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Environmental impacts of launchers and space missions

Clean Space industrial Days, October 25th 2017

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Environmental impacts of launchers

Outline

1. Context & objectives
2. Overview of calculation methodology
3. Results
4. Key methodological points
5. Conclusions & recommendations

Context

Why study the environmental impacts of launchers?

- **Growing public awareness** on the impacts of human activities on our ecosystem
- **More and more stringent public environmental legislation** & **increasing public pressure**
- ESA, as a public sector intergovernmental organisation, has **put the environmental concern as a priority in all its activities**
- The first step in this direction was a **deeper analysis and understanding of the environmental aspects of space programmes**. ESA wanted to get the know-how:
  - to be more active in facing legislation on this topic, and
  - to drive technical and scientific innovation in European space industry.
- Among all European space related activities, a particular attention needed to be paid on the **environmental impacts of launchers** since the launcher vehicles' production and operation are core activities of the European space industry.
  - **First impression: launch event is the main contributor to the environmental impacts of a launcher... What does science say?**

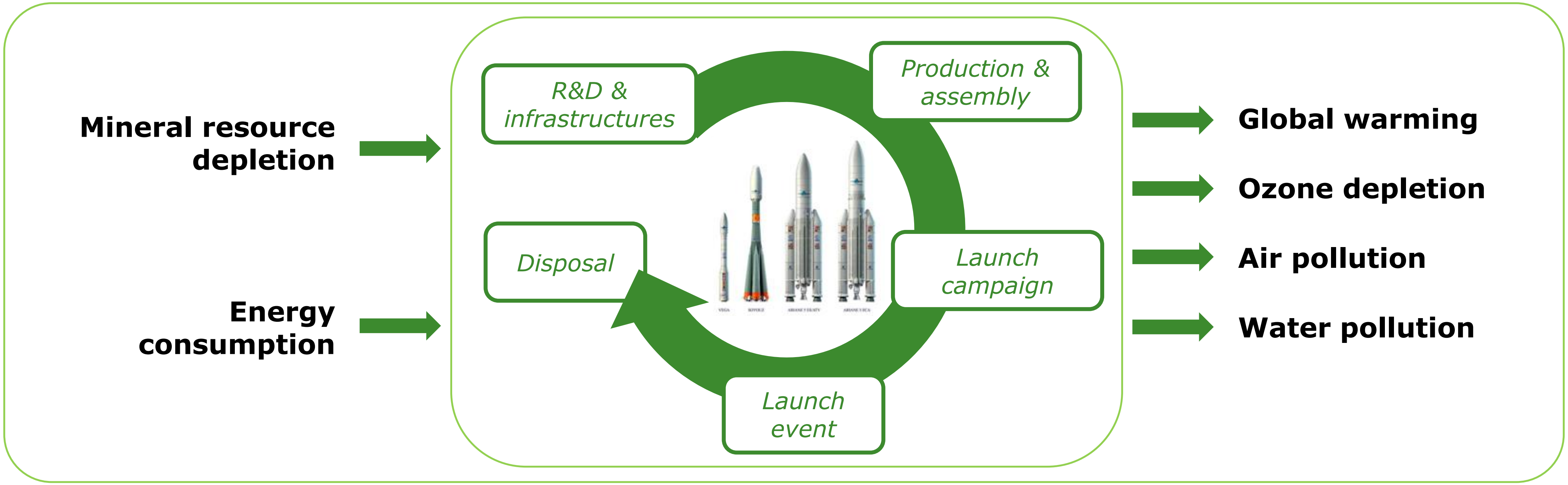
Study objectives

- Main objectives:
    1. To test the **applicability and relevance of Life Cycle Assessment** for the environmental analysis of space launchers
    2. To **better understand the environmental impacts of launchers** (Ariane 5, Vega and Soyuz ST) and the sources of these impacts
    3. To identify **possible actions of environmental impacts mitigation**
    4. To **set recommendations for further analysis** and next steps of the environmental impact assessment of launchers

Overview of calculation methodology

Life Cycle Assessment is a comprehensive, objective and science-based methodology to assess the environmental footprint of a system over its life-cycle

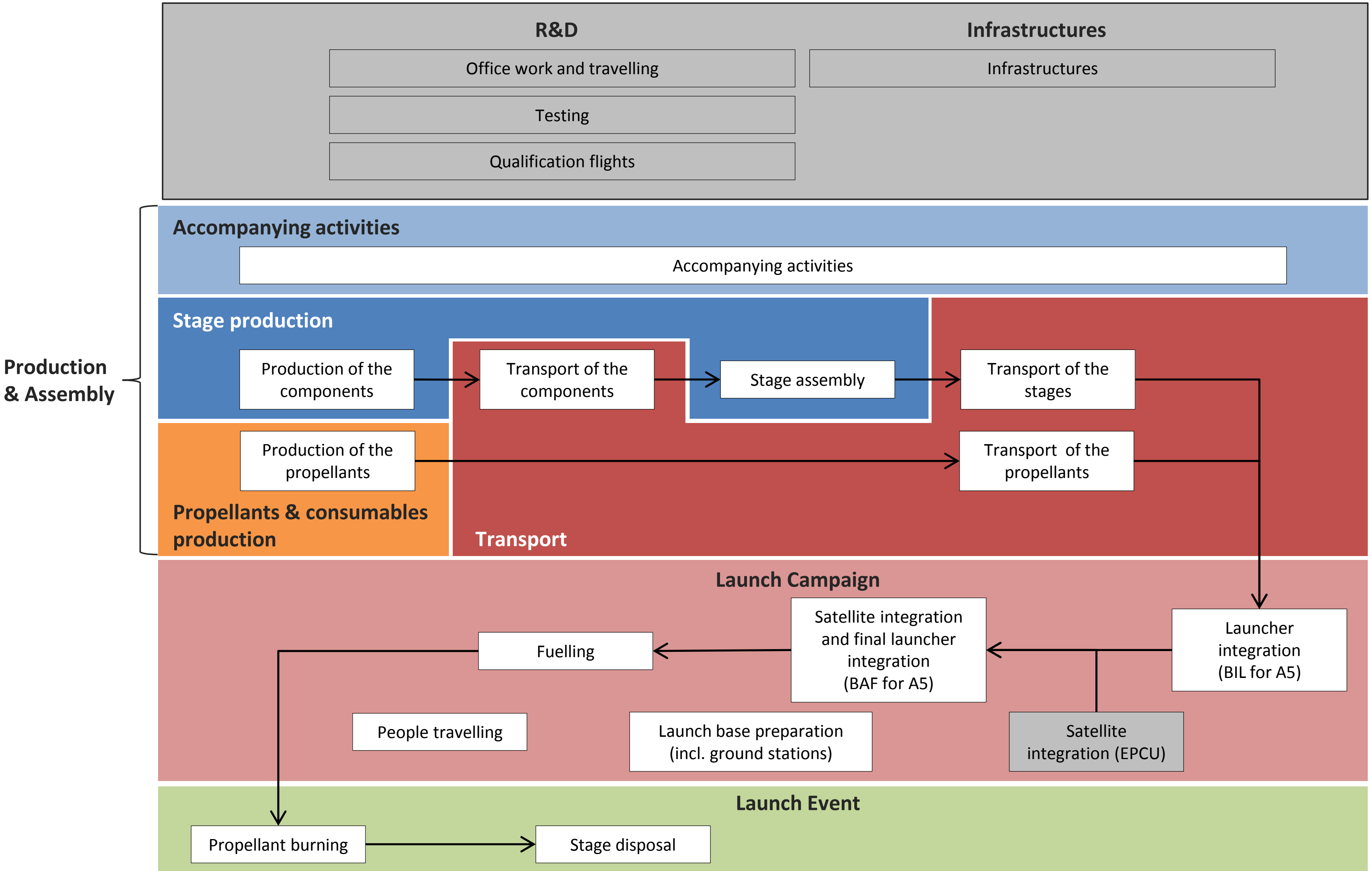
- LCA is a **standardised** approach (by ISO) which is:
  - **multi-step**, assessing potential impacts of a product all along its whole life cycle
  - **multi-criteria**, taking into account all environmental issues



  - **General principle: avoid burden shifting**
  - For the case of launchers: LCA needs to be complemented for the assessment of the atmospheric emissions during launch event

