Dow Corning Molykote | |
| | | A2 | | | 3M Scotch Ad-hesive tape | |
| | | M4 | | 2.4 | EPDM based Rubber | 14.81481481 |
| | | M4 | | | EPDM based Diaphragm | |

materials




transportation

| Supplier | Supplier | Transport method(s) | | Distance |
|---|---|---|---|---|
| Name (country code) | Location (city) | Type (truck, airplane, boat...) | Loading factor (%) | (km) |
| | | | | |
| MTA | MBDA (and back) | truck | 100 | 96.4 |
| MTA | OSE | truck | 100 | 6892 |

processes

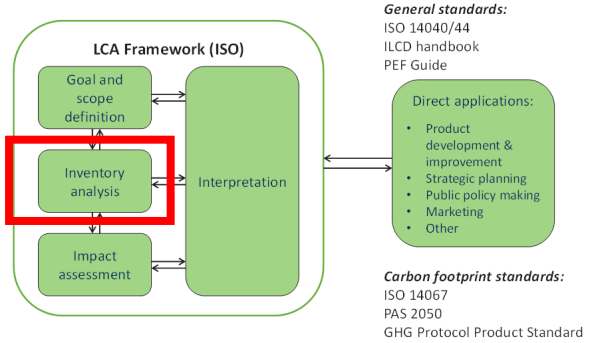
| Manufacturing processes | Input materials | | Auxiliary materials | | Consumed energy | |
|---|---|---|---|---|---|---|
| Type | Type | Quantity (kg) | Type | Quantity (kg) | Type (electricity, gas, oil...) | Quantity (kWh) |
| | | | | | | |
| Adhesive Bonding | ARALDITE 2 Part adhesive | 0.02 | wood & paper cup | | for wheighing of material | 0.02 |
| Cleaning and Descaling of Titanium Alloys | | | | | | |
| Contamination Control Specification – IPA | | | | | | |
| Contamination Control Specification – sealing | | | | | | |
| Contamination Control Specification – Cleanliness of fluids and equipment | | | | | | |
| TIG Welding fracture critical 6Al4V titanium alloy hardware | filler wire | | Tape | | electricity | |
| | | | IPA | | Argon Gas [l] | 8400 |
| TIG Welding (including quali-fied repairs) | filler wire | 0.1 | clean room Foil | | electricity | |
| Pre-penetrant etch of titanium alloys | | | | | | |
| Etching of tita-nium alloys | | | | | | |
| Machining and cutting of Titanium Hemisphere | Titanium | | IPA | | electricity | |
| Machining and cutting of Center section | Titanium | | IPA | 0.5 | electricity | 5109 |
| Machining and cutting of Clamp Ring | Titanium | 10 | IPA | | electricity | |
| Ti 6Al-4V Hemisphere forging | Titanium | | cleaning agent | unknown | electricity/Gas | 5777/25714 |
| Ti 6Al-4V Centre section forging | Titanium | 130 | cleaning agent | unknown | electricity/Gas | |
| Clamp ring forging | Titanium | | cleaning agent | unknown | electricity/Gas | 3389/15086 |

# CO2M – LCA

## LIFE CYCLE INVENTORY ANALYSIS (LCI)

### IN-HOUSE CONSUMPTION

| Electrical Energy Consumption [kWh(el)] | Phase B2 | Phase C | Phase D | E1 | Total | Average Yearly Consumption [kWh(el)/year] |
|---|---|---|---|---|---|---|
| Offices | 60266 | | 119106 | | 405775 | 75143 |
| Cleanroom | | | 910845.00 | | 3074102 | |
| Total | | **1764762** | | **260561** | | |
| **Water Consumption [l]** | **Phase B2** | **Phase C** | **Phase D** | **E1** | **Total** | **Average Yearly Consumption [l/year]** |
| Office Staff | | 1338750 | | | | |
| Cleanroom Staff | | | 220500 | | 260694 | **48277** |
| Total | **381024** | | | **62370** | | |
| **Thermal Energy Consumption [kWh(th)]** | **Phase B2** | **Phase C** | **Phase D** | **E1** | **Total** | **Average Yearly Consumption [kWh(th)/year]** |
| Offices | **48958** | **175738** | | **8187** | | |
| Cleanroom | | | | | **181423** | |
| Total | | **267121** | **150514** | | | **94642** |




OHB cleanroom and office consumption used as baseline to calculate supplier's energy consumption

### SUPPLIERS OFFICE/CLEANROOM ENERGY CONSUMPTION

| Overview | B2 Office Hours | CD PFM Office Hours | D FM2 Office Hours | B2 Cleanroom Hours | CD PFM Cleanroom Hours | D FM2 Cleanroom Hours | Total Office hours - Space Segment | Total Cleanroom hours - Space Segment | Cleanroom Time [days] | Cleanroom time [Years] | cleanroom occupied area (estimated) [m2] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **PLATFORM** | | | | | | | | | | | |
| Electrical and Power Subsystem | | | | | | | - | - | 0 | | |
| Battery Unit | | 652.77 | | 0.00 | | | 1977 | 1679 | 0 | 0.000 | 50 |
| Power Conditioning and Distribution Unit | 7107.5 | | | | 7587 | | | 17606 | 241 | | 50 |
| Solar Array | | | 3625.5 | | | | | | | 0.419 | |
| Solar Array Drive Assembly | | | | 0.00 | | 0.00 | see questionnaire | see questionnaire | | | |
| *not applicable* | | | | | | | - | - | *0* | | |
| Payload Power Distribution Unit | 4209 | | | | 4205 | | | 10683.5 | | 0.660 | 50 |
| Data Handling Subsystem | | | | | | | - | - | 0 | | |
| On-Board Computer | | | | 1000 | | | see questionnaire | see questionnaire | | 0.315 | |
| *not applicable* | | | | | | | - | - | *0* | | |
| Remote Terminal Unit 1 | | 4287.08 | | | 0.00 | | | | | 0.882 | 50 |
| Remote Terminal Unit 2 | | | | | | | included in RTU1 | included in RTU1 | manufactured in parallel to RTU1 | | 50 |
| Remote Terminal Unit 3 | | | | | | | included in RTU1 | included in RTU1 | manufactured in parallel to RTU1 | | |
| Payload Data Handling Unit | | | 1558.5 | 13315.5 | | | | | | | |

