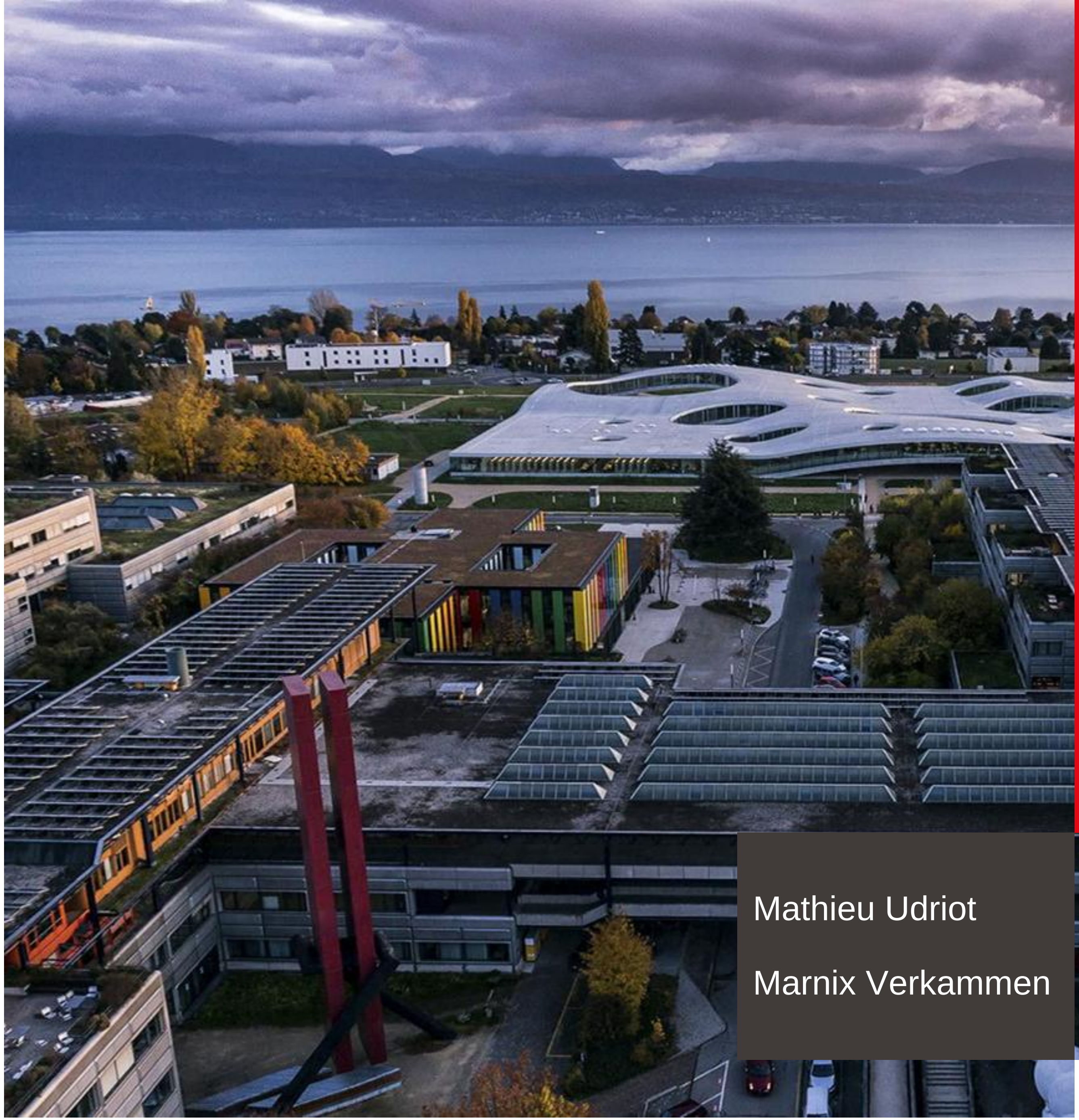


EE-587

L8 – Life Cycle Assessment

Mathieu Udriot

Marnix Verkammen

Spring 2025

LCA and ecodesign – lectures over 3 weeks

Lecture	Date	Time	Detailed agenda
L08	07.04.25	1415	Intro
		1430	LCA
		1445	LCA
		1515	LCA in space
		1530	Gaps
		1545	Ecodesign (intro)
L09	14.04.25	1415	Refresh
		1425	LCA in energy sector + ACT project (LCA expert testimony)
		1445	Example + intro to project
		1515	Time for project
		1530	
		1545	
L10	28.04.25	1415	Refresh
		1430	Ecodesign
		1445	Ecodesign / handbook / application with CHESS
		1515	Time for project
		1530	
		1545	

Learning outcomes

- Understand the importance of **life cycle thinking** in ecodesign (in the space sector)
- Know and apply the basics of LCA as standardised in ISO norms:
  - **Goal** and scope: What/why to assess
  - Life Cycle Inventory: It's all about **data**
  - Calculate and **interpret** Life Cycle Impact Assessment results
- Learn the basics of **prospective** LCA
- Learn about methodology of Life Cycle Assessment (LCA) **for space**:
  - Mission life cycle phases
  - Key hotspots and points of attention
  - Known knowledge gaps
- Understand the relevance for your future position

EPFL

Your current knowledge

Instructions

Go to

www.menti.com

Enter the code

5289 2960

Or use QR code

eSpace

Introduction and context

Space sustainabilities

Timely topic

The role of LCA

A bit of history

“Space sustainabilities” ?

Sustainability **from space**

“ Using space as a platform to directly or indirectly address global problems. ”

- Getting space data from earth observation (EO) satellites
- Using space assets for problems on Earth (GNSS)

Sustainability **in space**

“ Viewing space as a natural resource for preservation, exploitation and exploration. ”

- Risk mitigation and management of space debris,
- Preservation of Dark & Quiet Skies

Sustainability **for space**

“ Protecting the terrestrial environment from the impacts of space activities. ”

- Assessing the impacts using Life Cycle (Sustainability) Assessment
- Mitigating impacts using ecodesign

Cited from: Wilson, A. R., & Vasile, M. (2023). The space sustainability paradox. Journal of Cleaner Production. DOI: 10.1016/j.jclepro.2023.138869

A timely topic

- Climate change and planetary boundaries… **No planet B**.
- Growth from ~200 launches / year now to ~1700 in 2030 ! → ~5% of total ozone loss ?
- LCA of space systems was a topic in major **conferences** recently:
  Stuttgart workshop, CleanSpace Days 2024, International Astronautical Congress 2024
- Systems, propulsion engineers, and climate scientists start to work **together**
- Several **LCA studies** are done by industries and agencies
  CSD: Galileo; Copernicus sats: CO2M, CRISTAL, LSTM; Nyx; Maiaspace, Ariane “NEXT”; ground segments; technologies; etc.
- Many are trying to **simplify** the LCA to apply it earlier and support ecodesign
- A lot of **misunderstanding** and incorrect shortcuts → common language

“Green” propellant

“Clean” technology

“Reusability = sustainability”

Examples for studies presented at CSD 2024

Topic	Study goals	Functional Unit	Link
Copernicus mission (CO2M)	Identify environmental impacts of the mission, Identify the hotspots Identify possible improvements to be flown down to future space programs	*Definition, production, testing and spacecraft-related launch activities of the space segment of the CO2M mission (launch/ground segment excluded)*	https://indico.esa.int/event/516/contributions/9942/
Galileo Satellites provided by Airbus (G2GB1)	Identify environmental hotspots of G2GB1 Propose mitigation actions through eco-design approaches Create input datasets for LCA of future missions	*The definition, manufacturing, integration, qualification, testing and preparation for launch of the Galileo Second Generation Satellite Batch 1 space segment to fulfil its requirements.*	https://indico.esa.int/event/516/contributions/9953/
CRISTAL mission (Arctic/Southern Ocean sea-ice thickness and snow depth) **LSTM mission** (land surface temperature)	See above.	*The manufacturing, integration, qualification, testing and preparation for launch of the CRISTAL/LSTM space segment to fulfil its requirements.*	https://indico.esa.int/event/516/contributions/9949/
Satellite **communication system service**	Environmental impacts of video distribution by 2030		https://indico.esa.int/event/516/contributions/9943/
In-space propulsion system	Comparison of the production of propellants, and propellants used for mission; Architecture vs. propellant loading	*Production/Loading of 1 kg propellant*	https://indico.esa.int/event/516/contributions/9941/
Future **reusable launchers**	Screening LCA: Compare two families of reusable launchers and compare equivalent systems with different propellants	*Sum(Xi kg of payload to orbit Yi) with launcher classes small to super heavy*	https://indico.esa.int/event/516/contributions/9946/

The role of LCA

Europe in general

LCA **influences many EU policies**, mostly for carbon footprints, e.g.

- Critical Raw Materials Act / Net Zero Industry Act
- Batteries regulation
- EU Ecolable, Regulation on Eco-design for Sustainable Products

LCA based **indicators for monitoring sustainable production and consumption**, e.g. as Consumption Footprint official indicator for Circular Economy Action Plan / Sustainable Development Goal 12

(https://eplca.jrc.ec.europa.eu/sustainableConsumption.html)

In the space sector

Starting to play a role for European actors only, but not (knowingly) discussed within NASA, SpaceX, CN/RU/IN

- **Used by ESA directorates**
  Cleanspace Office, Climate and Sustainability Office, Future Launchers Preparatory Programme;
- **ESA Green Agenda** (must be **monitored**)
  ESA goal: 46% GHG reduction by 2030 (-28% in scope 3) – LCA mandatory for all missions!
- **Industries / agencies** perform LCAs
  → reporting, CSR, coming slowly for ecodesign
- **EU commission**: Space Product Environmental Footprint Category Rules → Will feed into EU space law

LCA context: SDGs

Life Cycle Impact Assessment: potential impact in 16 impact categories linked with SDGs

Each emission to the environment and resource used collected in the inventory is then characterized in terms of potential environmental impacts in the life cycle impact assessment phase, covering the 16 impact categories recommended for the Environmental Footprint.

3 GOOD HEALTH AND WELL-BEING

- Human toxicity, cancer
- Human toxicity, non-cancer
- Particulate matter
- Photochemical ozone formation
- Ionising radiation

6 CLEAN WATER AND SANITATION

- Impact due to water use
- Ecotoxicity
- Eutrophication

13 CLIMATE ACTION

- Climate chance
- Impact due to resource use
- Ozone depletion

14 LIFE BELOW WATER

- Eutrophication marine and freshwater
- Ecotoxicity

15 LIFE ON LAND

- Impact due to land use
- Eutrophication terrestrial
- Acidification
- Impact due to mineral and metal resource use
- Ozone depletion

A bit of history

60s

https://www.packagingoftheworld.com/2015/05/coca-cola-true-friendship.html

80s

"Ecobalances"

"Resource and Environmental Profile Analysis"

first widely used commercial LCA software

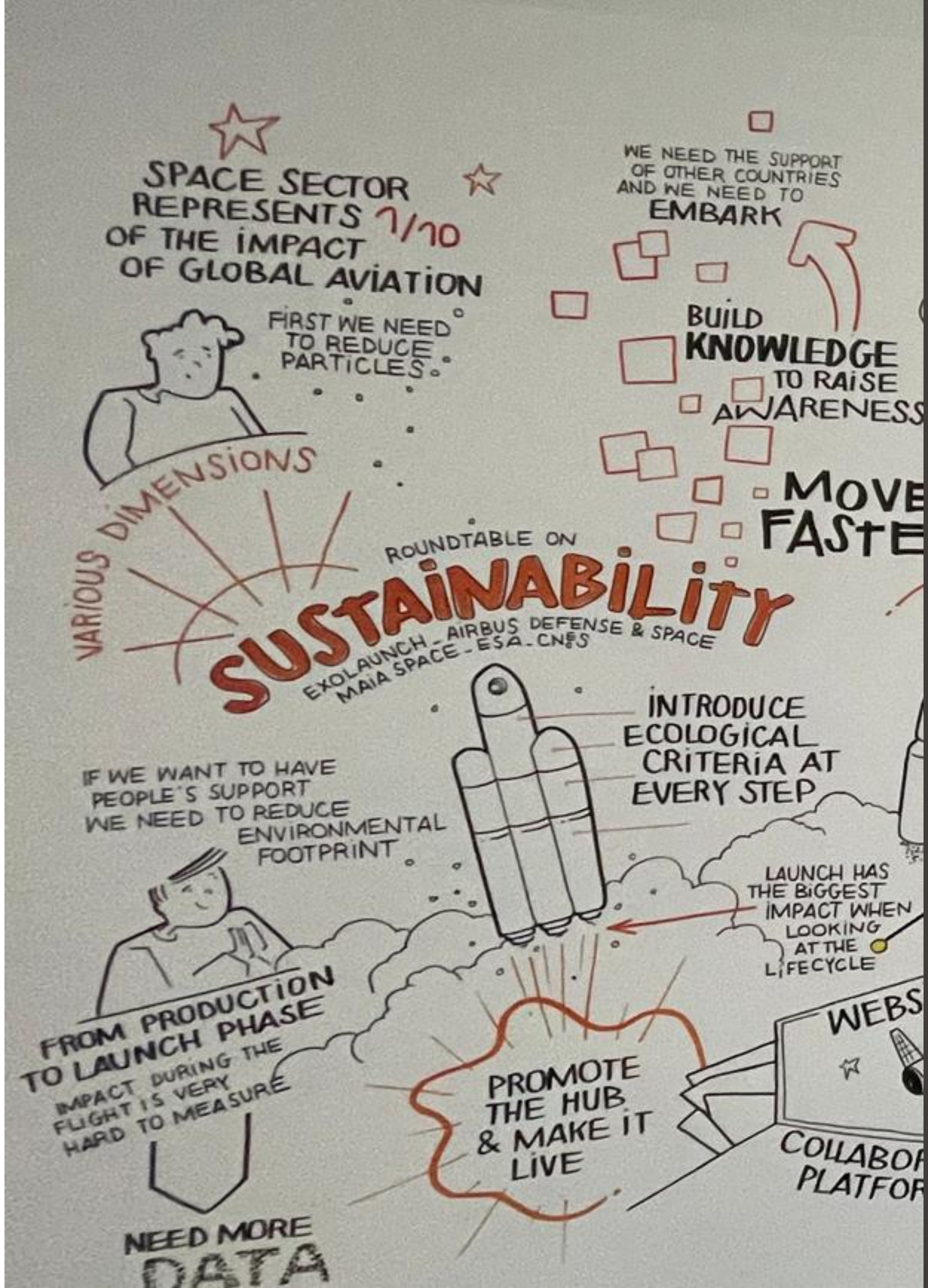
90s onwards

"Life cycle assessment"

more software / database / impact assessment methods

2024

Reproducibility, transparency
More «realistic» modelling
Coupling with other databases / models
Open source
Implementation in policies / regulations