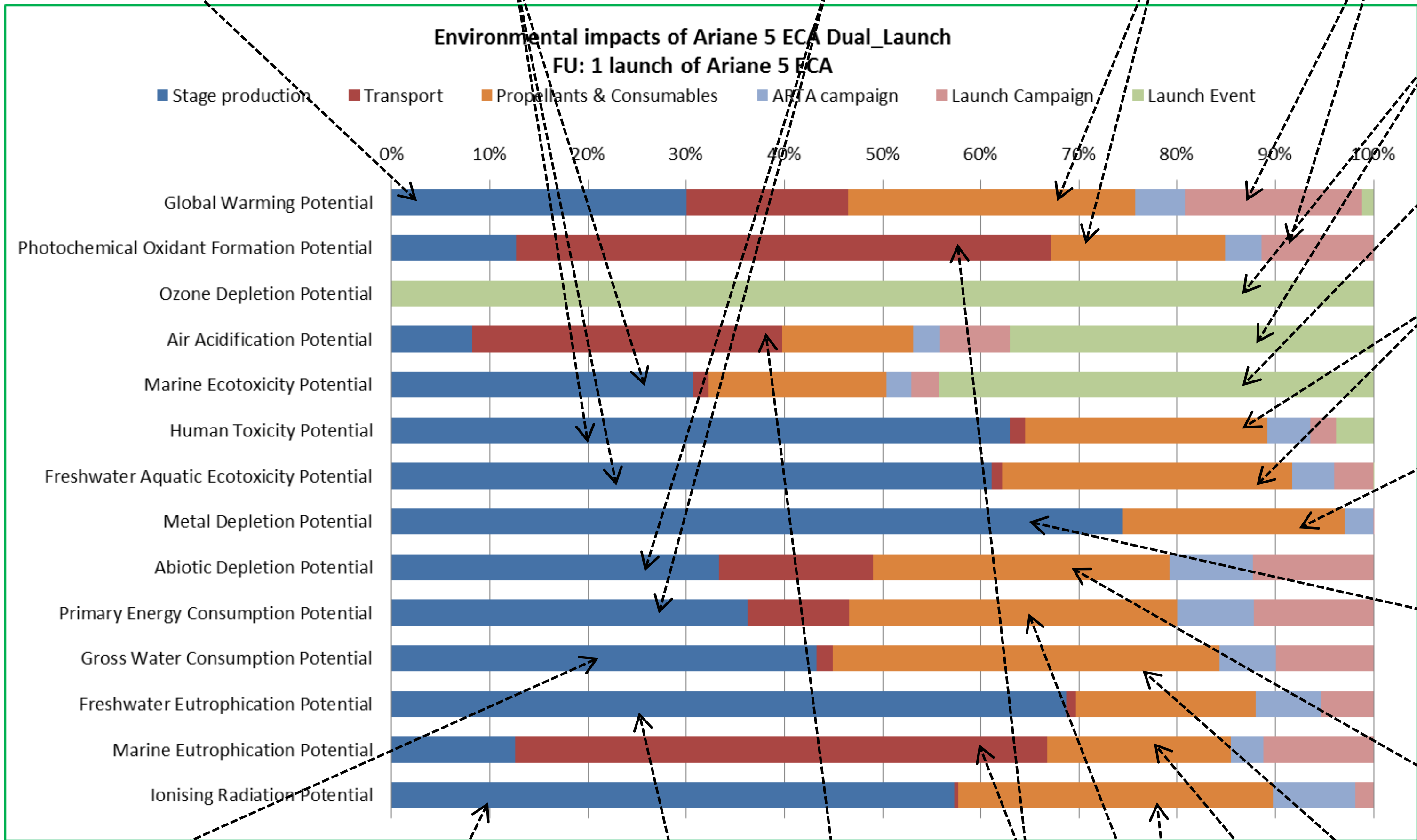
Overview of calculation methodology

Life cycle breakdown



LCA results of Ariane 5 ECA

Main contributors are stage production, propellants & consumables produc[illegible]un[illegible]m[illegible]ns



EAP > MPS > CPP > Electricity and heat consumption

EAP > MPS > CPN > stainless steel production > Molybdenum production

EAP > MPS > CPP > Natural gas consumption during production

UPG activities > Electricity consumption

Launcher integration > Electricity consumption

Propellant burning > HCl emissions

EPC disposal > Nickel, ion emissions

Ammonium perchlorate production > sodium chlorate production > Cr VI emissions in water

Ammonium perchlorate production > Platinum consumption

EAP > MPS > CPN > stainless steel production > Molybdenum consumption

LH2 production > Methanol production > natural gas consumption

Ammonium perchlorate production > sodium chlorate production > water consumption

UPG activities > Electricity consumption > NOx

EAP > MPS > CPN > direct water consumption
EPC > Propulsion > Vulcain 2 > French electricity for acceptance test

EPC > Propulsion > Vulcain 2 > French electricity for acceptance test and assembly

EAP > MPS > CPN > German electricity mix

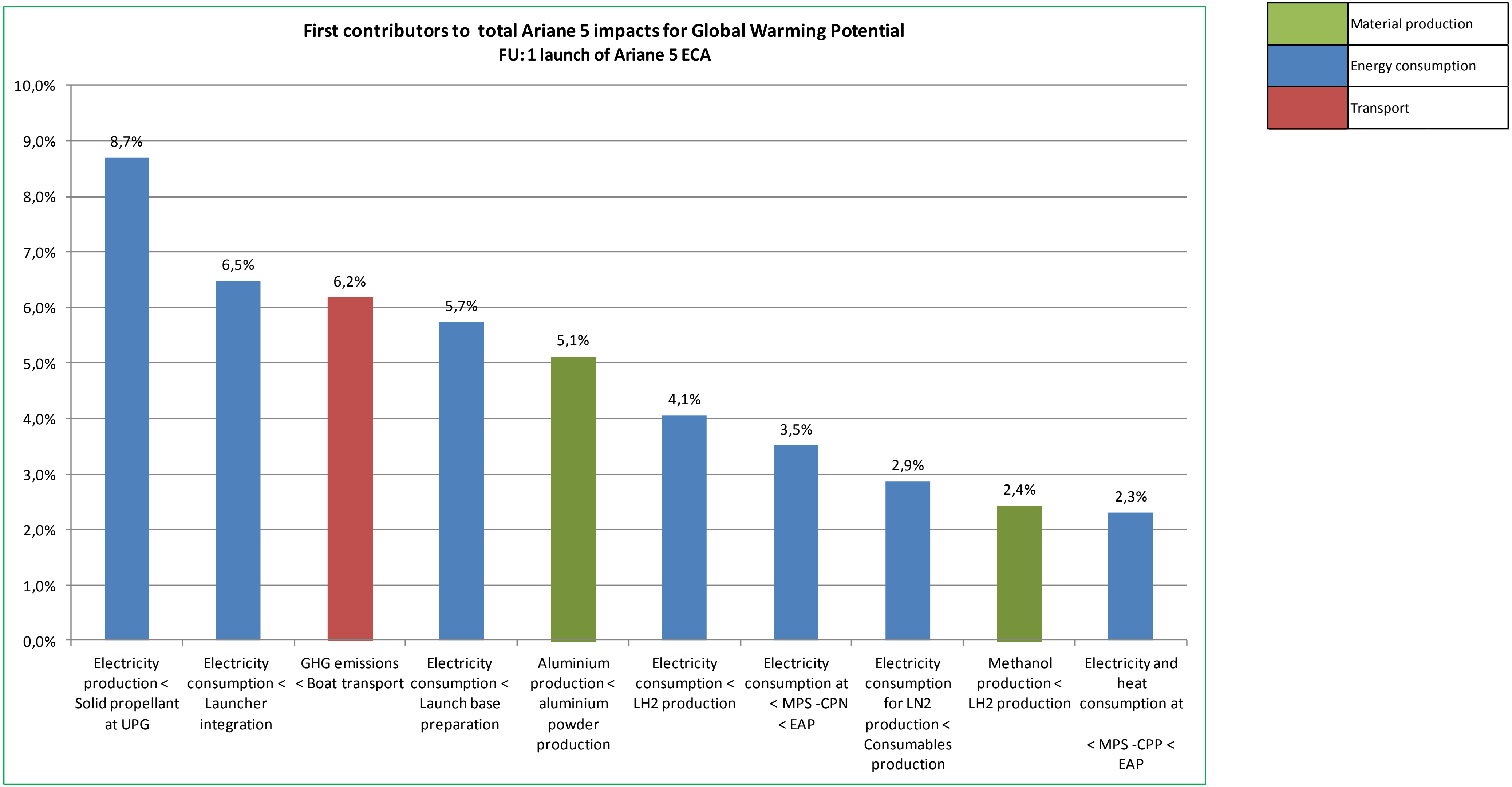
Boat transport > SO_2 and NOx emissions

Boat transport > NOx emissions

Ammonium perchlorate production > sodium chlorate production > French electricity consumption