# CO2M – LCA

## LIFE CYCLE INVENTORY ANALYSIS (LCI)

### SUPPLIERS TESTS MATRIX

| Overview | Configuration Item Number | Supplier location (for energy mix) | Modeling | TVAC (includes always thermal cycling) | Thermal cycling | Vibration Test | Bake-out | Doc Ref / comments |
|---|---|---|---|---|---|---|---|---|
| **PLATFORM** | 111.00.00.00 | | | see "AIT - Platform & Spacecraft" | see "AIT - Platform & Spacecraft" | see "AIT - Platform & Spacecraft" | see "AIT - Platform & Spacecraft" | NA |
| Electrical and Power Subsystem | 111.01.00.00 | | - | | - | - | - | - |
| Battery Unit | 111.01.01.00 | | - | - | - | - | - | - |
| Battery Module | 111.01.01.01 | FR | rPBA | X | | X | | Batt test plan docs |
| Junction Box | 111.01.01.02 | FR | Testing as per S10 MoM PM10 | X | | X | | Batt test plan docs |
| Inter-Module Harness | 111.01.01.03 | FR | bakeout: 278.6 kWh for 72 h | | | | x | bakeout assumed |
| Power Conditioning and Distribution Unit | 111.01.02.00 | CRISA SA (ES) | rPBA | X | | X | | CO2M-PL-ADSC-PCDU-1001027967 Is.04 PCDU Test Plan |
| Solar Array | 111.01.03.00 | SpaceTech GmbH (DE) | Testing as per S10 MoM PM10 | **X (SA Panels)** | | **X (SA Wings)** | performed on Solar Panels (without hinges) within the TVAC test | CO2M-PL-STI-SAW-0004_04 MAIT Plan |
| Solar Array Drive Assembly | 111.01.04.00 | Kongsberg Defence & Aerospace AS (NO) | rPBA | **X** | | **X** | **X (harness only)** | MTG-RSA-SADA-PL-0005 MAIT Plan |
| *not applicable* | *111.01.05.00* | | - | *not applicable* | | *not applicable* | *not applicable* | *not applicable* |
| Payload Power Distribution Unit | 111.01.06.00 | CRISA SA (ES) | rPBA | X | | X | | CO2M-PL-ADSC-PPDU-1001027969 I.s04 PPDU Test Plan |
| Data Handling Subsystem | 111.02.00.00 | | - | | - | - | - | - |
| On-Board Computer | 111.02.01.00 | RUAG Aerospace Sweden AB (SE) | rPBA | X | | X | | CO2M-OBC-RSE-PL-0006 Is.04 AIV Plan |
| *not applicable* | *111.02.02.00* | | - | | - | - | - | - |
| Remote Terminal Unit 1 | 111.02.03.00 | Terma A/S Dänemark (DK) | rPBA | x | | x | | CO2M-RTU-TER-PL-0004 Is.3.2 |
| Remote Terminal Unit 2 | 111.02.04.00 | Terma A/S Dänemark (DK) | rPBA | x | | x | | CO2M-RTU-TER-PL-0004 Is.3.2 |
| Remote Terminal Unit 3 | 111.02.05.00 | Terma A/S Dänemark (DK) | rPBA | x | | x | | CO2M-RTU-TER-PL-0004 Is.3.2 |
| Payload Data Handling Unit | 111.02.06.00 | Airbus Defence and Space France | rPBA | x | | x | | CO2M-PDHU-ADSE-PL-1000945386 Is.3 |

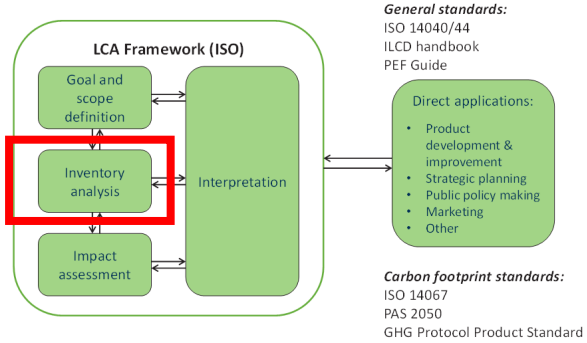
Tests energy consumption gathered via selected suppliers' data collection questionnaire and used as baseline for all other equipments

# CO2M – LCA

## LIFE CYCLE INVENTORY ANALYSIS (LCI)

### TEST CAMPAIGNS

| Overview | Applicability | | | Consumables and outputs | | | |
|---|---|---|---|---|---|---|---|
| Test list | Development Models | | | Energy consumed | | Duration | Cleanroom |
| Type (environmental, laboratory, cleanroom tests) | SM | EM | FM | Type (electricity, gas, oil...) | Quantity (kWh) | Hours | Type |
| **Structural Model Test Campaign** | | | | | | | |
| SM Vibration out of plane | 1 | | | | | 48 h, 30 min effective test | 8 |
| SM Vibration in-plane | 1 | | | | | 48 h, 60 min effective test | 8 |
| Storage in Galileo Hall | 1 | | | Electricity | | | 8 |
| **PFM Model Test Campaign** | | | | | | | |
| Units storage, Assembly and PL+PF Integration | | | 1 | Electricity | | | |
| TVAC - PFM | | | 1 | | | 720 | 8 (included in record) |
| TVAC - FM2 | | | 1 | | | 480 | 8 |
| Vibration | | | 1 | | | 160 h, 90 min effective test | 8 |
| Accoustic | | | 2 | | | 40, 20 min effective test | 8 |
| Mass Properties | | | 2 | | | 32 | 8 |
| EMC | | | 2 | | | 40 | 8 |
| Time in Cleanroom PFM | | | | | | | 9 month - TVAC |
| Time in Cleanroom FM 2 or 3 | | | | | | | 6 months - TVAC |
| **EM Test Campaign** | | | | | | | |
| EM integration | | 1 | | Electricity | | | NA |
| Test campaign Level 0 + Level 1 | | 1 | | Electricity | | | NA |
| Test campaign Level 2 and higher | | 1 | | Electricity | | | NA |