Life cycle assessment

Overview of the methodology

Goal and scope

Inventory

Impact assessment

Interpretation

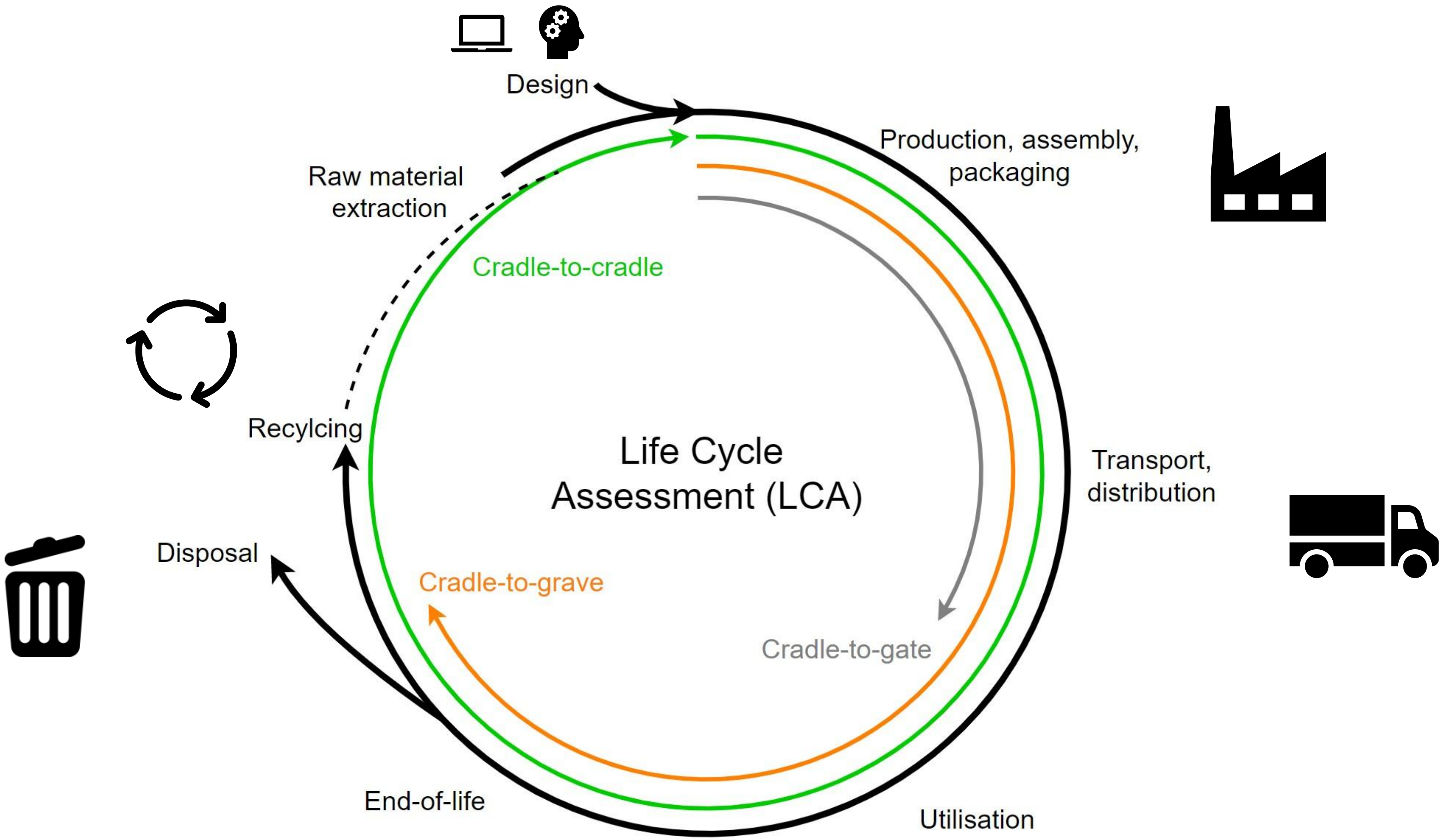
Metrics for impacts on Earth

- Life Cycle Assessment (LCA, see more later)
- Risk Analysis (toxicity)
- Environmental Impact Assessment (only local)
- Material Flow Analysis (in // to supply / cost)
- Carbon footprint
- Water footprint

https://psyche.asu.edu/mission/launch

EPFL

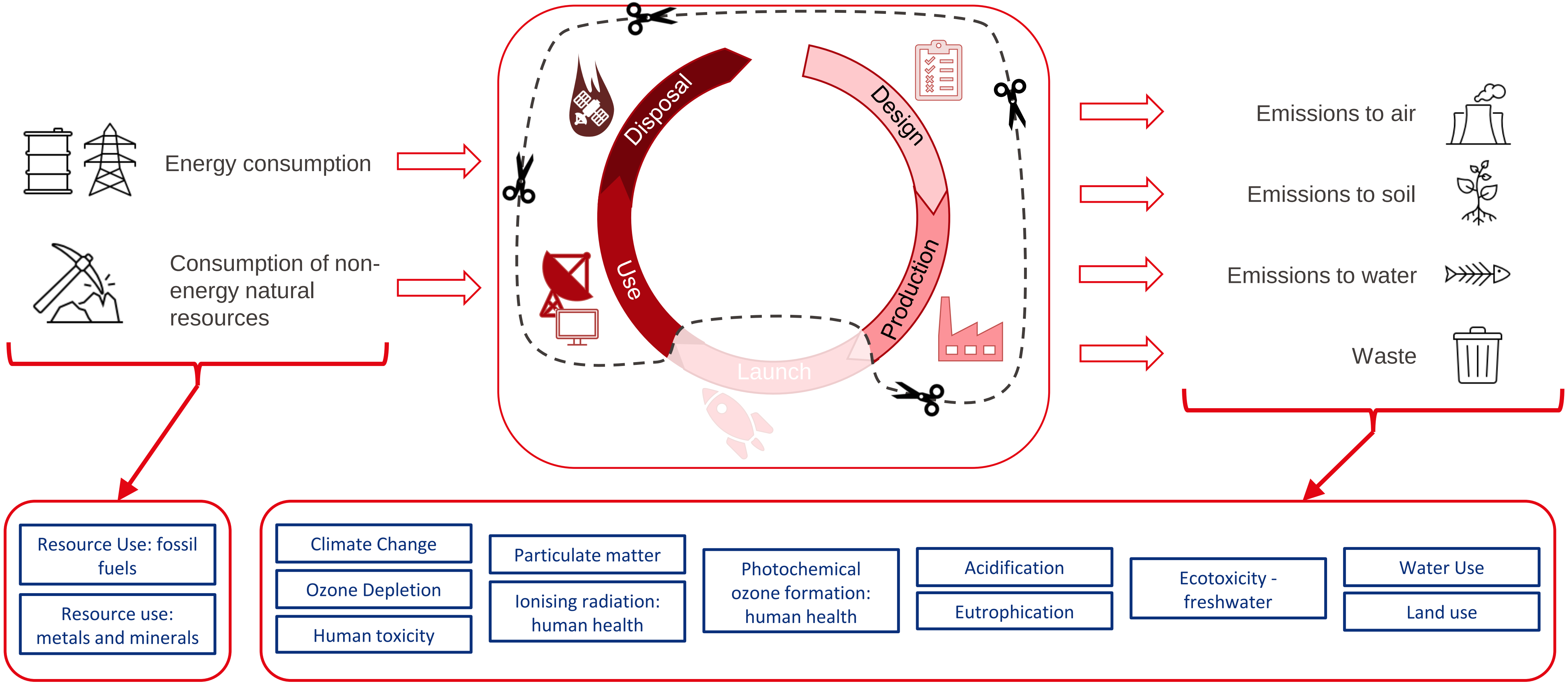
Introduction to life cycle assessment (LCA)



Adapted from https://ecochain.com

Overview of LCA methodology

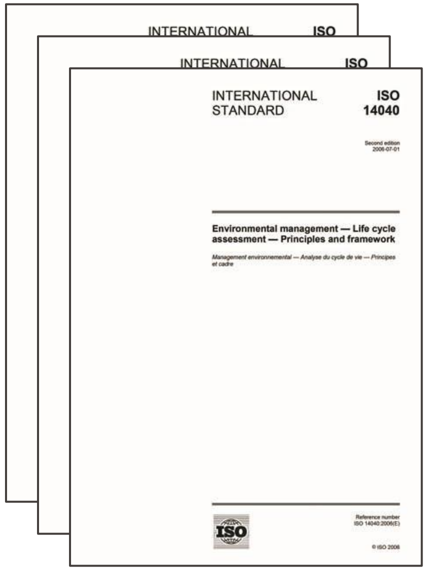
Life cycle stages, LCA boundary definition, inputs, outputs, impact indicators



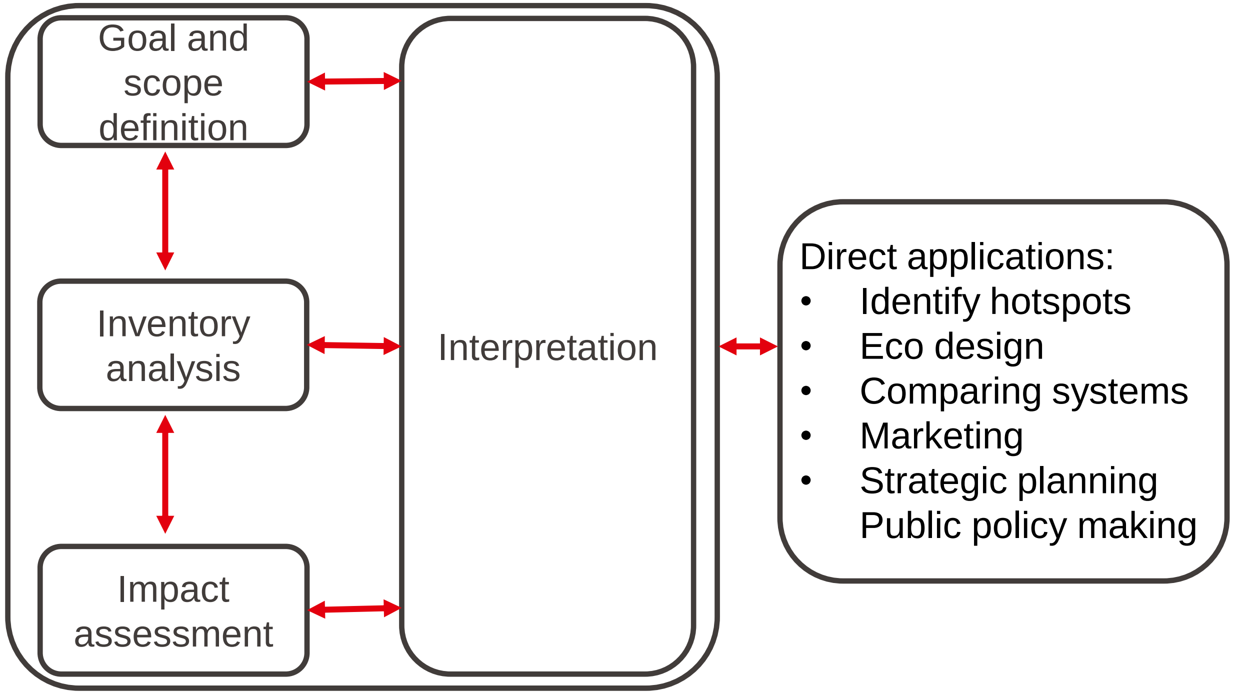
Introduction to life cycle assessment (LCA)

ISO standards

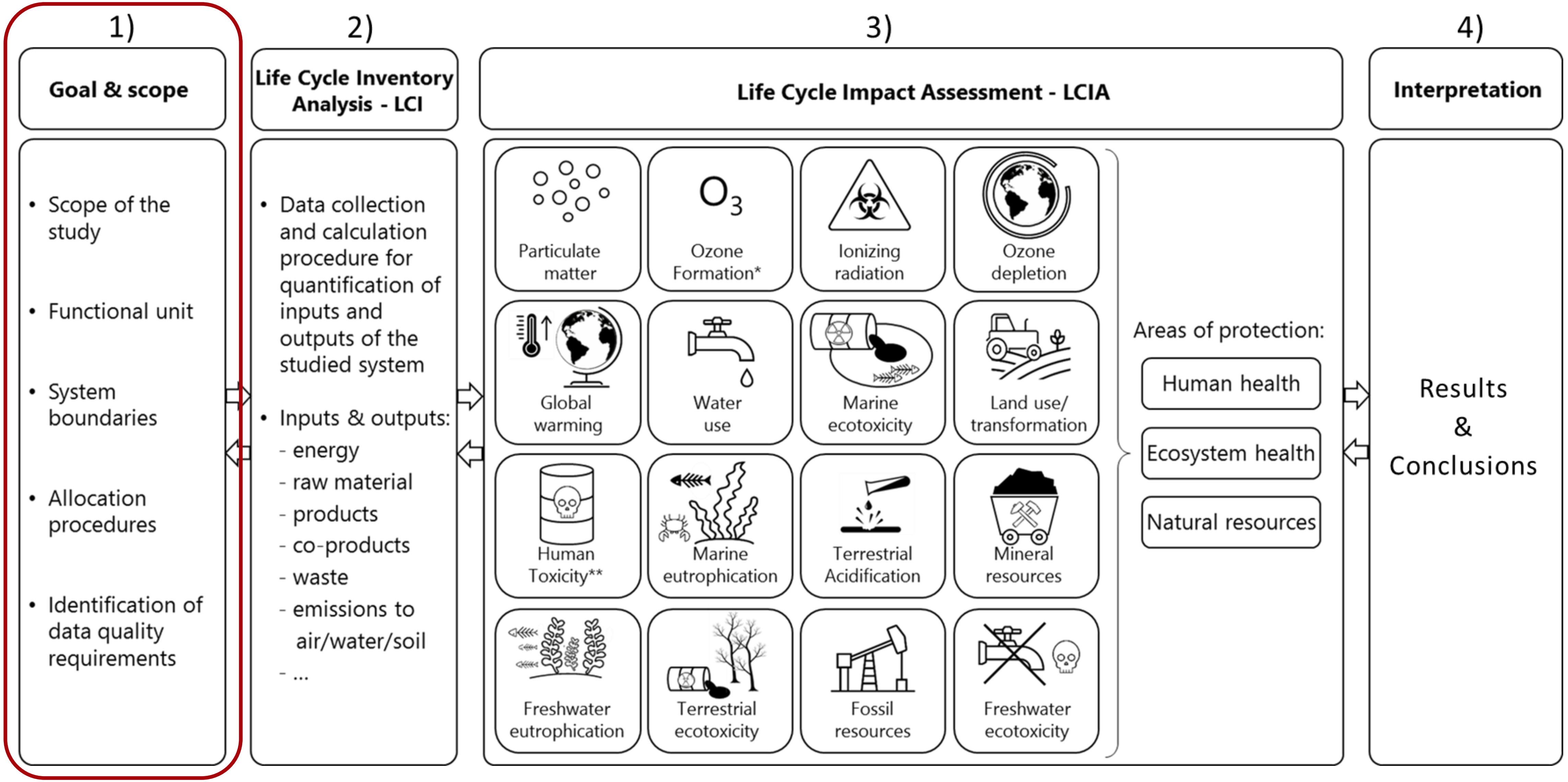
- 14040 = Principles and framework
- 14044 = Requirements and guidelines
- 14047 = illustrative examples