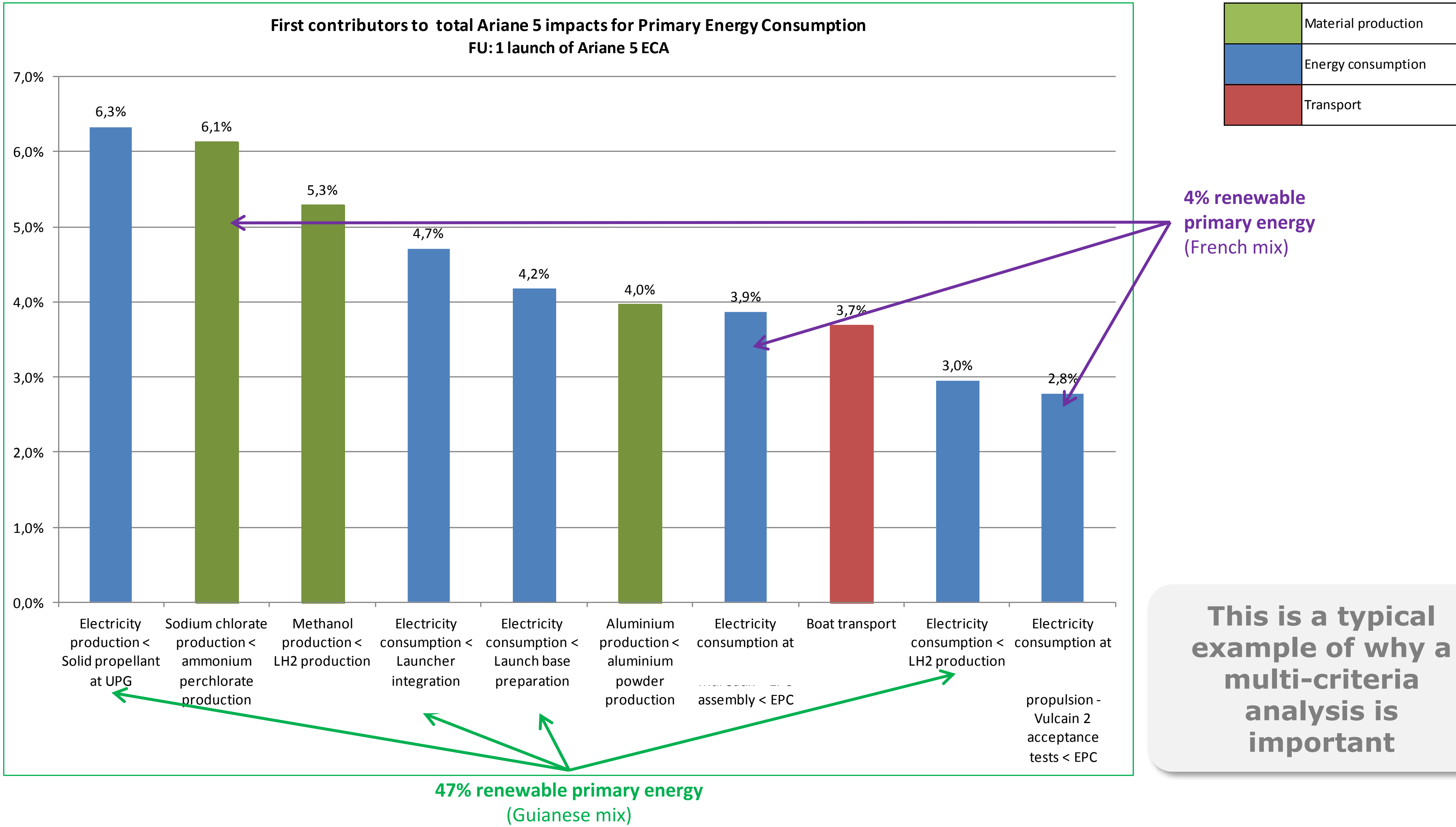
LCA results of Ariane 5 ECA

Carbon footprint: first 10 contributors < 50% of total carbon footprint (CF) of Ariane 5: CF distributed homogeneously among numerous contributors
=> many improvement areas



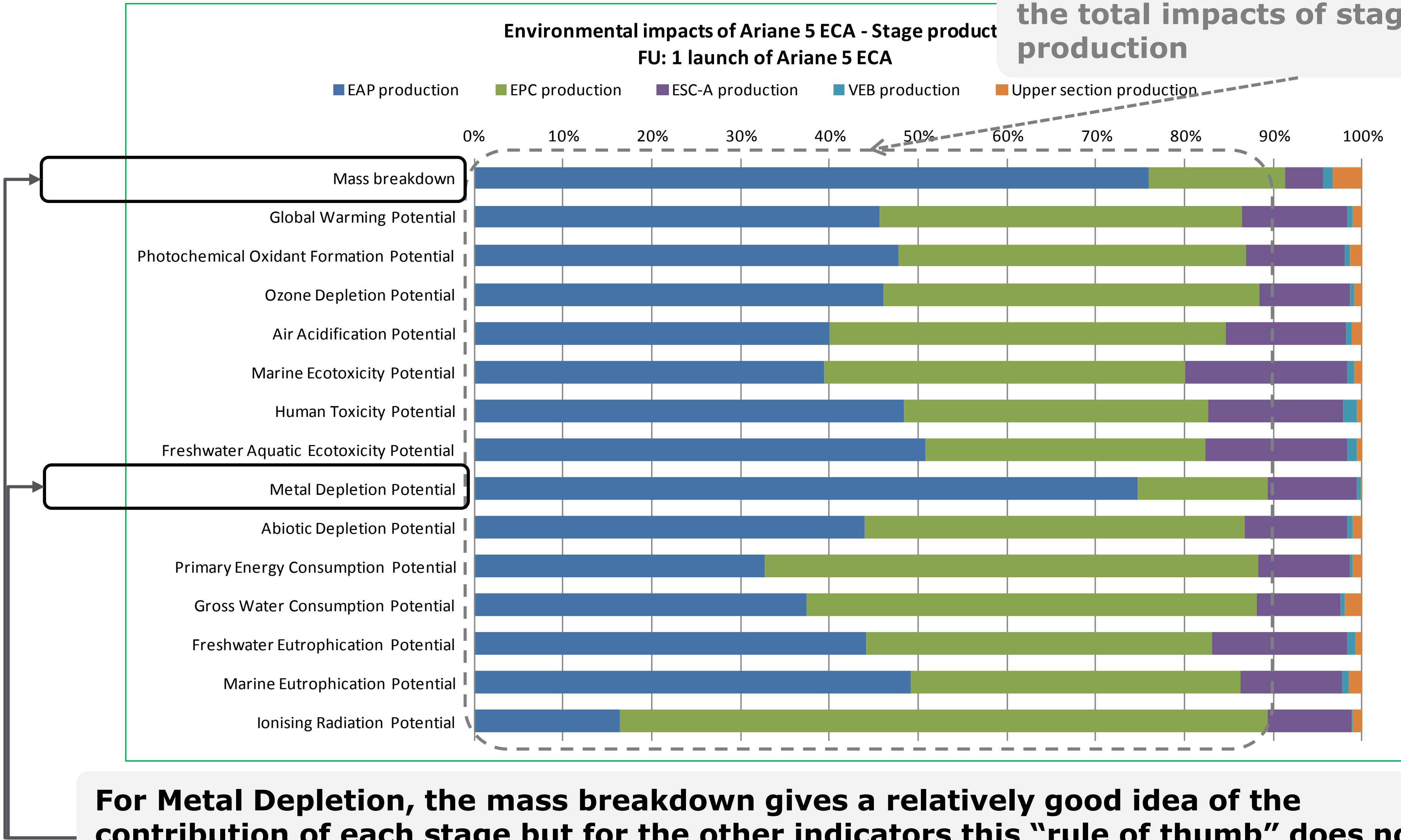
LCA results of Ariane 5 ECA

Energy consumption: same contributors and ranking as for the carbon footprint, except activities in metropolitan France and French Guiana



This is a typical example of why a multi-criteria analysis is important

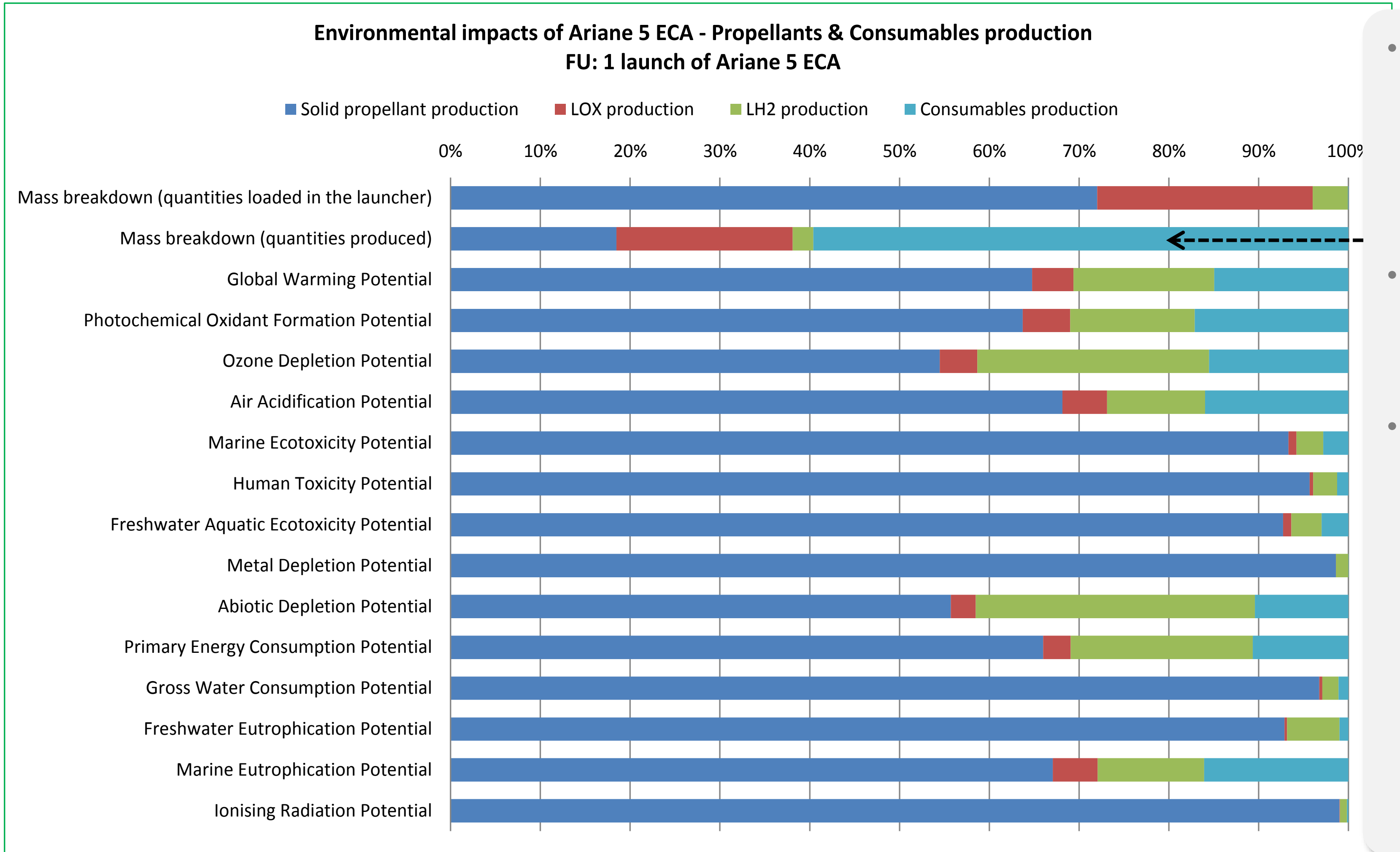
LCA results of Ariane 5 ECA
Focus on stage production