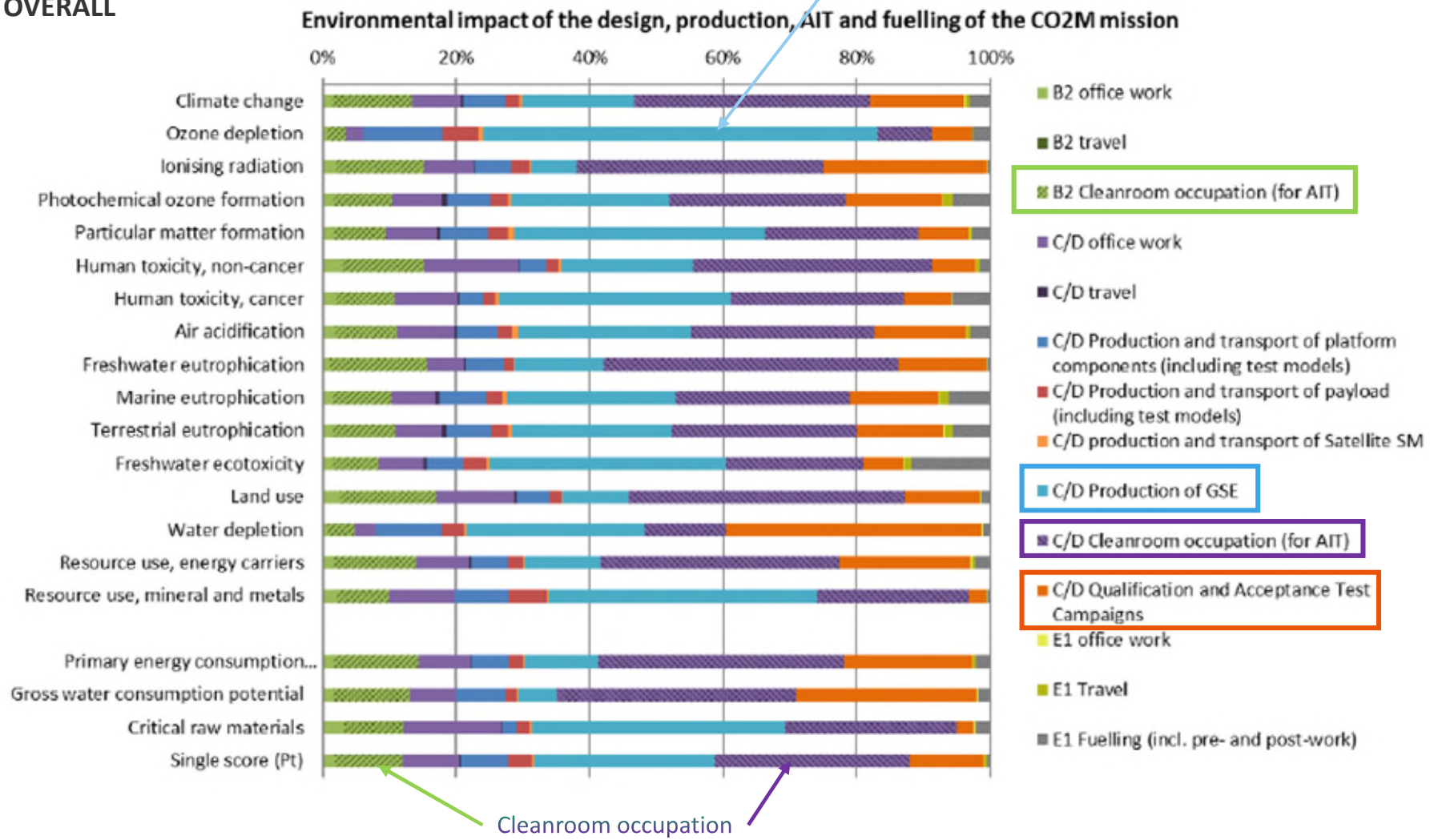

Energy values from **ESA database**

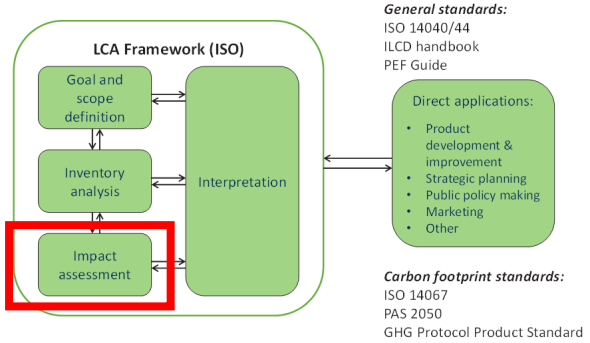
# CO2M – LCA

## LIFE CYCLE IMPACT ASSESSMENT (LCIA)

ETFE cables used in GSE

### OVERALL




The **climate change impact** of the definition, production, testing and spacecraft-related launch activities of the space segment of the CO2M mission amounts to:

**9.13 kton CO2-eq**

# CO2M – LCA

## LIFE CYCLE IMPACT ASSESSMENT (LCIA)

### PLATFORM

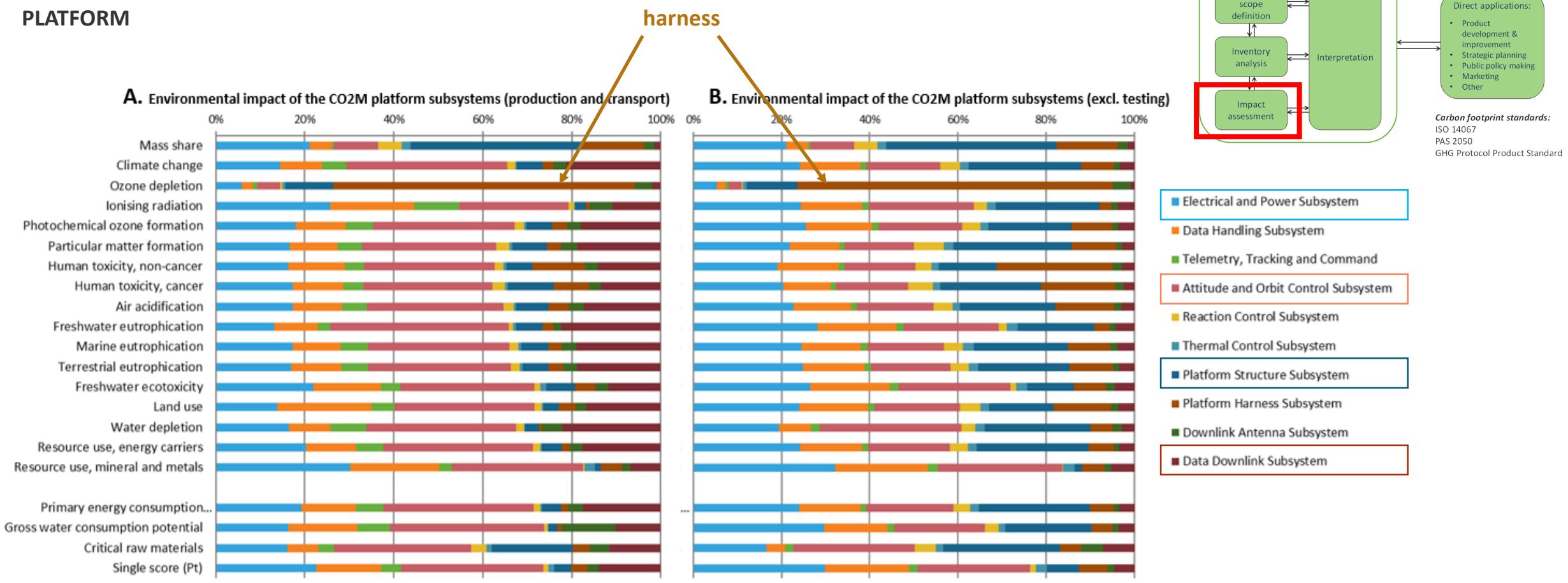
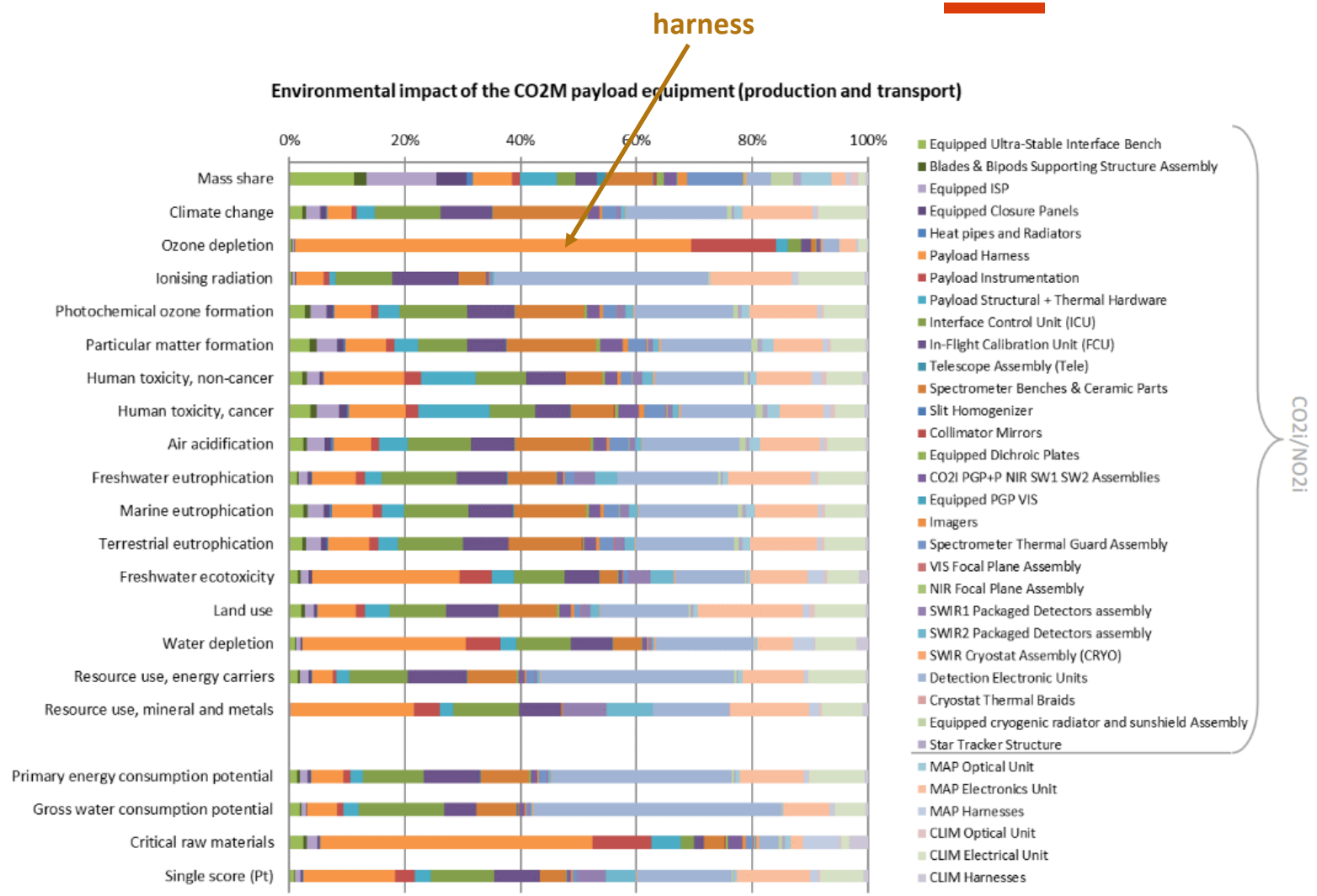