Life Cycle Assessment (LCA)
(adapted from ISO 14040)



Scientific LCA framework: ISO 14044/14044



LCA – goal and scope definition

Functional unit: quantified performance of a product system for use as a reference unit [in an LCA]. (ISO 14040)

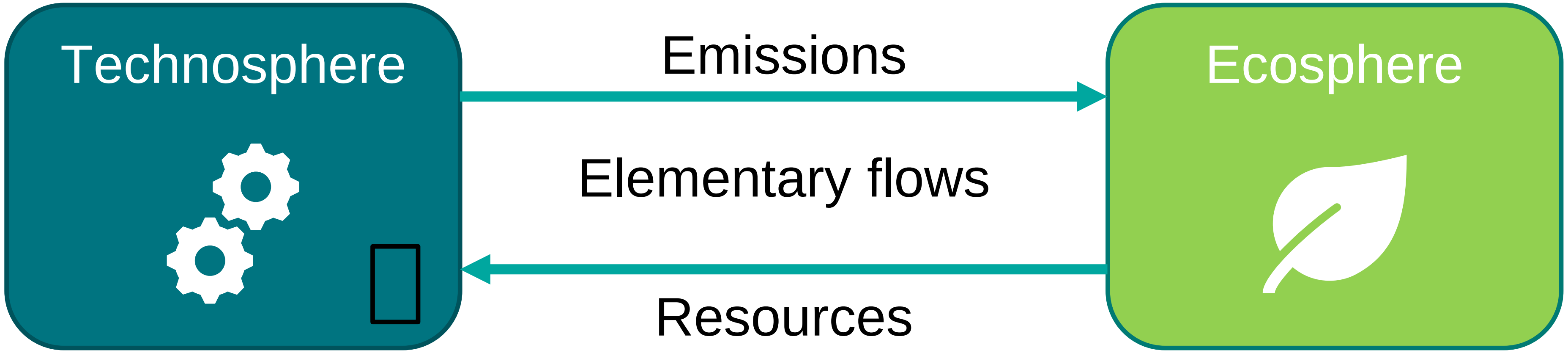
To describe the product / service by answering PEF expectation:

- Function / service provided (what)
- Magnitude (how much)
- Duration / lifetime (how long)
- Expected level of quality (how well)
- (Where and when)

} Action verb, quantitative

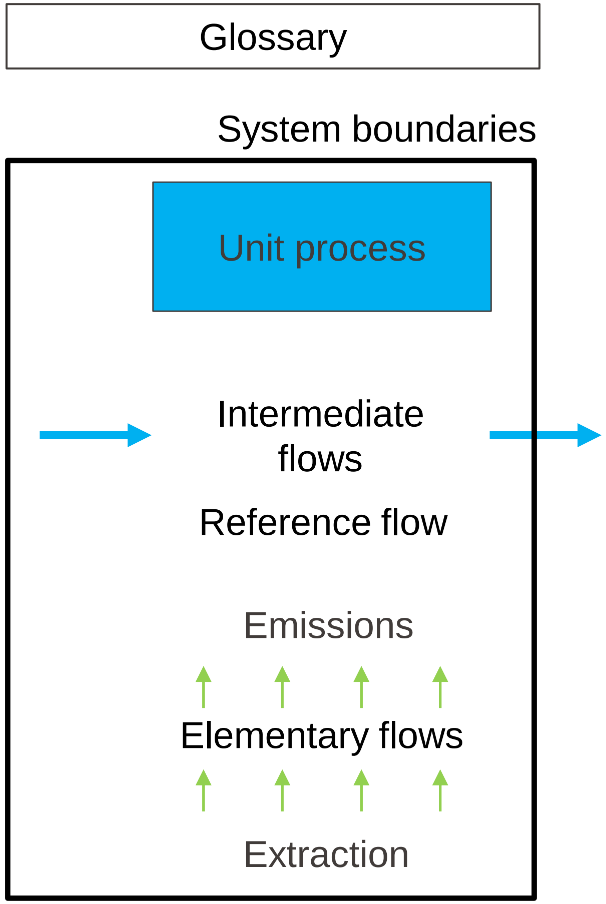
To allow comparisons

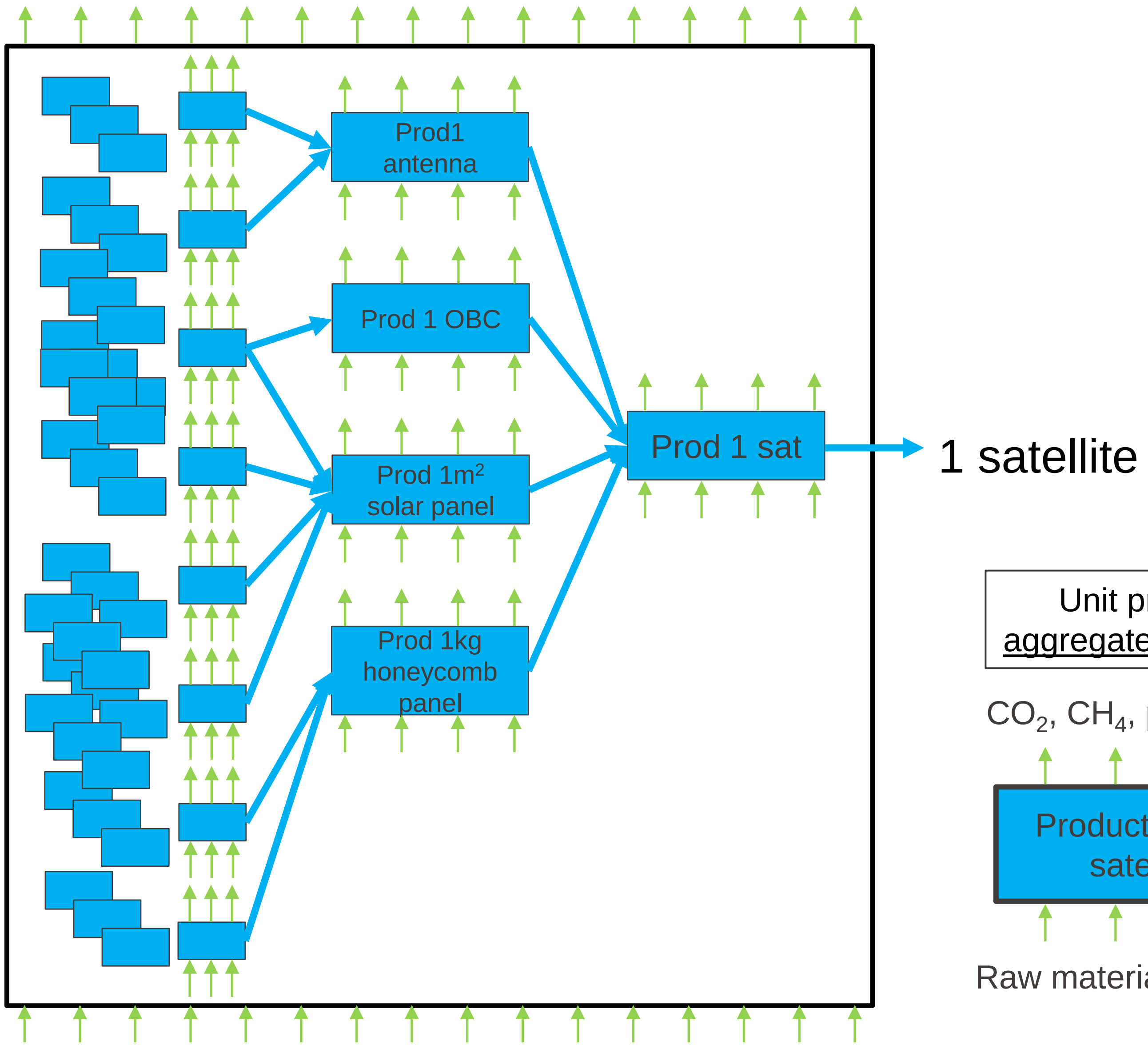
LCA – goal and scope definition



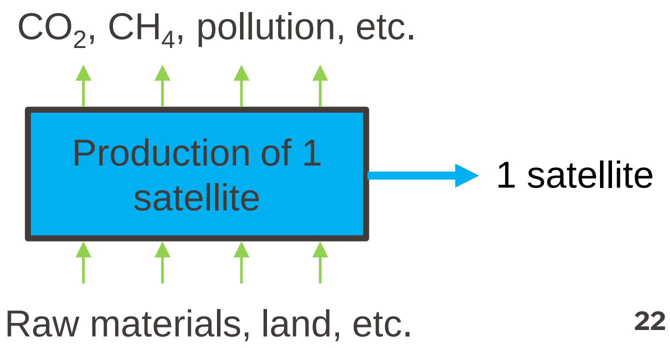
Adapted from "Introduction à l'Analyse du Cycle de Vie - de la pensée à la pratique », EdX

LCA – goal and scope definition





Unit processes can be <u>aggregated</u> in LCA databases



Scientific LCA framework: ISO 14044/14044

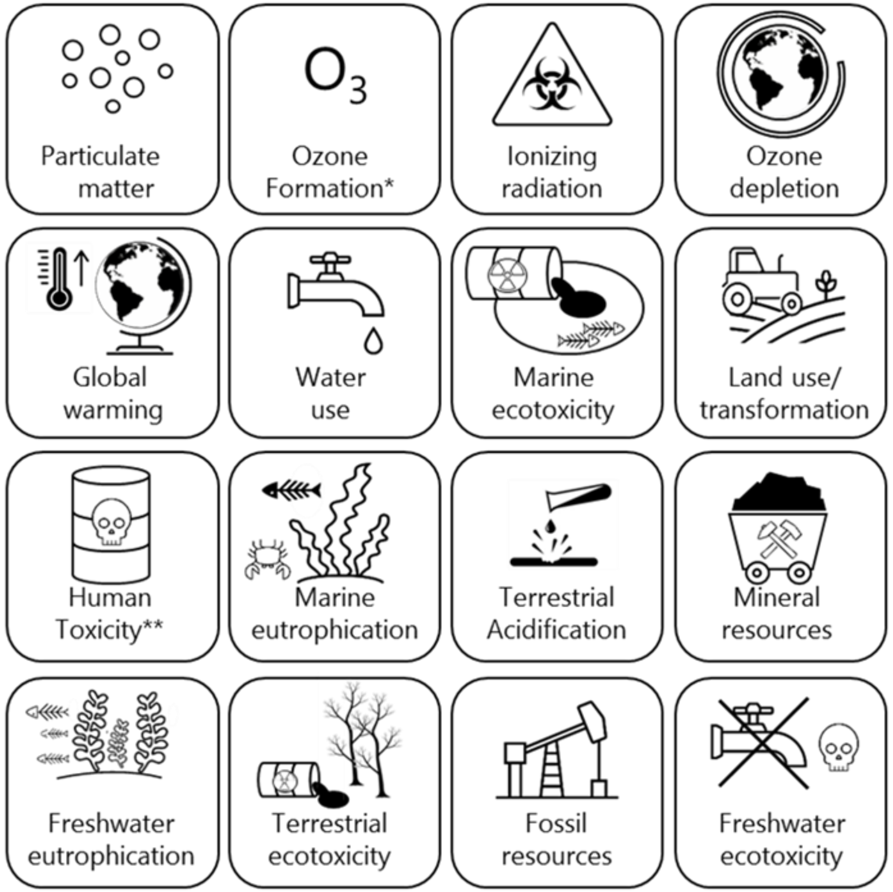
1) Goal & scope

- Scope of the study
- Functional unit
- System boundaries
- Allocation procedures
- Identification of data quality requirements

2) Life Cycle Inventory Analysis - LCI

- Data collection and calculation procedure for quantification of inputs and outputs of the studied system
- Inputs & outputs:
  - energy
  - raw material
  - products
  - co-products
  - waste
  - emissions to air/water/soil
  - ...