EAP and EPC production: most impacting sub-steps for all environmental impacts: 85-90% of the total impacts of stage production

For Metal Depletion, the mass breakdown gives a relatively good idea of the contribution of each stage but for the other indicators this "rule of thumb" does not reflect reality: EPC more impacting than EAP while 15% (vs. 75%) dry mass

LCA results of Ariane 5 ECA
Focus on propellants & consumables production



- **Mass breakdown of quantities of propellants produced per launch: not representative of breakdown of impacts**
- **Notably because huge amount of N_2 produced in CSG (for ground facilities mainly)**
- **N_2 production impacts are low:**
  - ✓ **produced from air distillation, which requires only a relatively small amount of electricity (15x less than H_2 from methanol)**
  - ✓ **Elec. from the network in Guiana (with a high % of hydro)**

LCA results of Ariane 5 ECA

What about R&D & infrastructures? Difficult to assess: data accessibility and allocation

R&D

Scope
Due to limited data availability, only R&D office work (no testing and qualification activities) and carbon footprint

Data
Number of man.years for the development of A5: provided by ESA
Carbon footprint of R&D centre used as a proxy for impact of 1 man.year

Results
60 A5 launches:
R&D office work = 45% of CF of 1 launch
= production & assembly
100 A5 launches:
R&D office work = 33% of CF of 1 launch

Infrastructures

Scope
All infrastructures included in the assessment

Data
- Specific infrastructures @CSG
- W/o specific data for Production & Assembly, infrastructures of car manufacturing used as a lower limit for dry mass

Results
200 Ariane launches:
Infrastructures = 5% of A5 carbon footprint
= 25% of A5 metal depletion

R&D and infrastructures could be an important issue, to be further analysed in the future

Key methodological points

Methodology

First LCA of space launchers: no prior knowledge of the environmental hotspots

1. **Iterative approach (4 iterations for A5):**
   - LCA model refined progressively, prioritising on the main hotspots
2. **In-depth review**:
   - Independent review performed by external LCA expert to ensure LCA compliant w/ ISO standards
   - Internal review by ESA experts to check data and assumptions on space-specific activities
3. **In-depth analysis of the robustness of the model**:
   - Data quality assessment
   - Sensitivity analyses on input parameters with high uncertainty
   - Uncertainty analysis

Data

Low level of availability of data representative of the space sector

- Specific materials, manufacturing & assembly processes
- Specific production chain: little recurrent production

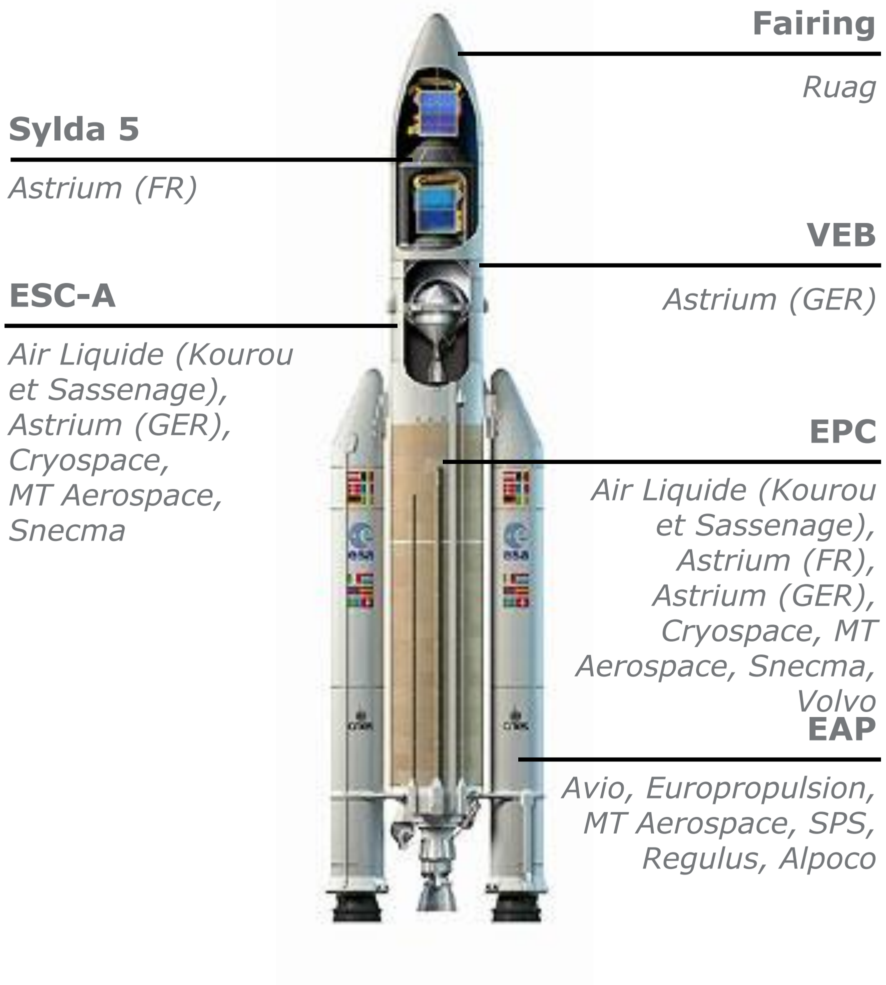
Intensive data collection process on most space-specific activities:

- More than 40 companies contacted
- 15 participated in data collection

Industry has a major role to play!

Key methodological points
Focus on industry data collection

Ariane 5 ECA double launch



- More than **40** companies contacted
- **15** participated in data collection
- Data collected on all parts of the launchers
- Several types of data collected:
  - Consumptions:
    - Raw materials
    - Water
    - Energy
    - Auxiliary materials
  - Emissions:
    - Waste of raw materials
    - Waste of auxiliary materials
    - Specific emissions: in air, in water, in ground

Key methodological points

Analysis of the robustness of the model

1. Data quality assessment

What for?
Shows the **weaknesses of the input dataset** (and priorities for improvement)

How?
Assessment of representativeness, precision and completeness of each individual input data
(scoring of quality from 1 to 3)

2. Sensitivity analyses

What for?
Shows the **relative importance of the choice of one specific key parameter/assumption**

How?
Assesses results sensitivity to the variation of one key parameter/assumption (all other key parameters are kept constant)

3. Uncertainty analysis

What for?
Shows the **overall robustness of the outputs**

How?
Assesses the uncertainty of the outputs by propagating the uncertainty of the input data (all data vary at the same time)
Monte-Carlo analysis