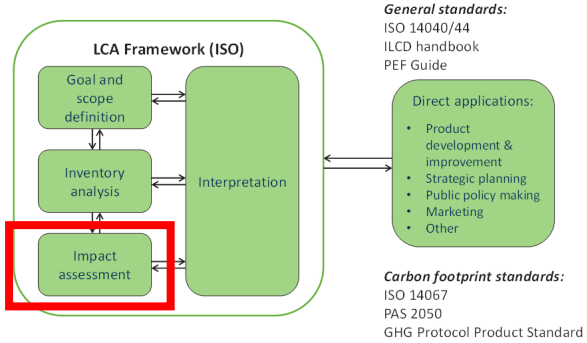

*Figure 9: Environmental profile of the $CO_2M$ platform equipment production and transport, breakdown in subsystems, A. including testing and B. excluding equipment testing.*

# CO2M – LCA

## LIFE CYCLE IMPACT ASSESSMENT (LCIA)

### PAYLOAD

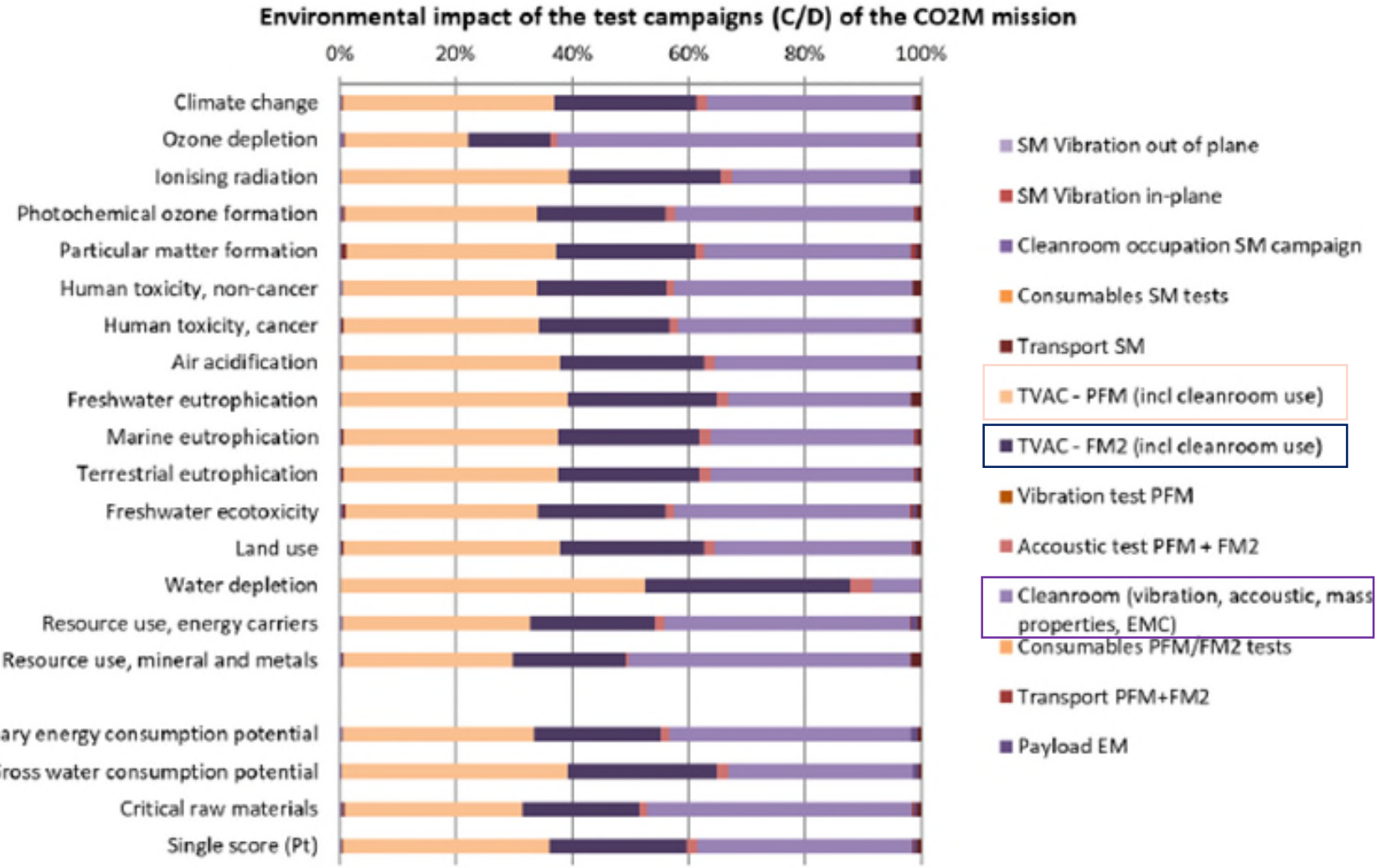


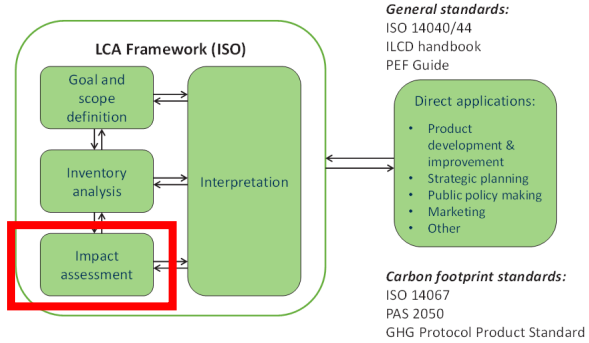



# CO2M – LCA

## LIFE CYCLE IMPACT ASSESSMENT (LCIA)

**EVT**

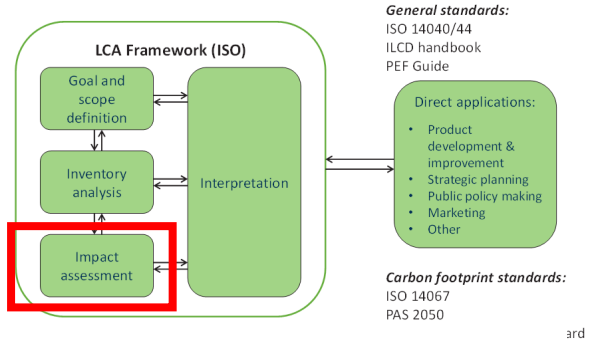


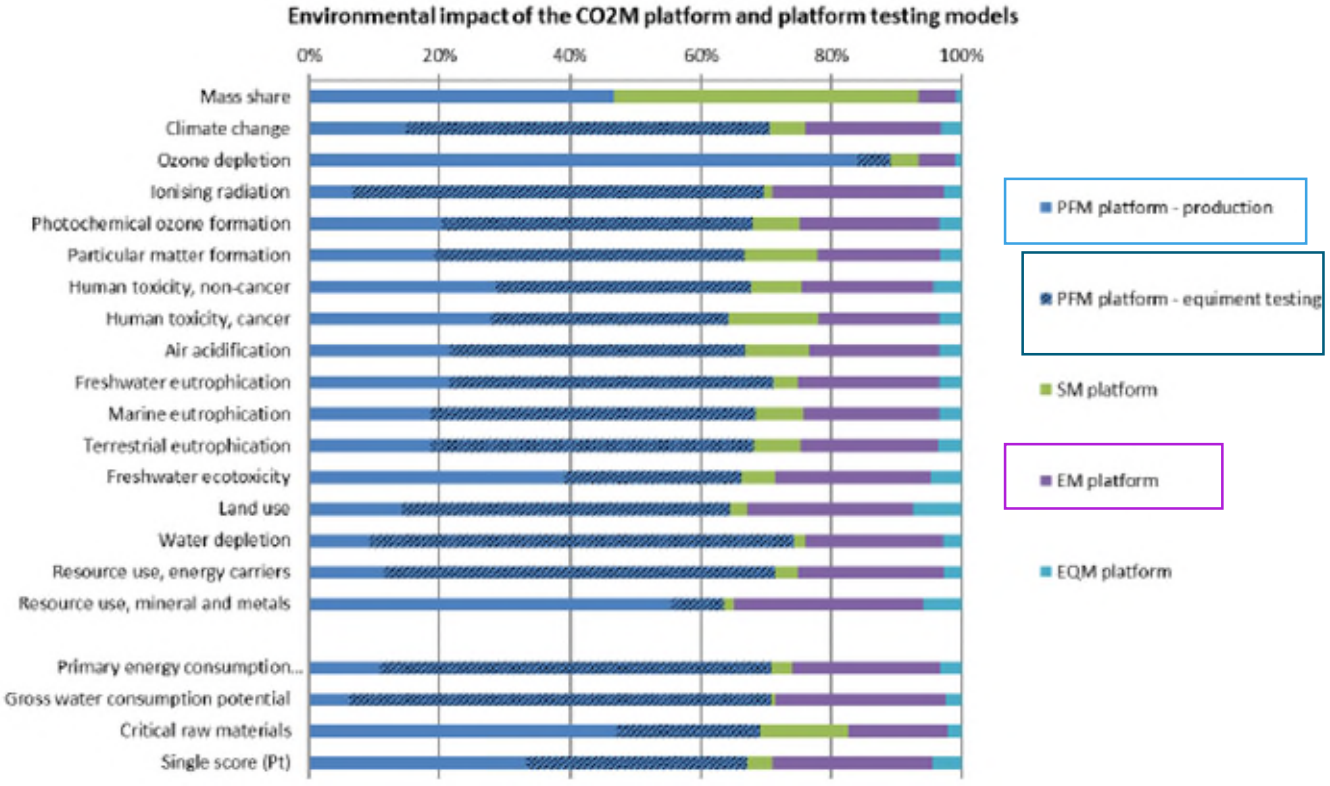



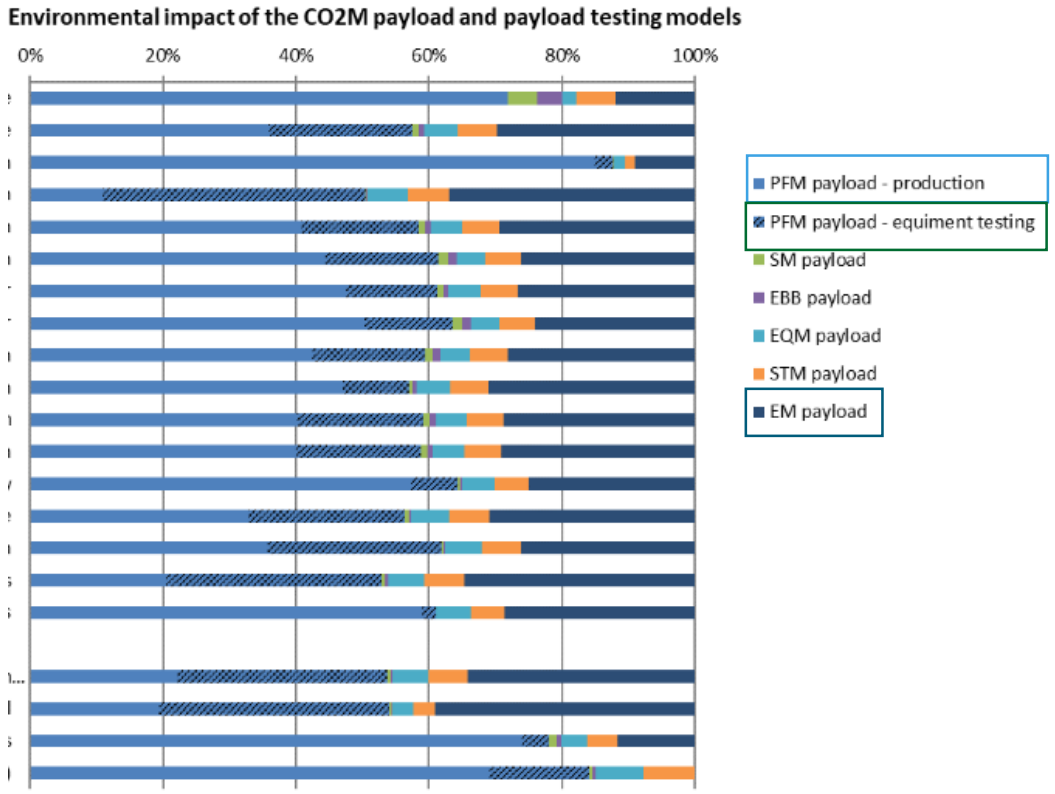
# CO2M – LCA

## LIFE CYCLE IMPACT ASSESSMENT (LCIA)

### MODELS



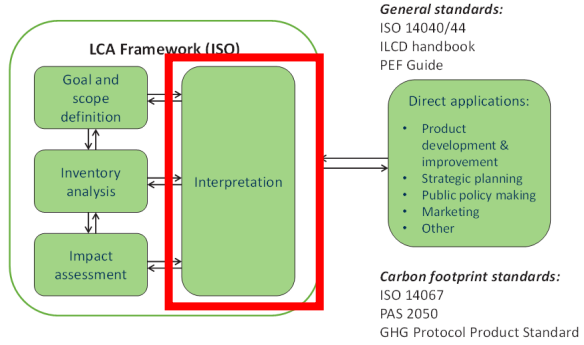



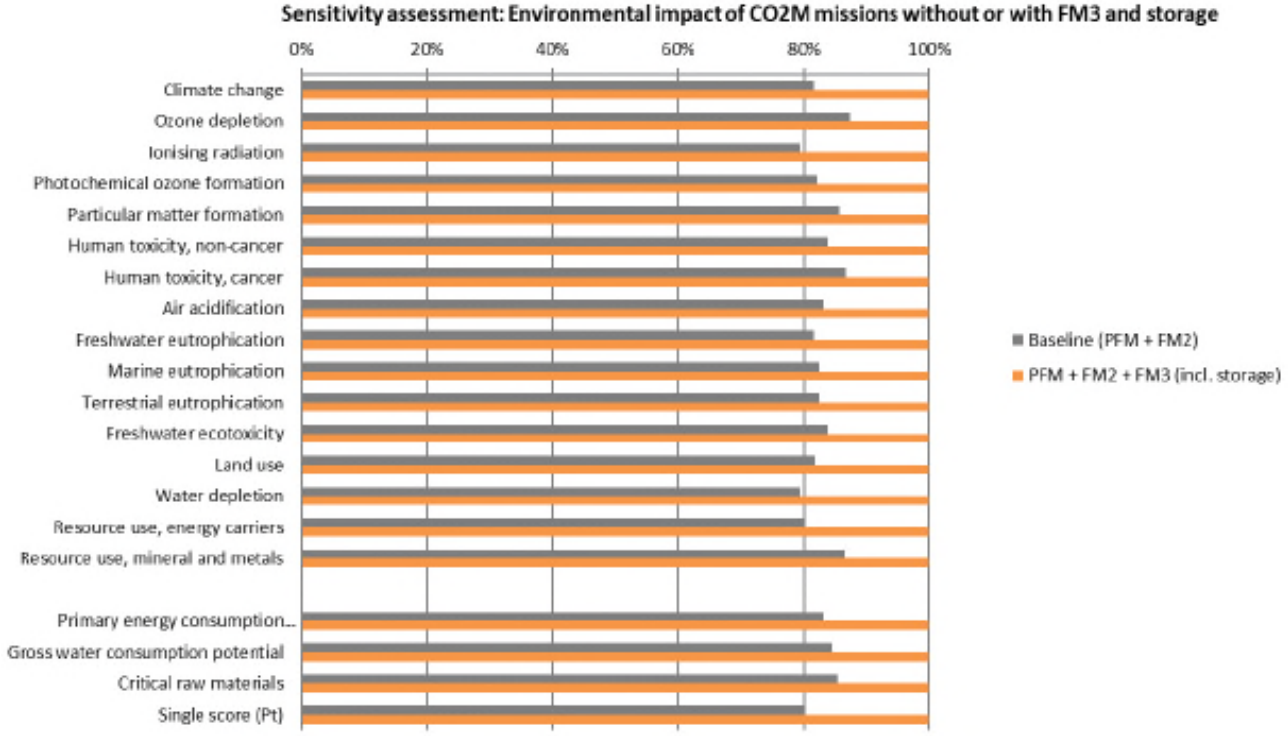
# CO2M – LCA

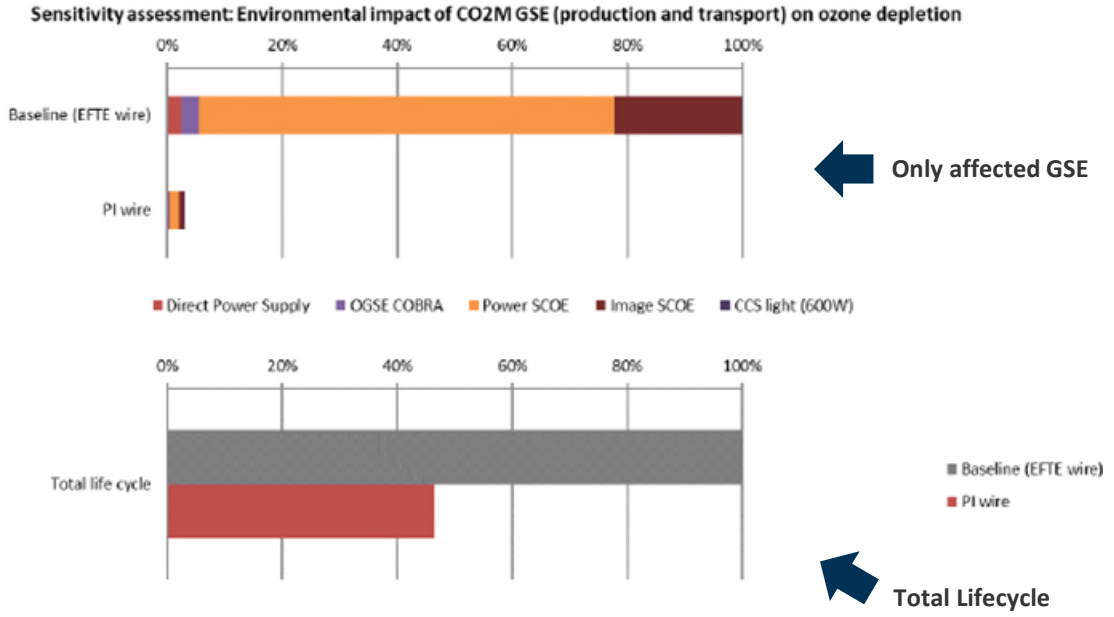
INTERPRETATION