3) Life Cycle Impact Assessment - LCIA



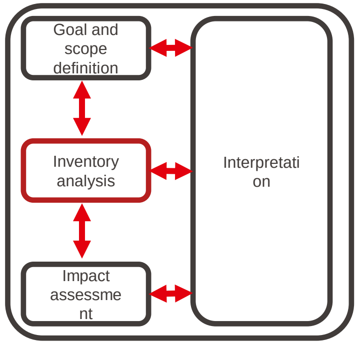
Areas of protection:

- Human health
- Ecosystem health
- Natural resources

4) Interpretation

Results & Conclusions

Life cycle inventory



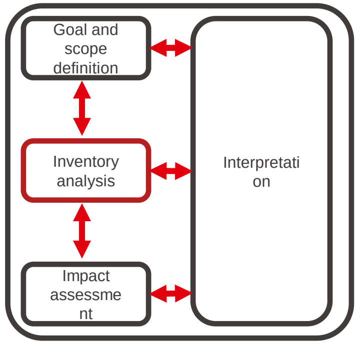
Potential sources

- Project proposal
- Product tree
- Contracts
- Heritage missions
- Mass budget / Bill of Materials
- Test plans
- DML/DPL
- Facilities
- ESA LCA guidelines
- Literature
- On-site measurements
- …

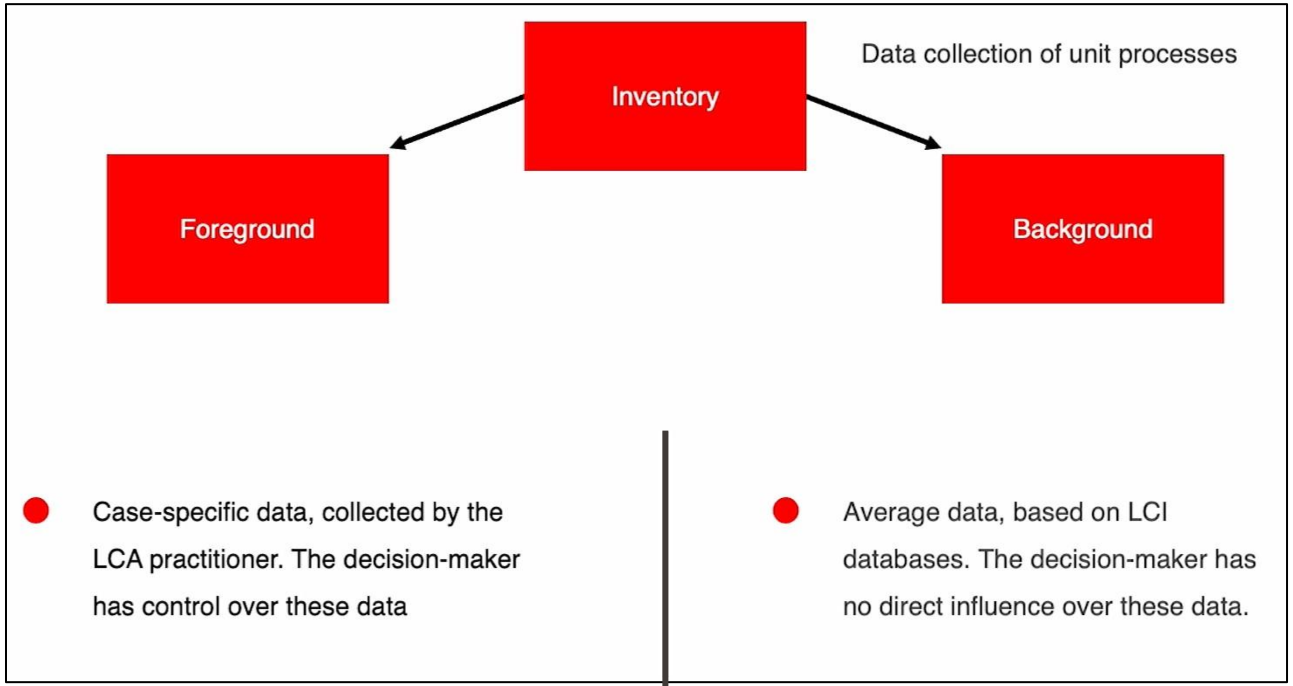
Data collection → Mapping of inventories (using databases)

E.g. “10kg aluminium” with 10kg associated to *Aluminium generic part AA 2219, RER*

Foreground and background data



Ecoinvent e-learning, Fundamentals of the Database (Module 1A).



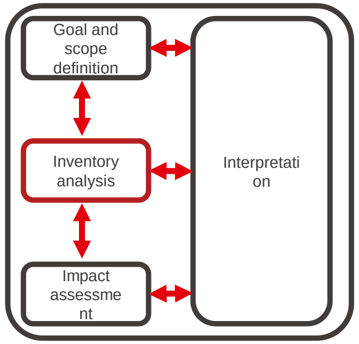
Parameters of the system under study

Technosphere in the background
- Extraction of raw material
- Electricity production & mixes
- Transportation fleet average
- …

Possible sources: Measurements, stoichiometric calculation, Bill of Material, engineers, expert interviews, literature

Possible sources: Expert interviews, literature, reports, **LCI databases**, proxies

Transparent documentation of sources, assumptions, modeling choices, data, calculation is crucial !

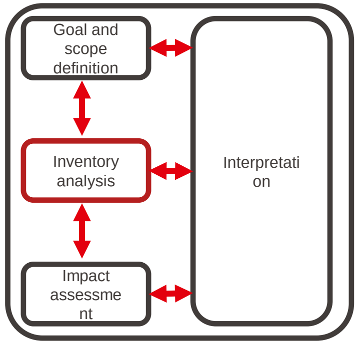


Exercise:

(Mentally) decompose an object in front of you (a pen, a cup of tea, a smartphone, …)

to create its inventory

Life cycle inventory example

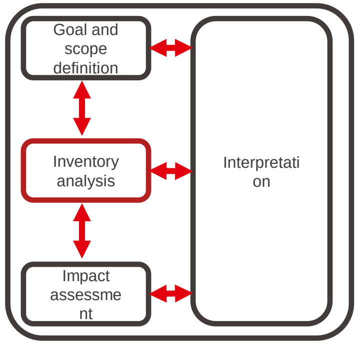


- Life cycle inventory of a pen

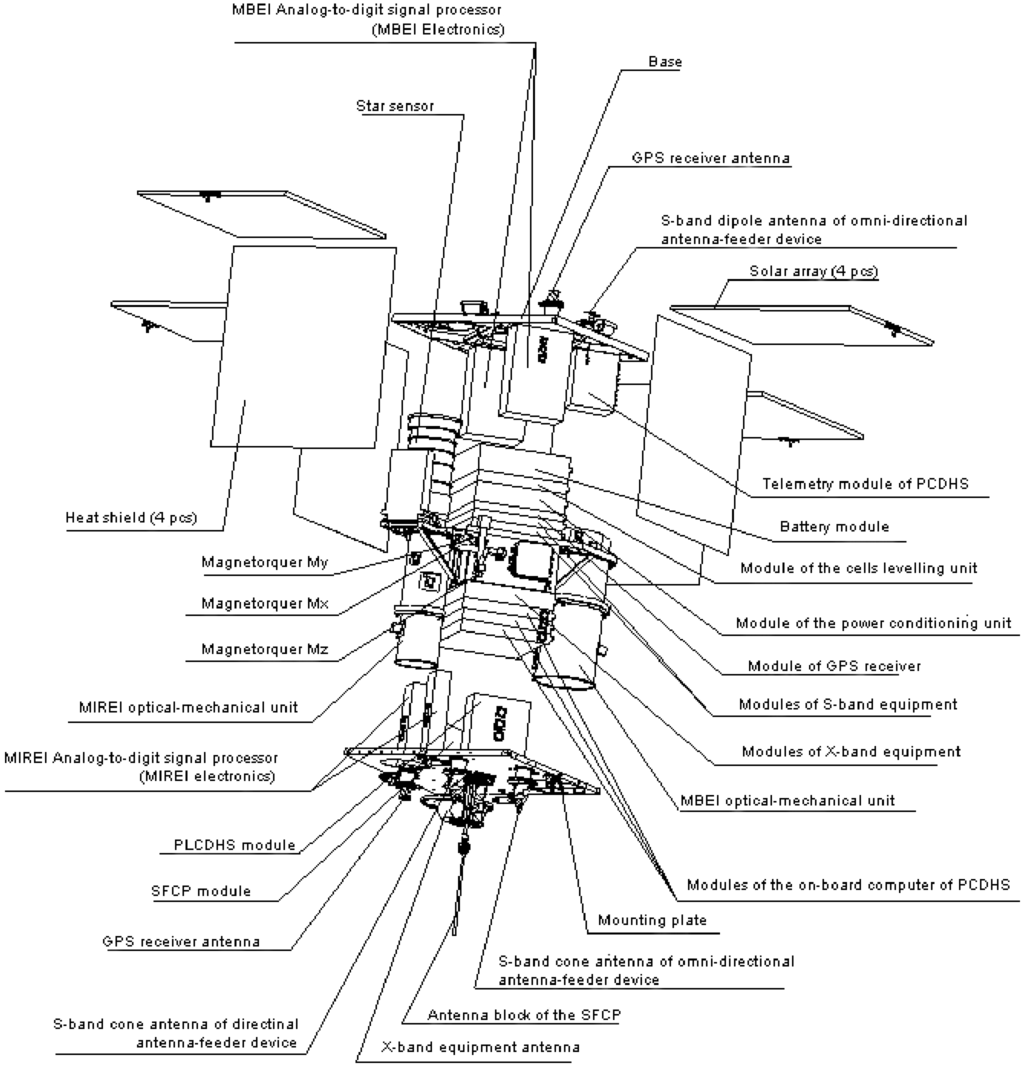
Activity	Qty	Unit	Comment
Polystyrene barrel	1E-3	kg	Raw material extraction and emissions
Polypropylene tube and caps	1E-3	kg	Raw material extraction and emissions
Brass tip	2E-3	kg	Raw material extraction and emissions
Tungsten carbide ball	1E-4	kg	Raw material extraction and emissions
Ink	2E-2	l	Raw material extraction and emissions
Manufacturing/Assembly processes	1	unit	Energy consumption and emissions
Transport to shop	1E-3	ton·km	Very small emissions for 1 pen, but cumulatively significant if many pens ?
Storage	1	unit	Waste from losses ?
Customer transport to shop	10	pers·km	1 person 10km, emissions
Utilisation ?	1	unit	Health risk, leak in environment ?
End-of-life process (management of waste)	5E-3	kg	Health risk, leak in environment ?

https://fr.wikipedia.org/wiki/Bic_Cristal

Now imagine the same for a spacecraft or a launch vehicle !

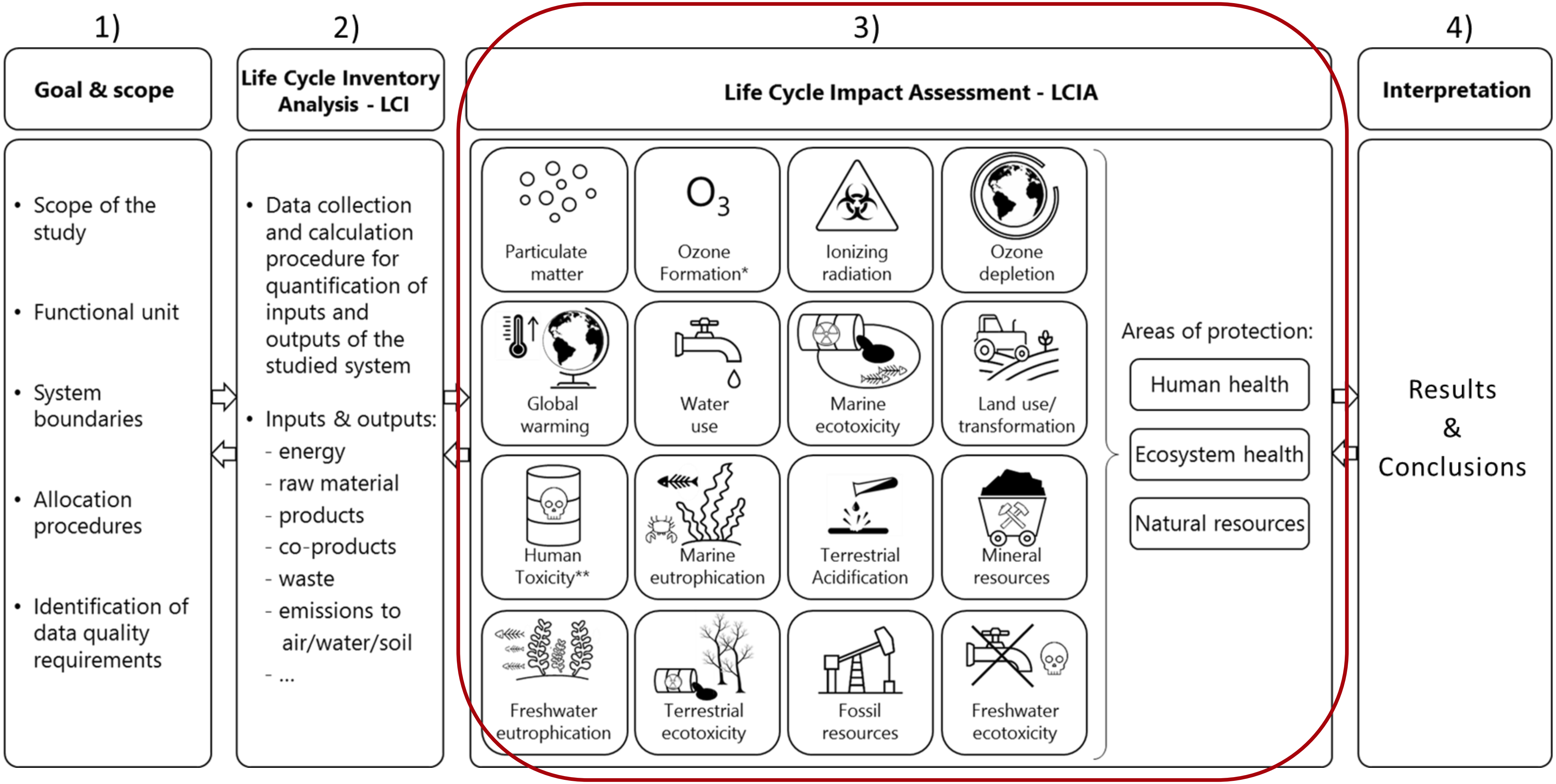


→ Need a software and a database ! (with aggregated datasets)

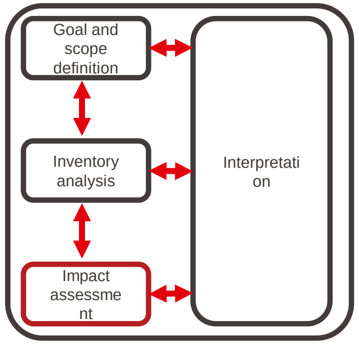


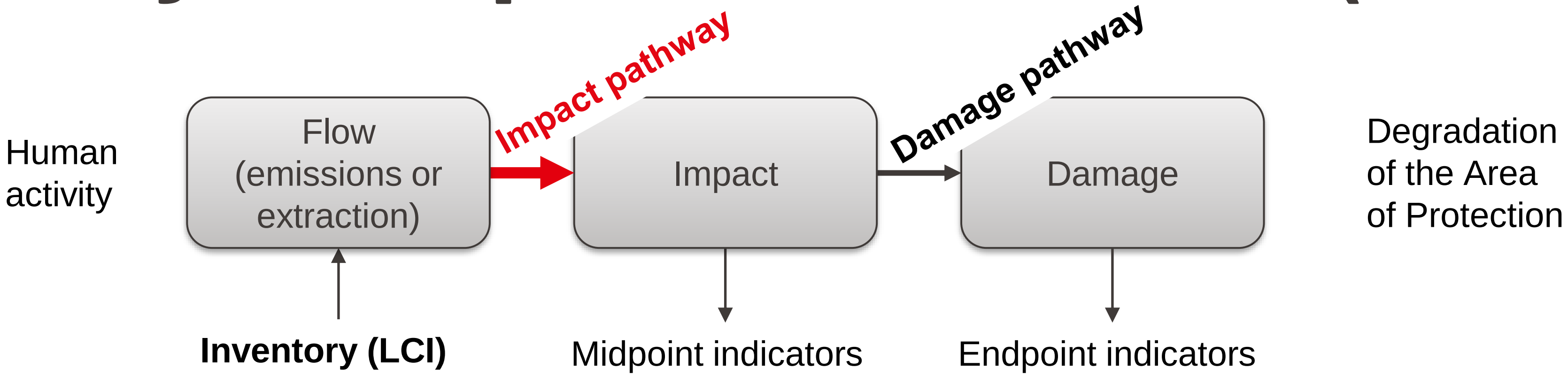
Abdelal, Gasser & Atef, Ayman. (2010). THERMAL DEFORMATION ANALYSIS OF MICROSATELLITE STRUCTURE.