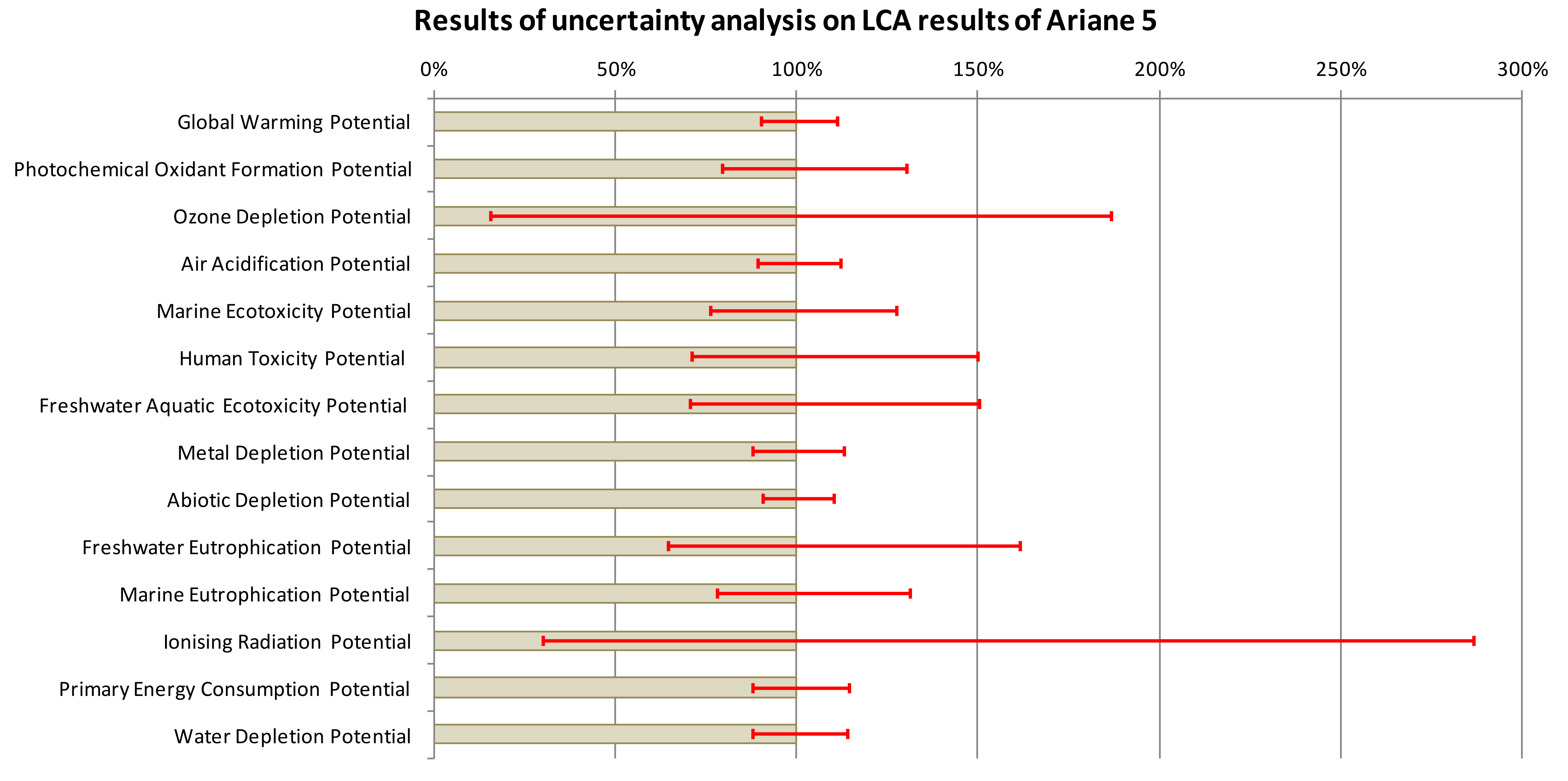
Key methodological points

Which parameters were tested through sensitivity analysis?

Launcher(s)	Sensitivity analysis	Main results
A5 / Vega	Rejection rate for metallic parts	Metal depletion: increase of 15% of rejection rate > 13% (8.5%) of increase of stage production impact for A5 (Vega)
A5 / Vega	Emissions during manufacturing processes of metallic parts	Not critical for the LCA of launchers
A5 / Vega	Emissions during the production of hydrazine	Not critical for the LCA of launchers
A5 / Vega	People travelling during Production & Assembly	~10% of launchers carbon footprint
A5 / Vega	Losses during solid propellant precursors production	Key parameter!
Vega	Use rate of ground stations	Significant influence on Launch Campaign, not the total impacts of the launcher
Soyuz ST	Energy efficiency of Russian processes	Results are sensitive to this assumption (it only impacts dry-mass production)
Soyuz ST	Electricity mix for aluminium production	No sensitivity, mainly because impacts stem from component manufacturing steps, not aluminium production
Soyuz ST	Use of CFC-113	ODP highly sensitive (almost only CFC plays a role)

Key methodological points

Uncertainty analysis is key to understand the robustness of the model



Conclusions & recommendations (1/2)

- Life Cycle Assessment proved to be both applicable and relevant for the study of the environmental performance of launchers
- The study allowed ESA to have an in-depth understanding of the environmental hotspots and impact sources of launchers, and areas where more focus should be put
- Having robust industry data is key. At the same time, industry can get much benefit from inititiating an LCA approach:
  - To communicate results and approach to clients
  - To gain knowledge on the environmental impacts of products
  - To identify mitigation measures (e.g. ISO14001:2015)
  - From a methodological standpoint, LCA is the first step towards an ecodesign approach
  - LCA increasingly becoming a standard tool in industry, e.g. Product Environmental Footprint initiative of the European Commission
  - The life-cycle approach could even be mandatory in the future, so anticipating this a wise choice

Conclusions & recommendations (2/2)

Recommendations for future work:

- Most of the data on manufacturing processes, materials and propellants not specific to space

  ➡ **Need to develop a space-specific LCA database**

- In this LCA:
  - More robust calculation needed for ozone depletion (Al_2O_3 and chlorine)
  - Effect of H_2O, O_3 and Al_2O_3 on global warming was excluded from the scope: only the GWP of carbon compounds (CO_2 and CO), which has a lower level of uncertainty, is included.

  ➡ **In-depth study needed on impact of atmospheric emissions**

- W/o precise knowledge of the toxic impact of falling launcher stages, a crude model was used

  ➡ **In-depth study also needed on this particular aspect**

Thank you for your attention!

Any questions?

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Environmental impacts of space missions

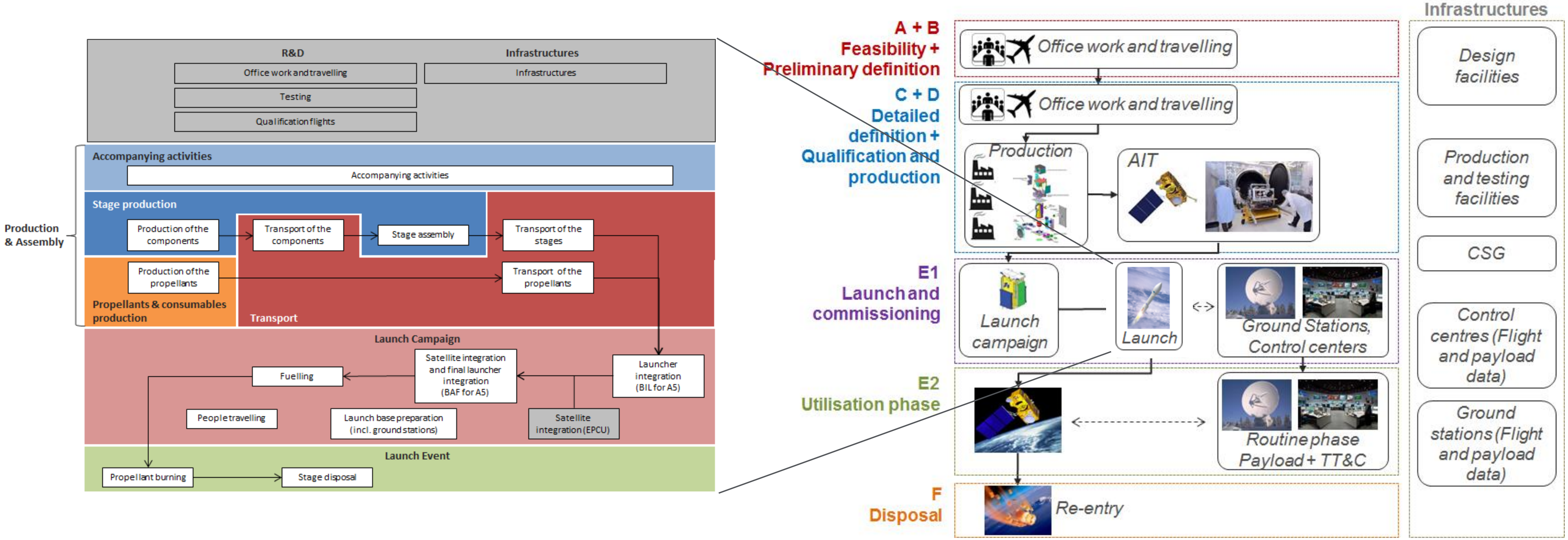
Outline

1. Context
2. Objectives
3. Scope
4. Results
5. Key methodological points
6. Conclusions

Context

Launchers are only a part of space programmes

From launchers… *… To space missions*

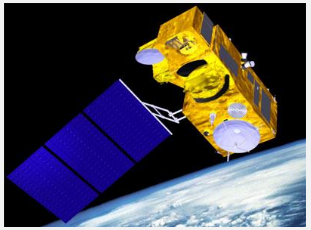


- ESA wanted to extend the use of LCA to whole space projects:
  - To foster technical and scientific innovation by integrating environment as a decision criterion in the design of space missions
  - (possibly) to allow the comparison with other sectors

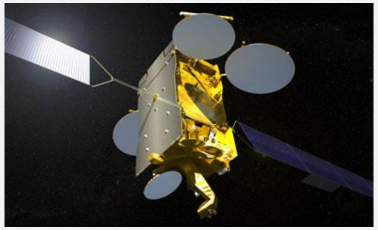
Objective of the project:

To provide ESA with the necessary tools to design future space missions in a more environmentally friendly way