## SENSITIVITY ASSESSMENT

- **Infrastructure** has important impact in the CO2M mission, however the relative importance of the life cycle stages and activities are unchanged.
- **Inclusion of FM3** (optional satellite) showed that the environmental impact would increase by about 15%
- **Ozone depletion** impacts related to **ETFE wires** used in some EGSE could be strongly reduced by use of product with different jacket, i.e. Polyimide jacket



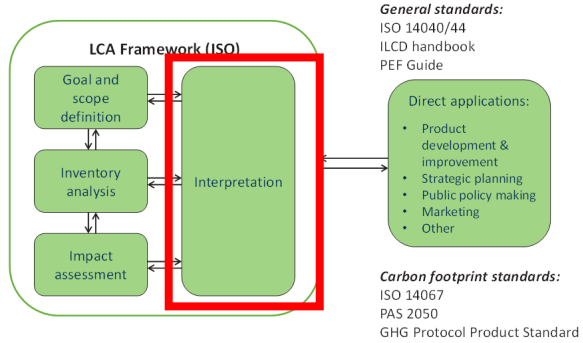



# CO2M – LCA

INTERPRETATION

## IMPROVEMENT MARGINS

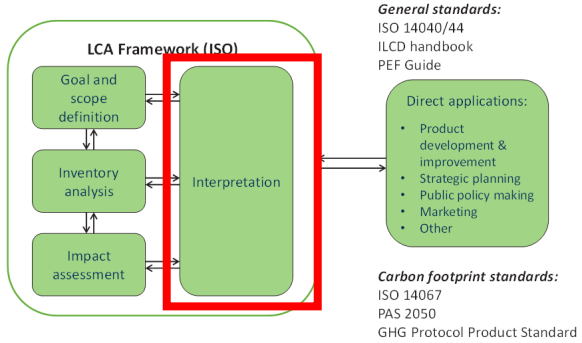



- ***Electronic Units:*** use of direct detailed data on EEE composition in place of use of rPBA proxy (applied to most of e-boxes due to difficulty from the supplier to estimate micro-electronics composition and mass share)