Scientific LCA framework: ISO 14044/14044

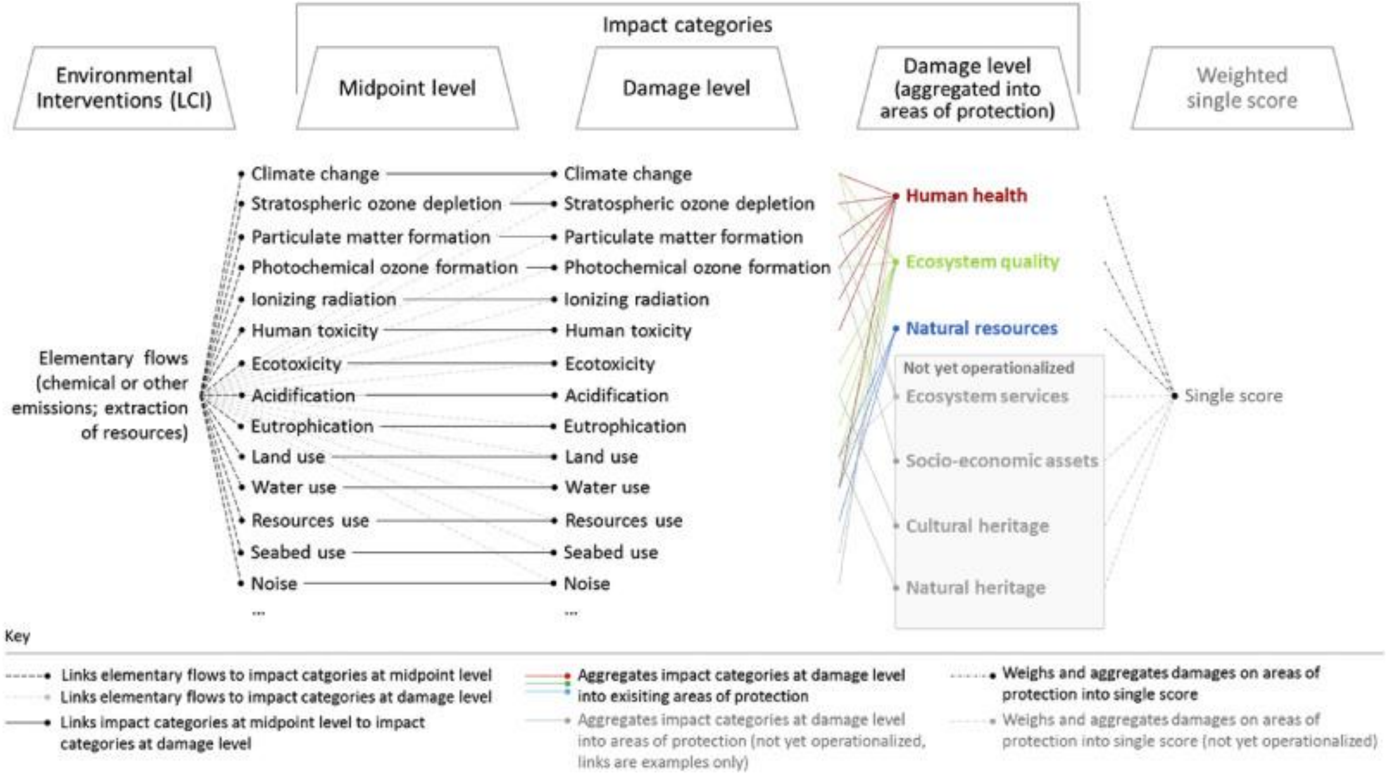


Life cycle impact assessment (LCIA)





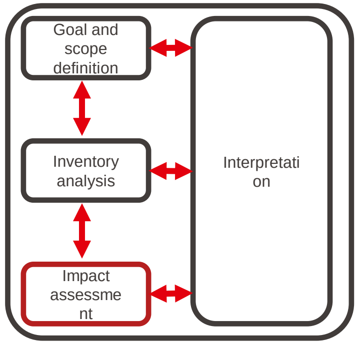
Characterisation factors (**CFs**) are computed with a methodology (for each flow for each impact indicator)



Verones et al., "LCIA framework and cross-cutting issues guidance within the UNEP-SETAC Life Cycle Initiative", J. Clean. Prod., 161 (2017), pp. 957-967, 10.1016/j.jclepro.2017.05.206

Table 1 Overview of the midpoint impact categories and related indicators

Midpoint impact category	Indicator	CF_m	Unit	Key references
Climate change	Infrared radiative forcing increase	Global warming potential (GWP)	kg CO_2-eq to air	IPCC 2013; Joos et al. 2013
Ozone depletion	Stratospheric ozone decrease	Ozone depletion potential (ODP)	kg CFC-11-eq to air	WMO 2011
Ionising radiation	Absorbed dose increase	Ionising radiation potential (IRP)	kBq Co-60-eq to air	Frischknecht et al. 2000
Fine particulate matter formation	PM2.5 population intake increase	Particulate matter formation potential (PMFP)	kg PM2.5-eq to air	Van Zelm et al. 2016
Photochemical oxidant formation: terrestrial ecosystems	Tropospheric ozone increase	Photochemical oxidant formation potential: ecosystems (EOFP)	kg NOx-eq to air	Van Zelm et al. 2016
Photochemical oxidant formation: human health	Tropospheric ozone population intake increase	Photochemical oxidant formation potential: humans (HOFP)	kg NOx-eq to air	Van Zelm et al. 2016
Terrestrial acidification	Proton increase in natural soils	Terrestrial acidification potential (TAP)	kg SO_2-eq to air	Roy et al. 2014
Freshwater eutrophication	Phosphorus increase in freshwater	Freshwater eutrophication potential (FEP)	kg P-eq to freshwater	Helmes et al. 2012
Human toxicity: cancer	Risk increase of cancer disease incidence	Human toxicity potential (HTPc)	kg 1,4-DCB-eq to urban air	Van Zelm et al. 2009
Human toxicity: non-cancer	Risk increase of non-cancer disease incidence	Human toxicity potential (HTPnc)	kg 1,4-DCB-eq to urban air	Van Zelm et al. 2009
Terrestrial ecotoxicity	Hazard-weighted increase in natural soils	Terrestrial ecotoxicity potential (TETP)	kg 1,4-DCB-eq to industrial soil	Van Zelm et al. 2009
Freshwater ecotoxicity	Hazard-weighted increase in freshwaters	Freshwater ecotoxicity potential (FETP)	kg 1,4-DCB-eq to freshwater	Van Zelm et al. 2009
Marine ecotoxicity	Hazard-weighted increase in marine water	Marine ecotoxicity potential (METP)	kg 1,4-DCB-eq to marine water	Van Zelm et al. 2009
Land use	Occupation and time-integrated land transformation	Agricultural land occupation potential (LOP)	$m^2 \times$ yr annual cropland-eq	De Baan et al. 2013; Curran et al. 2014
Water use	Increase of water consumed	Water consumption potential (WCP)	m^3 water-eq consumed	Döll and Siebert 2002; Hoekstra and Mekonnen 2012
Mineral resource scarcity	Increase of ore extracted	Surplus ore potential (SOP)	kg Cu-eq	Vieira et al. 2016a
Fossil resource scarcity	Upper heating value	Fossil fuel potential (FFP)	kg oil-eq	Jungbluth and Frischknecht 2010



Differences in LCIA methods:

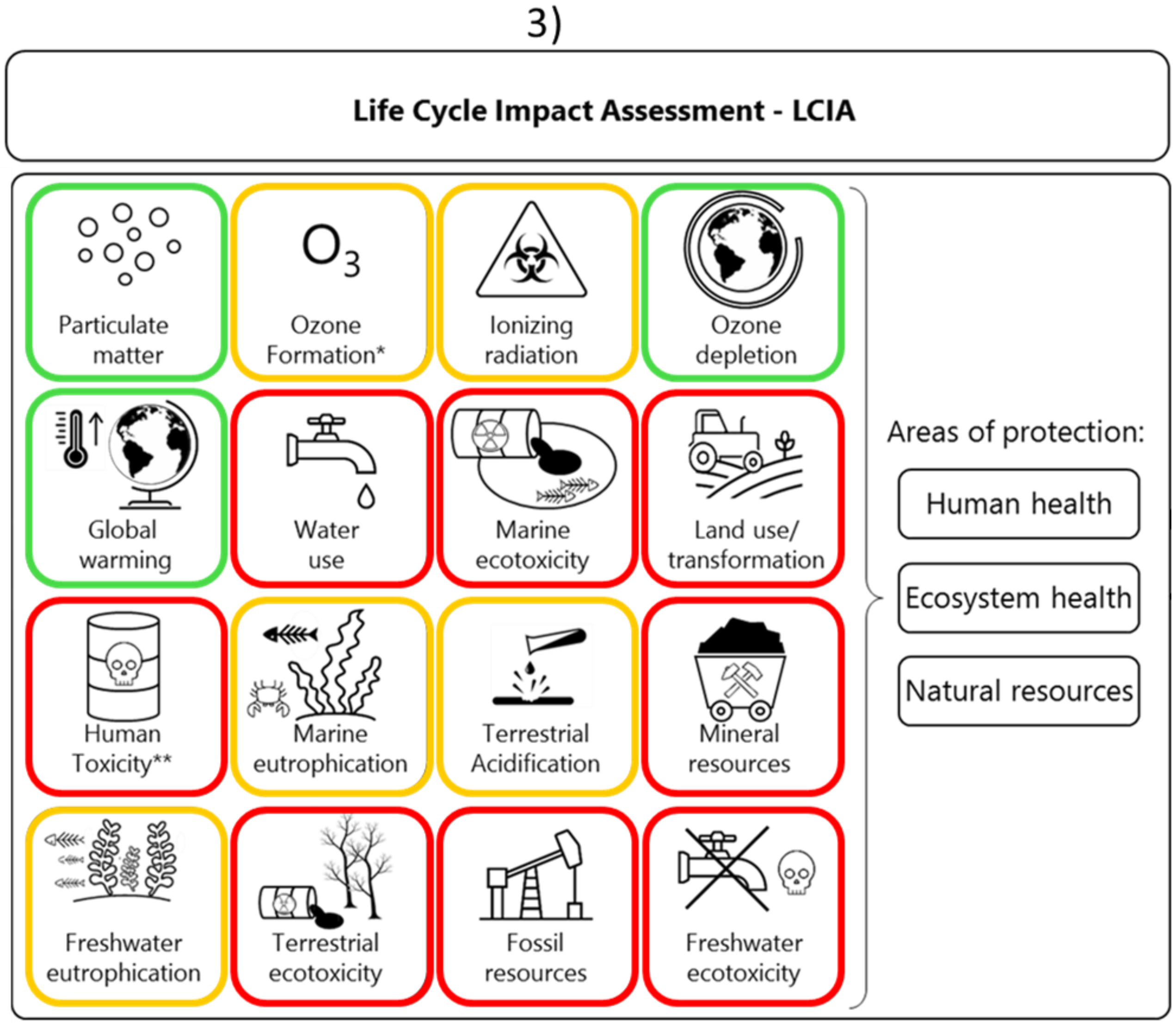
- Choice of impact categories
- Choice of indicator / model to quantify the impact categories

→ The various LCIA methods suggest different sets of impact categories, with potentially different models behind.

But e.g. climate change is always modelled based on IPCC

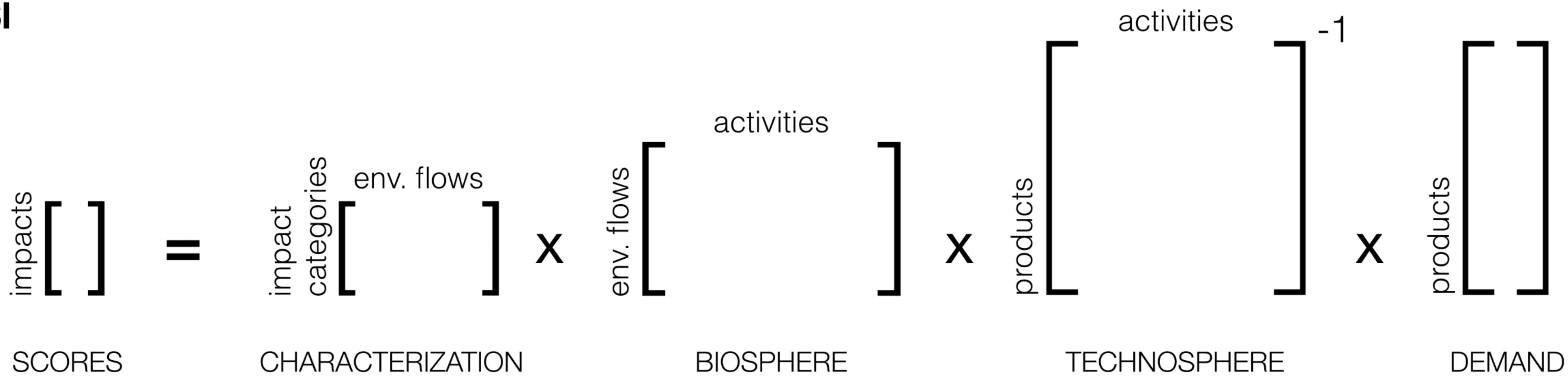
Sounds easy? It’s not…

Levels of robustness in impact assessment



Hauschild et al. 2012. Identifying best existing practice for characterization modeling in life cycle impact assessment. International Journal of Life Cycle Assessment. https://doi.org/10.1007/s11367-012-0489-5

LCA – mathematical framwork



$$h = CBA^{-1}f$$

h	Environmental impacts of final demand	e.g. climate change (kg CO_2eq/pkm), particulate matter formation, ecotoxicity, land use, ionising radiation, metal depletion,…
A	Technosphere (industrial economy) matrix	Processes vs. Processes
f	Final demand vector	Amount of product/service demanded
B	Biosphere matrix	Resource depletion/emissions vs. Processes
C	Characterisation matrix	Impact factors

EPFL PSI

Tools & Databases

Tools

thinkstep GaBi

SimaPro

Open-source

openLCA

polyviz : An interface between brightway2 and D3.js

Open-source

Brightway

AB

premise

lca_algebraic

Temporalis: an open source software for dynamic LCA

Databases

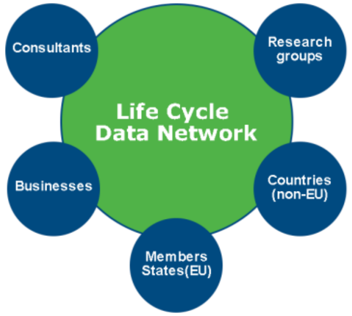
ecoinvent

thinkstep GaBi

ESA space LCA database (internal/external version)