Phases	Objectives
1. Scoping	• To better understand the **technical specificities** of space projects • To analyse the **state-of-the-art** in terms of environmental analysis of such systems
2. Pilot Life-Cycle Assessments	• To **assess the environmental impacts of space projects** *2 case studies selected:* *Earth observation*, *Communication* • To develop and test the **LCA methodology for space projects** to be implemented in the tool
3. Development of eco-design tool	• To develop an **enhanced software tool and database** adapted to space projects, to be integrated in the Open Concurrent Design Tool (OCDT) at ESA's Concurrent Design Facility (CDF), ESTEC



Earth observation

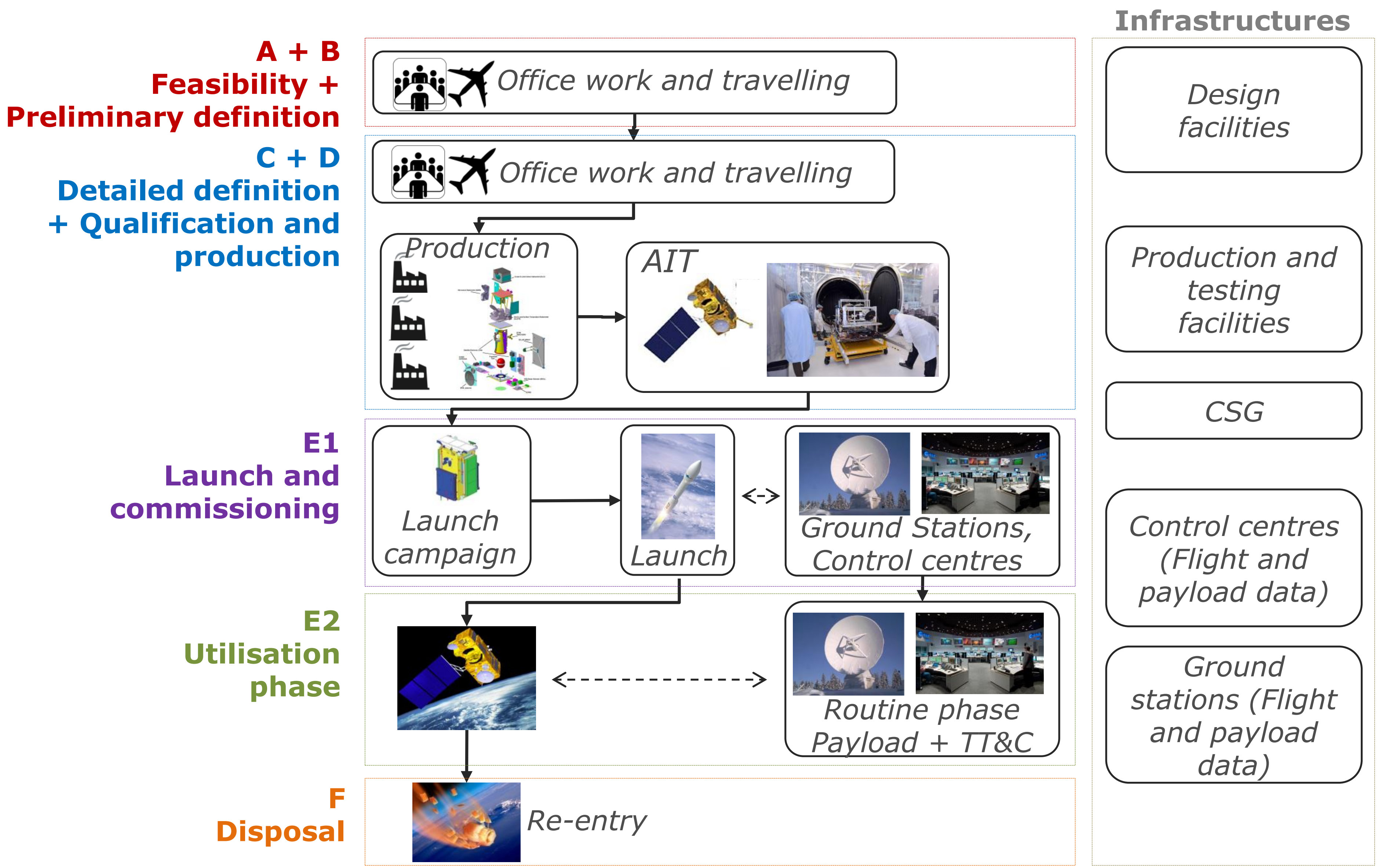


Communication

- In this presentation, we will focus on step 2. You are welcome to the presentation of the eco-design tool (step 3) this afternoon