- ***Cleanroom:*** More specific information about PL and suppliers cleanroom (OHB cleanroom data has been used)
- ***GSE:*** more data on GSE composition and production (no DPL/DML available for most of GSE)
- ***Testing:*** Primary data on energy use of test equipments and detail on single tests (energy has been derived from OHB cleanroom consumption or from specific suppliers test values)
- ***PF and PL Production:*** Improved data on the material composition and testing procedures of most payload equipment (PL data has been less complete than PF due to lower PL maturity level)

# CO2M – LCA

INTERPRETATION

## ECODESIGN RECOMMENDATIONS




- **Reusability of GSE equipment** will greatly reduce the missions' impact:
  - coordinated procurement among programs
  - intra-missions AIT plan to share needed GSE

- Due to the **high impact on ozone depletion due to tetrafluoroethylene**, the materials used in the jacketed wires should be investigated:
  - alternative on the space market? Radiation resistance?
  - Detailed radiation analysis to evaluate real need of PTFE jackets? Possible alternative radiation shielding systems?

- Investigation/Promotion of **manufacturing technologies with reduced BTF** and embodied energy waste
  - i.e. Al manufacturing Energy Consumption LPBF (BTF= 1.5:1) : around 30% of the energy of typical CNC (BTF=17:1) billet machining*

*calculation based on digitalalloys.com "Energy Consumption in Metal Additive Manufacturing", from "Digital Alloys Guide to Metal Additive Manufacturing, part 7"

# THANK YOU!