Data Platform

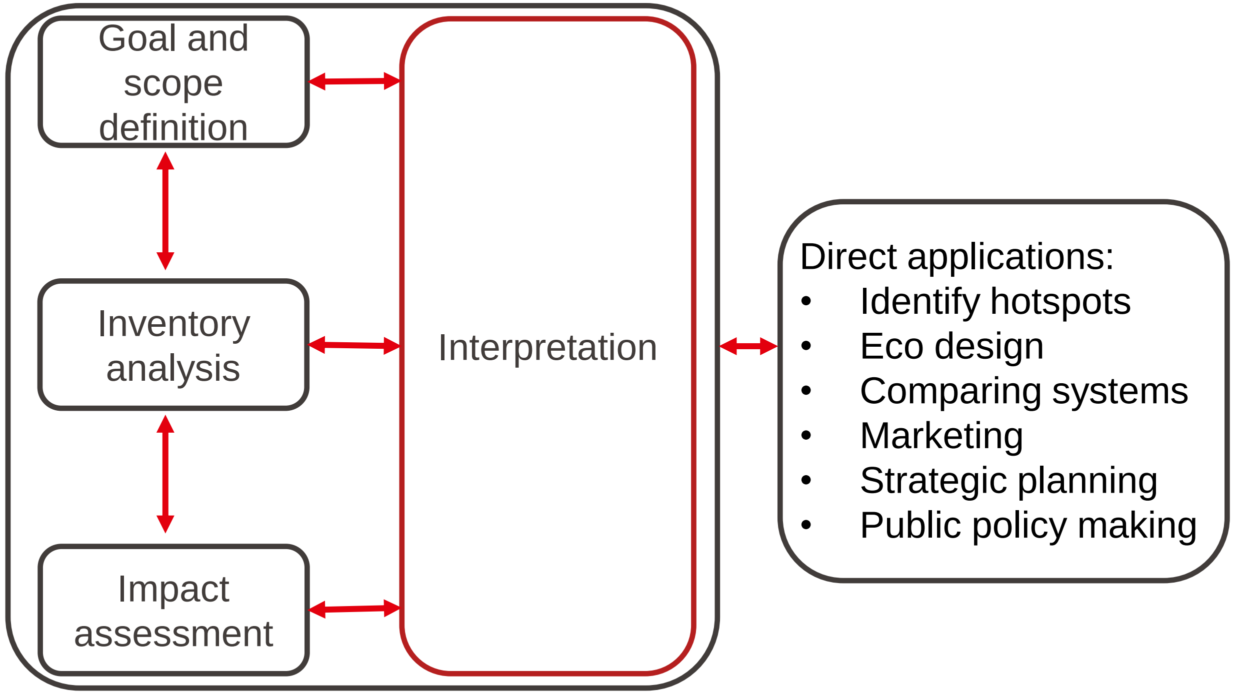
openLCA nexus



Global LCA Data Access

eSpace

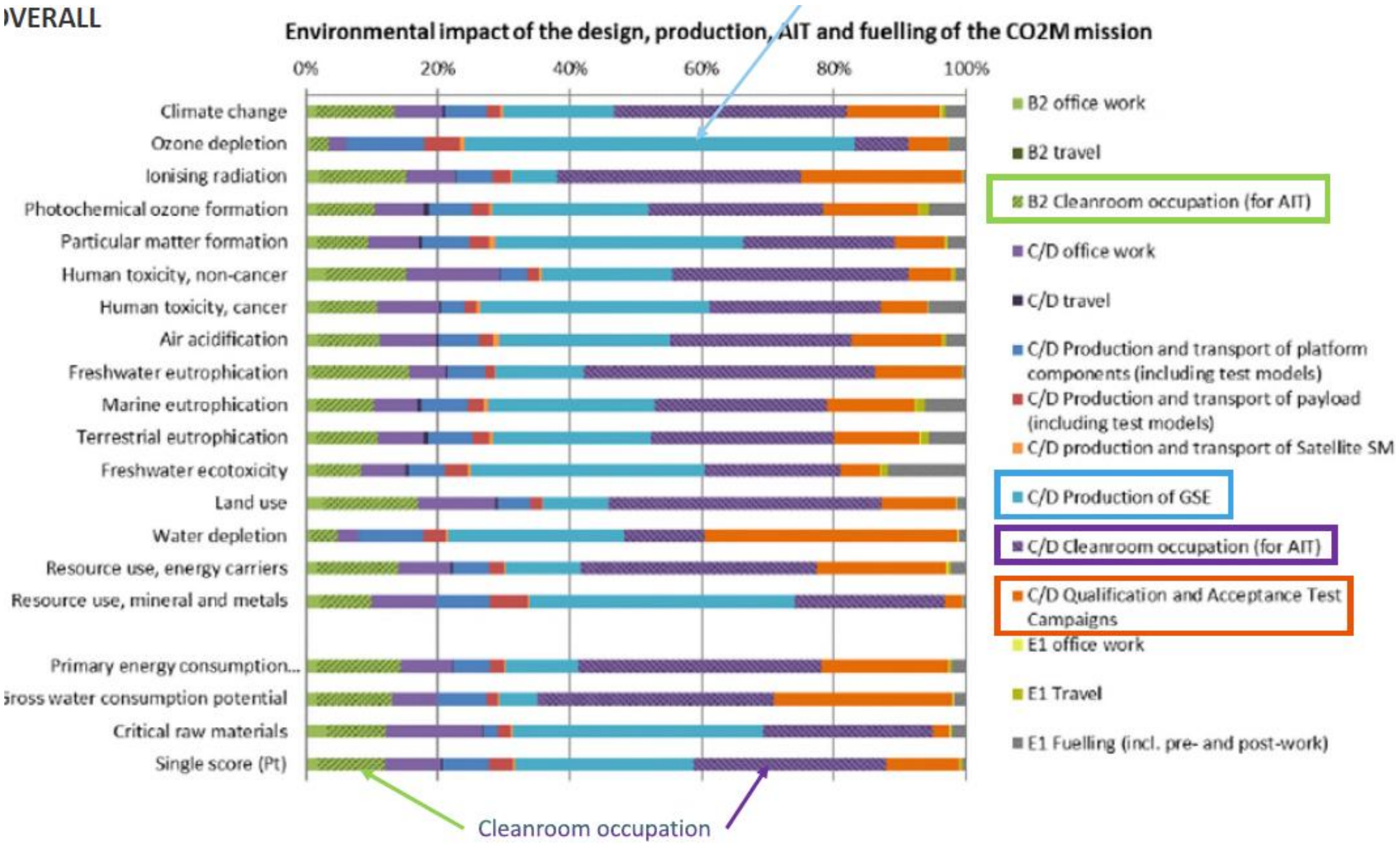
Interpretation



The biggest box

- At each step
- Find hotspots (where and why)
- Control quality / robustness

Scientific LCA framework: ISO 14044/14044



4)

Interpretation

Results
&
Conclusions

https://indico.esa.int/event/516/contributions/9942/

Uncertainties / Variabilities in LCA

In all three basic ISO steps:

- Methodological choices
- LCI
- LCIA (models, characterization factors)

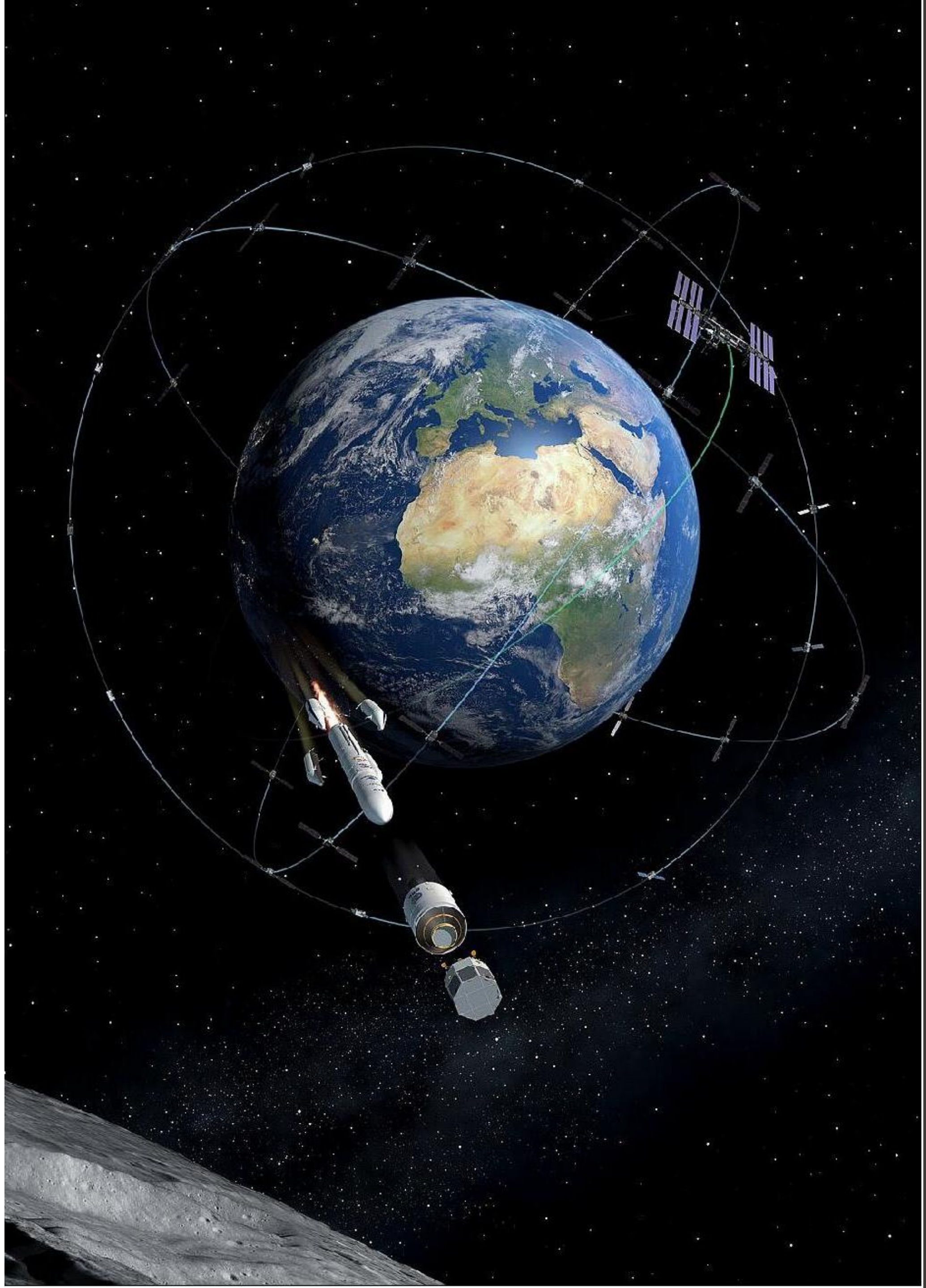
Types of uncertainty in LCA

- Variability: temporal, spatial, object-related
- Parameter uncertainty
- Model uncertainty
- Uncertainty due to choices: methodological, scenarios, preferences
- Lack of relevant knowledge (data gaps)
- Errors
- Relevance uncertainty (representativeness of indicators for decision

Judging the robustness, maturity and validity of the LCA study results.

Identify and prioritise areas which need further investigation.

Some uncertainties can be quantified much better than others
→ Quantitative uncertainty results in LCA always require a careful interpretation, as those not considered might be more important



Prospective LCA

A glimpse into the future

Consistent background LCI

A glimpse into the future: prospective LCA

Prospective LCA (pLCA) aims at the quantification of **environmental burdens of future** product systems

→ **LCI, foreground data:**

First designs/calculations on technology (from pilot to deployment to scaling up), if necessary with various scenarios / sensitivity or uncertainty ranges per amount, material etc.

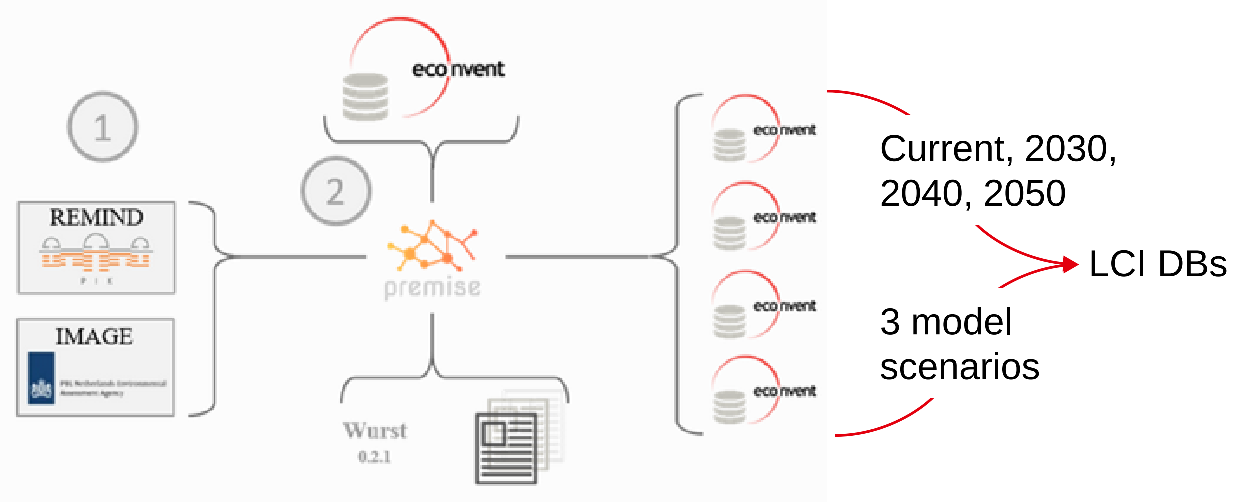
→ **LCI, background data**:

The world will change (quickly) in the coming decades => consistency in terms of future markets projects is important