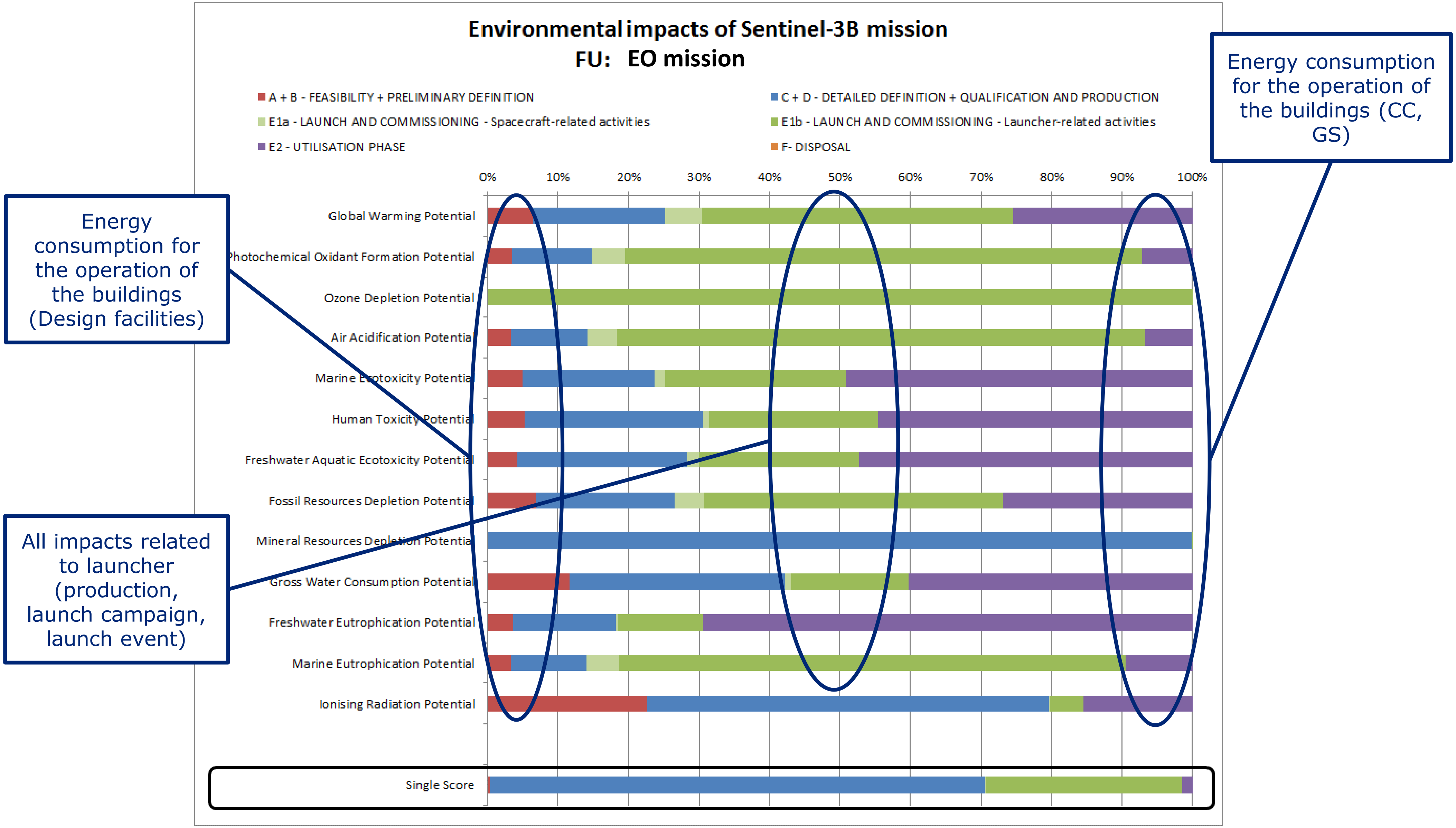
Scope of the assessment

The entire life-cycle of space missions was covered



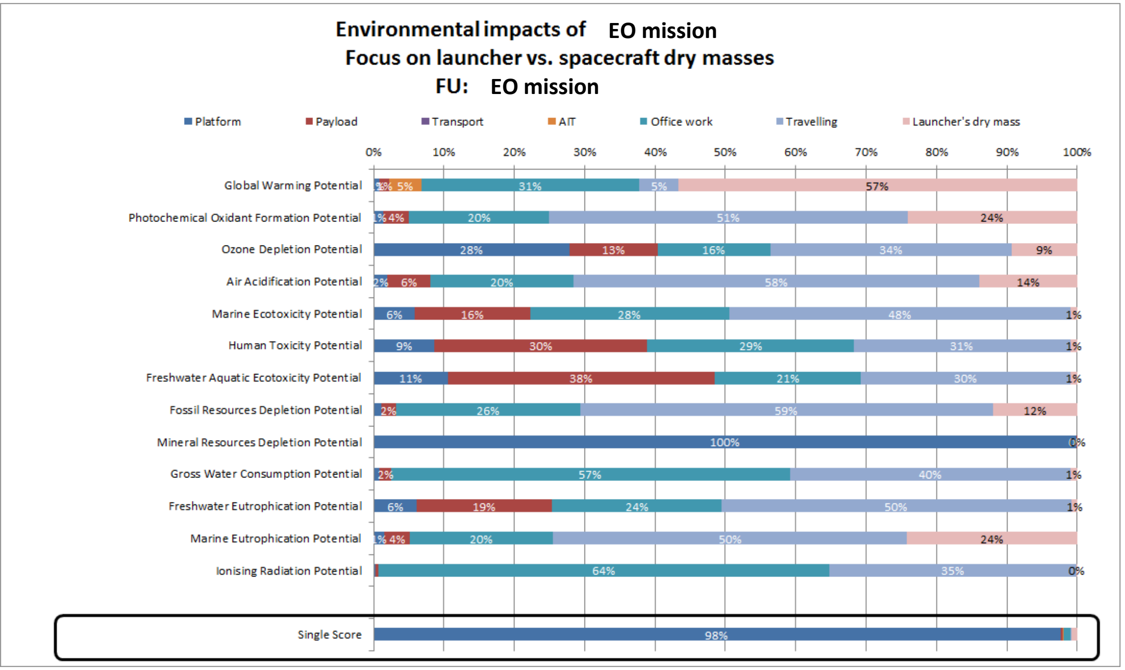
Results of the LCA of space missions

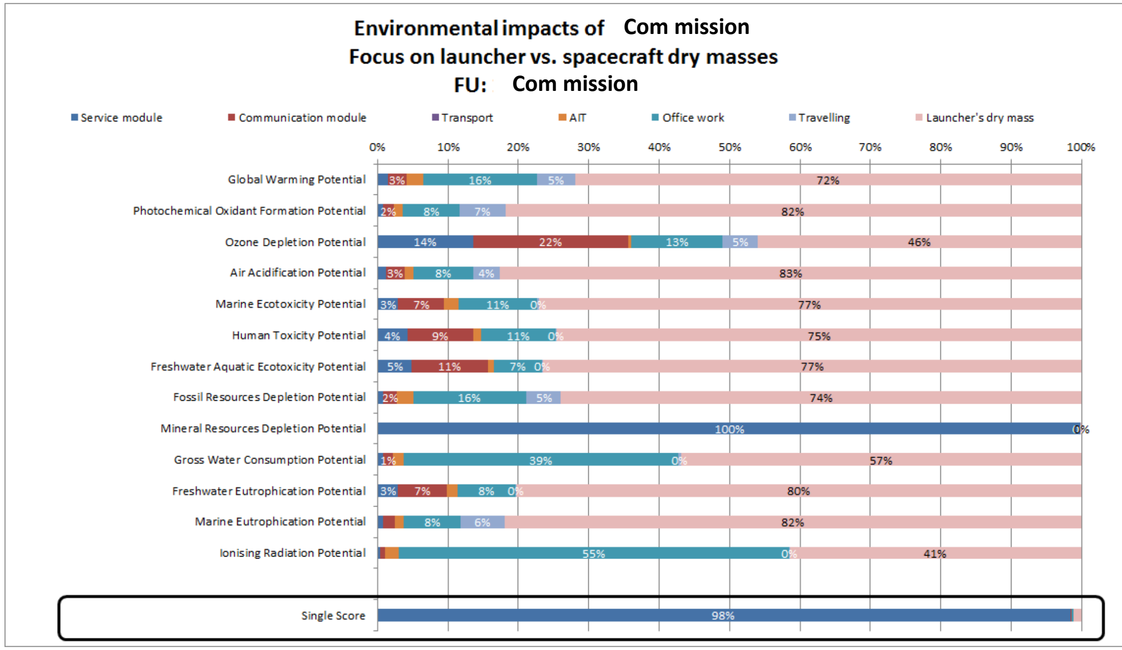
Where do the impacts come from? > Breakdown per life cycle step



Results of the LCA of space missions

What is the impact ratio between the S/C and the launcher?

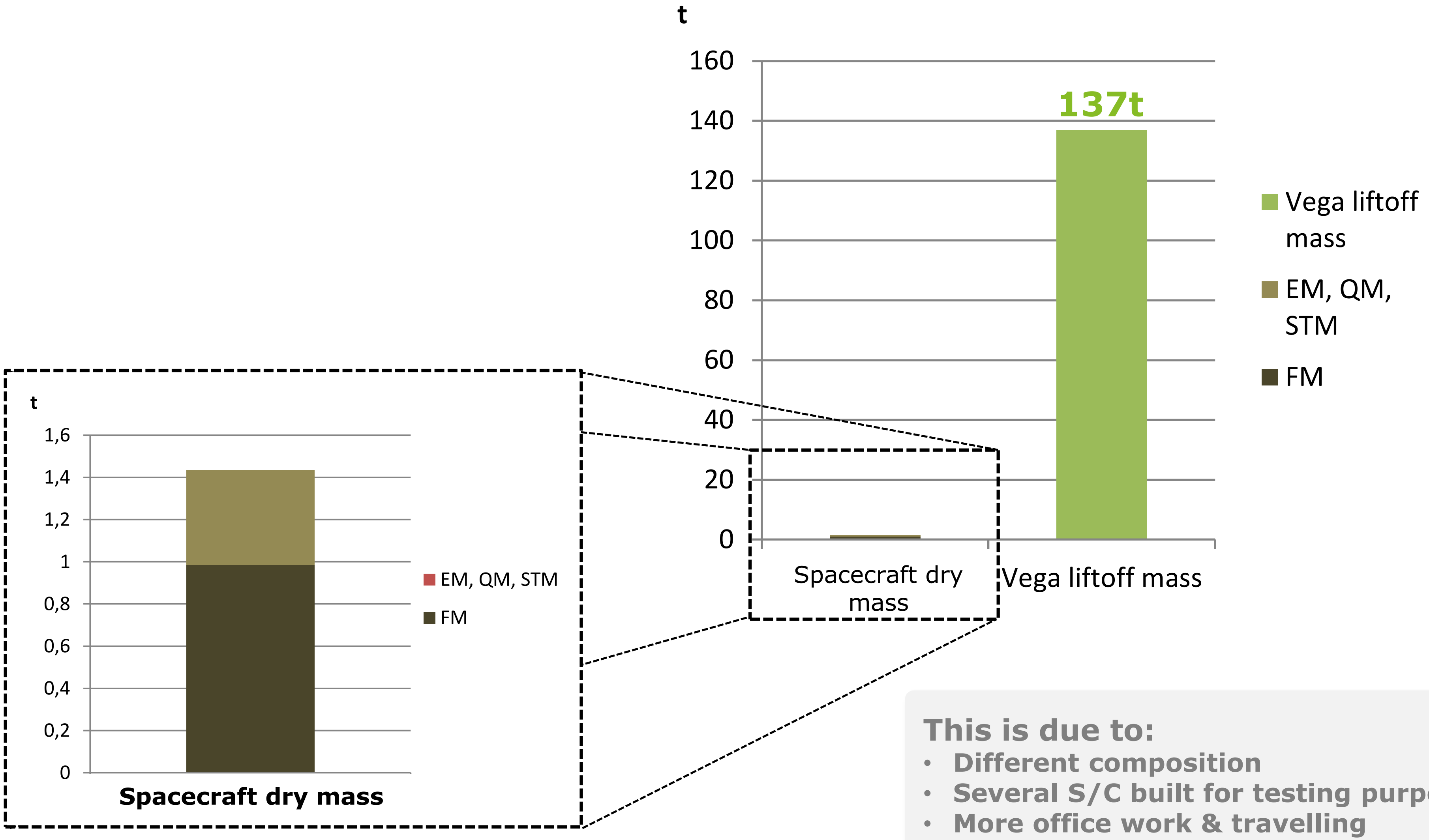




- Mass ratios:
  - EO: The dry mass of the S/C is about 1% of launcher's liftoff mass (1.4 t vs. 137 t)
  - Com: the dry mass of the S/C is about 0.3% of launcher's liftoff mass (2.2 t vs. 780 t)