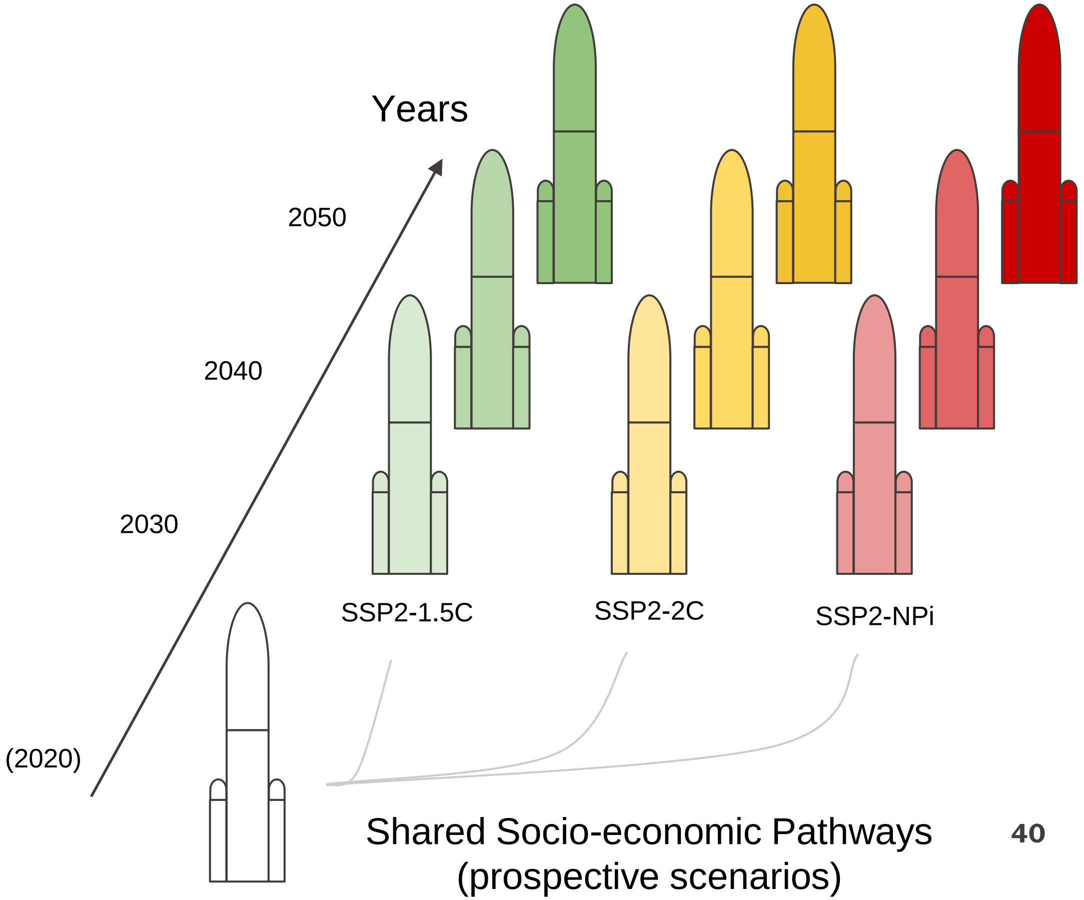
→ **LCIA:** Should also be adapted to future conditions / be made dynamic.
Discussed @LCA network, but not yet streamlined & implemented.

Consistent prospective background LCI

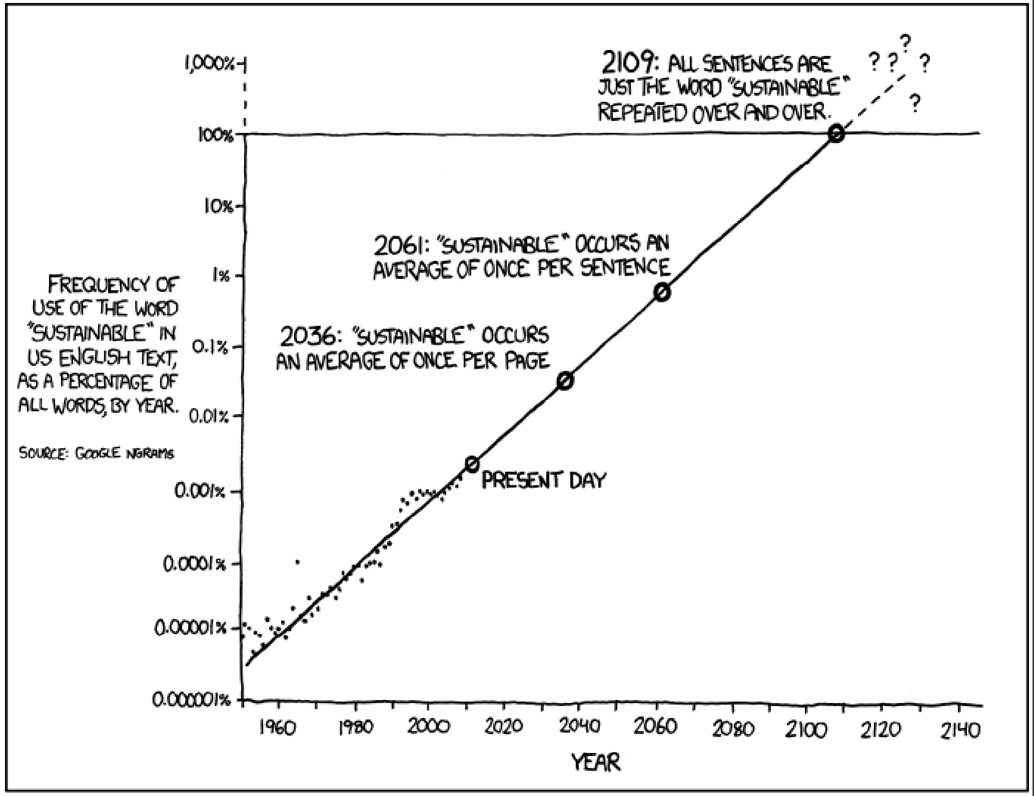
The open software python package «Premise” couples the IAM with ecoinvent and the ESA database (**background**).



Sacchi, R., et al. (2022). PRospective EnvironMental Impact asSEment (premise): A streamlined approach to producing databases for prospective life cycle assessment using integrated assessment models. *Renewable and Sustainable Energy Reviews*, *160* (April 2021), 112311. https://doi.org/10.1016/j.rser.2022.112311



- IAMs present a potential future world situation depending on policies to limit global warming (used in the IPCC reports)
- Historically focusing on sectors influencing climate change (energy, steel, etc.), but now starting to concentrate on raw materials use, ozone depletion etc.



THE WORD "SUSTAINABLE" IS UNSUSTAINABLE.

Sustainability for space

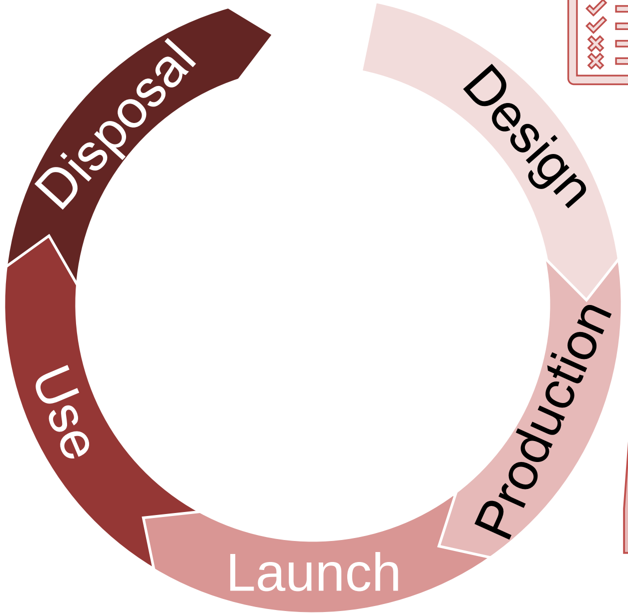
- LCA in the Space Sector
- (Ecodesign)
- Assessment and Comparison Tool (ACT)

Source of image: https://xkcd.com/1007/

Key considerations for the space sector

- Emissions in high atmosphere
  - Still a big research topic
  - Depends on demisability

- Long design cycles (10+ years)
  - Significant Office use impacts
- Very international industry
  - Travel impacts



- Long mission use phase (5-25+ years
  - Data center usage
  - Commuting impacts

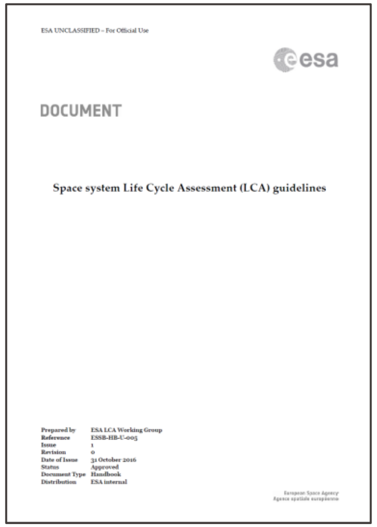
- Extensive Testing and Qualification
  - Use of Clean Rooms
  - Use of texting equipments (long TVAC, powerful shaker, etc)
- Use of space-specific materials
  - Toxic propellants, etc

- Transport to Launch site
- Emissions in high atmosphere
  - Ozone depletion
  - Still a big research topic!

LCA in the space sector

Much progress in Europe

- ESA LCA handbook (2016)
  - Update in progress (**2025**)
  - PEFCR is coming up



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DOCUMENT

Space system Life Cycle Assessment (LCA) guidelines

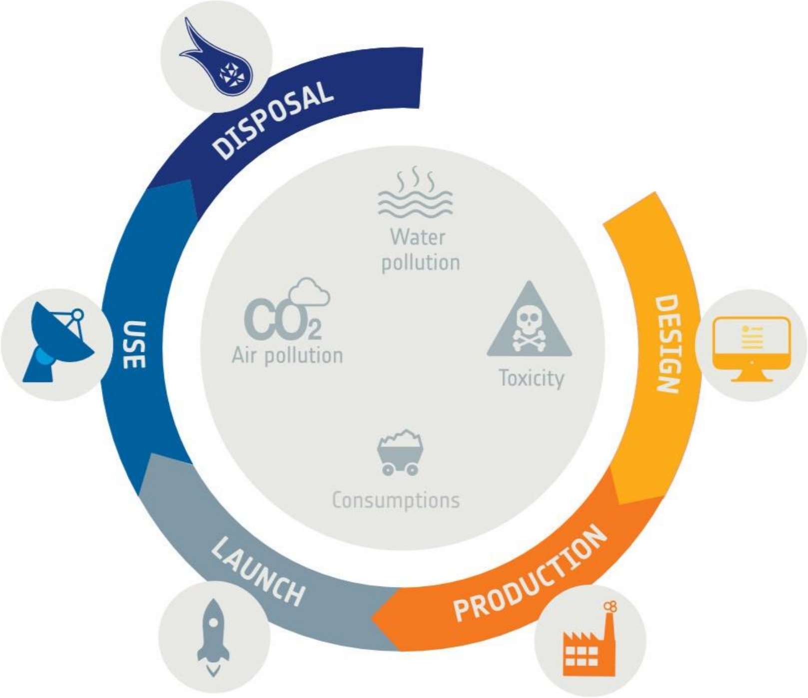
Prepared by	ESA LCA Working Group
Reference	ESSB-HB-U-005
Issue	1
Revision	0
Date of Issue	31 October 2016
Status	Approved
Document Type	Handbook
Distribution	ESA internal

European Space Agency
Agence spatiale européenne

- Several studies
  - Launch vehicles (since 2011)
  - Greensat (2019)
  - Ground segments (2021)

- To anticipate unknown impacts and new regulations

- Embedded in ecodesign approach



https://www.esa.int/Space_Safety/Clean_Space/Infographics

LCA and related standards

PEF Category Rules (PEFCRs)

- ✓ Even more standardisation: How to do an LCA of products in one specific **product group**
- ✓ Created voluntarily by EU, >50% market players, LCA professionals

Environmental Product Declaration (EPD)

- ✓ ISO 14025, EN 15804
- ✓ Standardised document with LCA results for a **specific product**
- ✓ Excludes confidential information, used for communication
- ✓ Product Category Rules (PCRs)
- ✓ **Not legally binding** under EU law, but sometimes mandated

Environmental Footprint: Product / Organisational (PEF/OEF)

- ✓ European Commission
- ✓ Make companies measure the env. impacts of their products
- ✓ Standardised/**harmonised** way for LCA study (env. impacts evaluation)
- ✓ Methodology & Database

ESA LCA handbook

- ✓ **Specific** guidelines for space/launch/ground segments
- ✓ First version from 2016
- ✓ Revision upcoming: Task group (**2025**)

ISO Standards:

- ✓ 14040 = Principles and framework
- ✓ 14044 = Requirements and guidelines
- ✓ 14047 = illustrative examples

These standards give a framework, but leave quite some freedom in the modelling

PEFCR for space systems

- Ongoing European-wide effort, led by the EU DG DEFIS → 2027
- Harmonising method to increase transparency and accountability
- Account for specificities of the sector
- Make more datasets available
- ESA LCA handbook update to be compatible

https://defence-industry-space.ec.europa.eu/product-environmental-footprint-category-rules-pefcr-space-sector_en

LCA in the space sector - scope

Generic FU: One space mission in fulfilment of its requirements

Other options:

- 1 MB of data transferred over a distance of x km
- One launch of a launch vehicle
- 1 kg of payload placed into orbit
- Fulfilment of requirements of Ground Segment for the entire mission, along its lifetime
- To place a payload of X_1 tons into orbit Y_1, X_2 tons into orbit Y_2, X_3 tons into orbit Y_3, etc., per year in 2035
- …

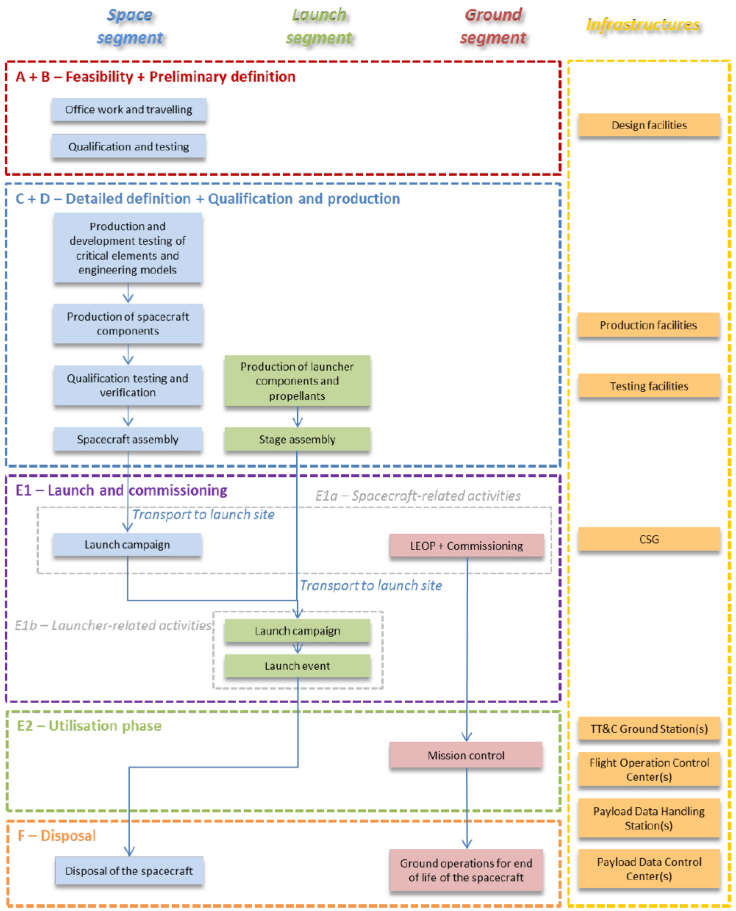
LCA in the space sector – boundaries (old)

Space Segment	Launch Segment	Ground Segment	Infrastructures
Phase A+B: Feasibility and Preliminary Definition			
Office work and travelling Qualification and testing			
Phase C+D: Detailed Definition and Qualification & Production			
Office work and travelling Production of SPS systems and prototypes Qualification, testing & verification Assembly & integration			Production and commissioning of rectenna sites
Phase E1: Launch and Commissioning			
Spacecraft related activities	Production of launchers Production of propellants Stage assembly and/or refurbishments Launch campaign Launch event		
Phase E2: Utilisation Phase			
Maintenance and operation of SPS systems		LEOP Commissioning Routine: Mission control	Maintenance and operation of rectenna sites
Phase F: End of Life			
Disposal of SPS	Launcher refurbishment	Ground operations for SPS disposal	Decommissioning of rectenna

Wilson et al. 2022. Metasat UK: A start-up in space LCA. Presentation at ESA Clean Space Industrial Days 2022.