Results of the LCA of space missions

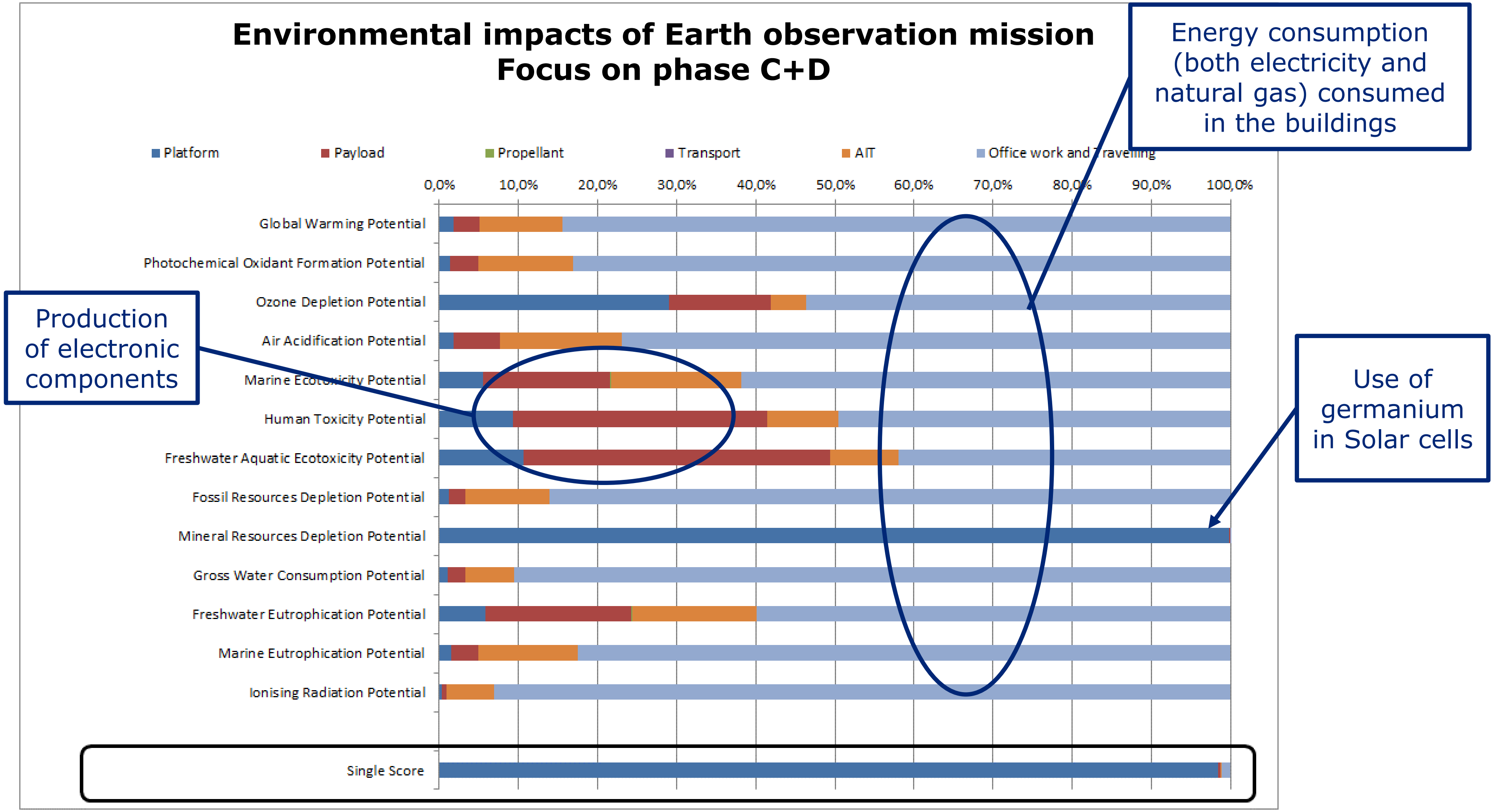
EO: phase C+D accounts for 20 to 40% (even 100% for mineral depletion potential) while dry mass of the spacecraft ~ 1% of Vega liftoff mass



This is due to:
- **Different composition**
- **Several S/C built for testing purposes**
- **More office work & travelling**

Results of the LCA of space missions

Focus on phase C+D: while office work is the main contributor to phase C+D, spacecraft components also contribute significantly to some impact categories



Results of the LCA of space missions

What are the key findings?

- **Launcher-related activities (phase E1b)**: main contributor to most environmental impacts of space missions.
- Other life-cycle steps also have significant contributions to the environmental impacts:
- **Definition, qualification and production of the spacecraft (phase C+D)** (raw material extraction, production, testing and transport of S/C models, office work and business travels):
  - main contributor on mineral resource depletion, due to the use of scarce materials.
  - Office work: also important contributor within this phase, due to the energy consumption of design buildings (office work)
- **The utilisation phase (phase E2)**, which covers ground segment activities performed during the routine phase, is also a major contributor on certain indicators, due to the electricity consumption of:
  - either control centres (case of the EO mission), or
  - ground stations for broadcast (case of the communication mission).
- **Feasibility + Preliminary definition (phase A+B)** is also an significant contributor to the impacts of space missions.

Key methodological points

Main challenges and how we addressed them

Methodology

First LCAs covering the entire life-cycle of space missions: no prior knowledge of the environmental hotspots

→

Iterative approach (4 iterations):
The LCA model was refined progressively, prioritising on the main hotspots

Data

Low level of availability of data representative of the space sector

- Specific materials, manufacturing & assembly processes
- Specific production chain: little recurrent production, almost "handmade"!

→

Collaboration with numerous experts (ESA and external):
e.g. definition of a "technical mapping": identification of the existing technological alternatives for each life-cycle step and subsystem of the spacecraft

How to populate an LCA database representative of a wide variety of space missions?
As many activities as possible had to be covered

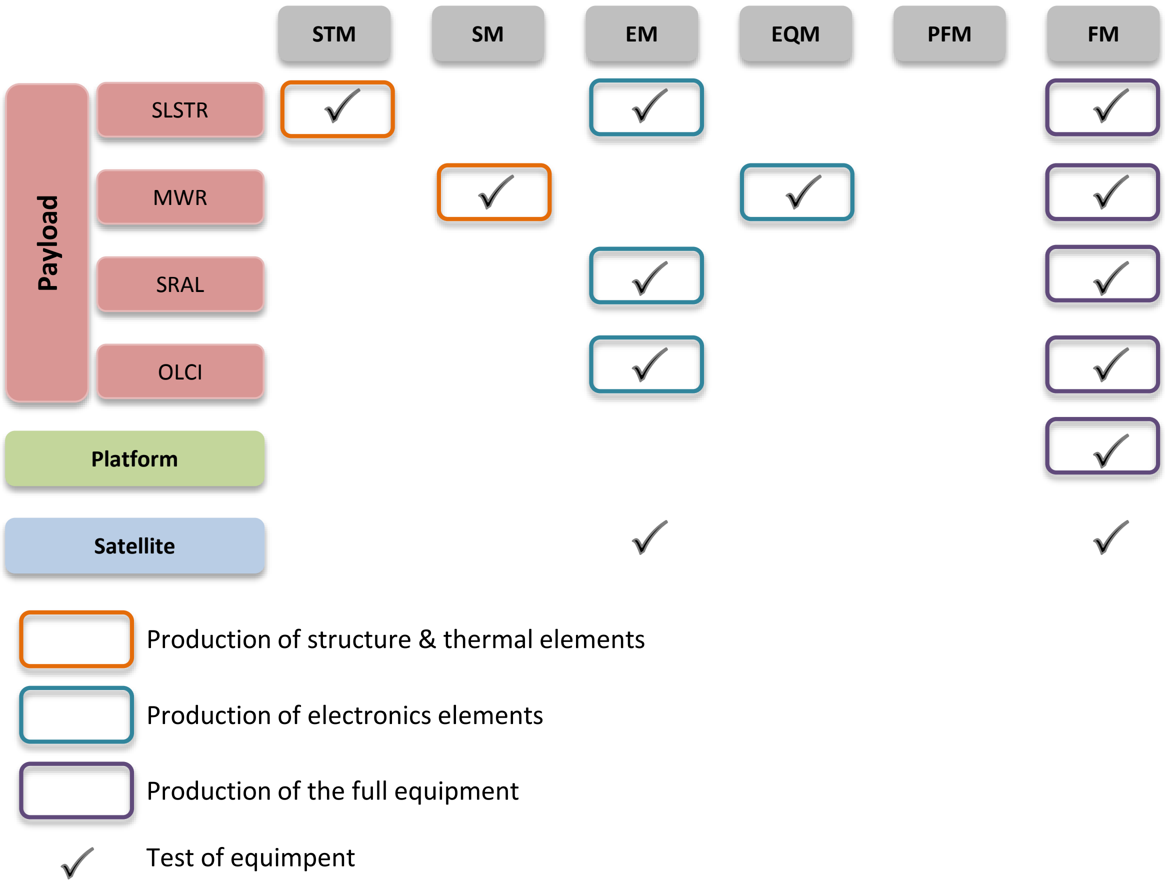
→

In parallel, ESA launched of a project dedicated to the development of an enhanced environmental database on space-specific activities (materials, processes and propellants)

Industry has a major role to play!

Key methodological points

Model philosophy for the EO mission



Conclusions

- Life Cycle Assessment is a relevant and efficient method for assessing the environmental performance of space activities: space launchers and space missions.
- The quality of environmental footprinting results (and thus the robustness of eco-design choices) will be improved with the development of the environmental database specific to the space sector.
  - Data quality can be improved with the implication of industry
- LCA is applicable to the entire life-cycle of a space mission in a cost-effective way!
- LCA can be used for the eco-design of space activities and can help anticipate future clients' requests, stakeholders' expectations and future environmental legislation

> *Please come to the presentation of the eco-design tool this afternoon!*

Thank you for your attention!

Any questions?

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