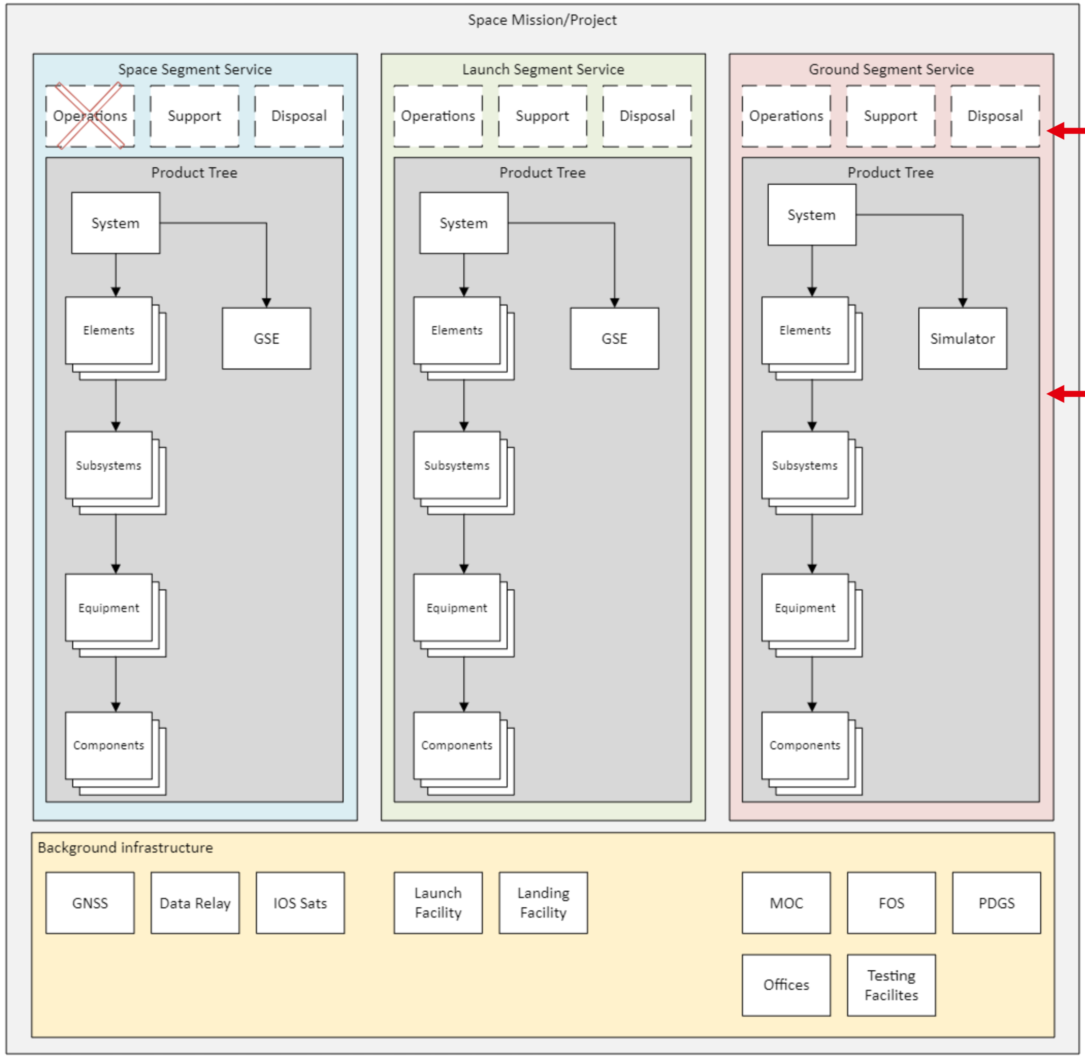
Source: Adapted from ESA LCA Handbook

for a space-based solar power system



ESA LCA handbook, 2016

LCA in the space sector - boundaries

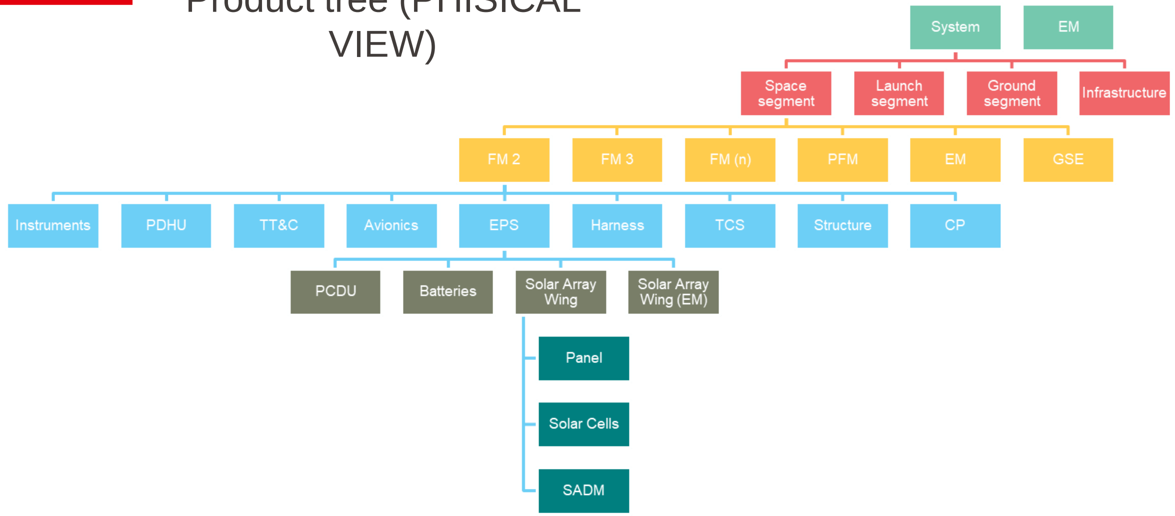


Enrico Tormena et al., ESA LCA Handbook Update, Cleanspace Days 2024

To comply with the ECSS

Operations, support operations and disposal (FUNCTIONAL VIEW)

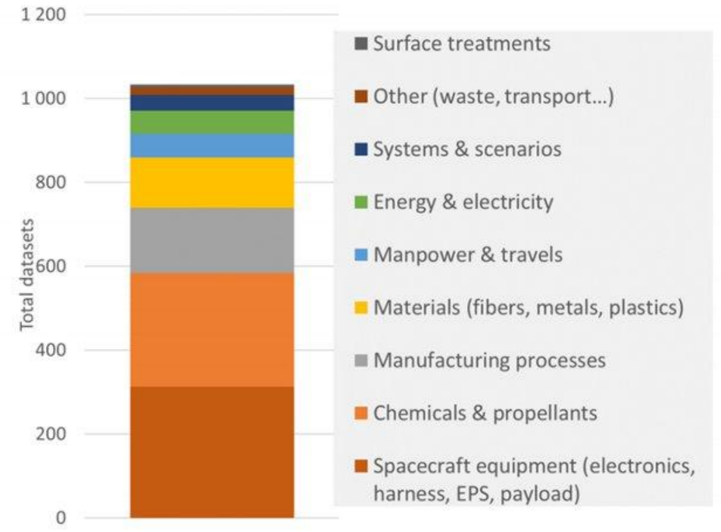
Product tree (PHISICAL VIEW)



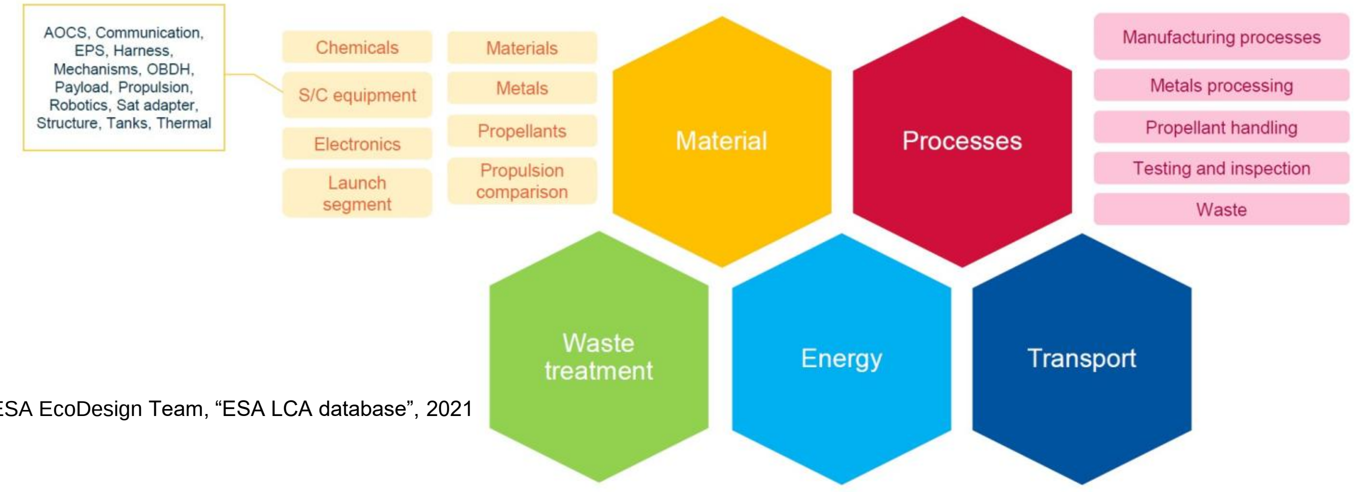
- Raw materials and lower level items
- Processes
- Transport
- Staff
- Testing
- Clean Room

LCI in the space sector

Datasets included within the ESA E-LCA Database (as of 2018)



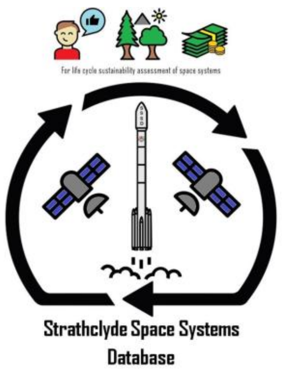
Wilson, Andrew. (2019). Advanced Methods of Life Cycle Assessment for Space Systems.



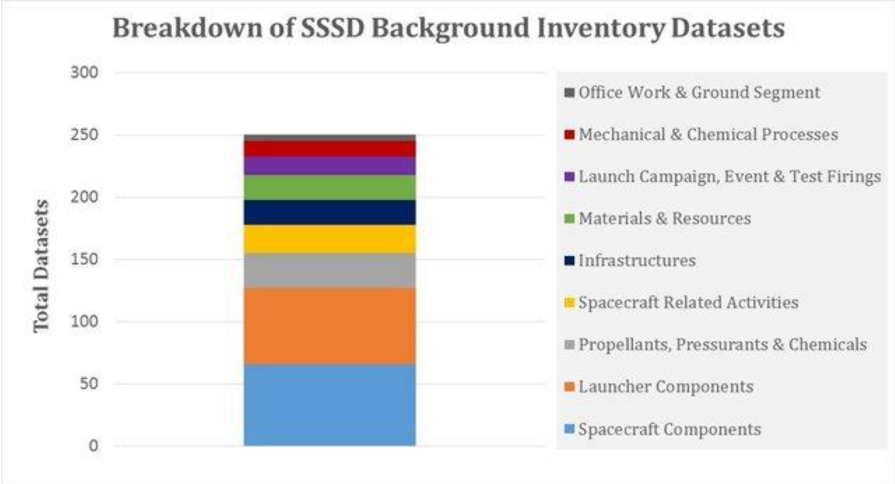
ESA EcoDesign Team, “ESA LCA database”, 2021

New open database (2027)

European Commission

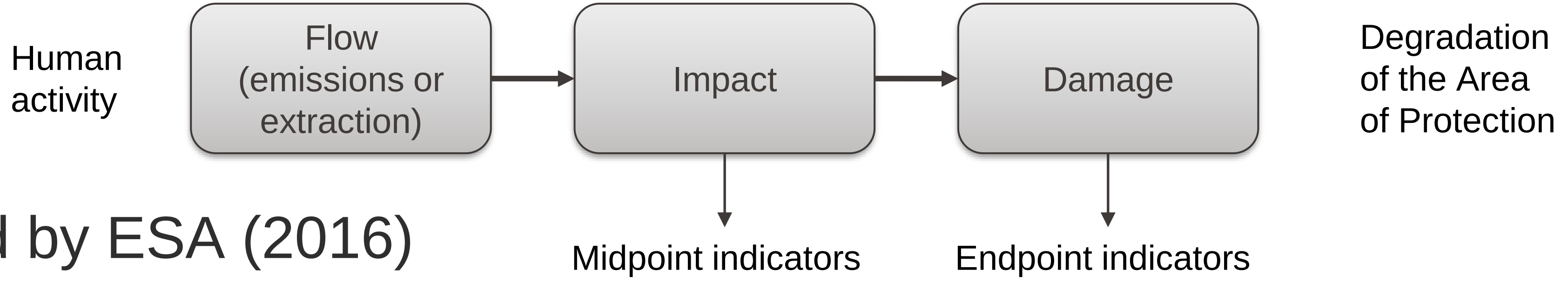


	Baseline Option	Backup Option
Level 1: Whole Mission	1 process	1 process
Level 2: Mission Phases	5 processes	5 processes
Level 3: Phase Activities	14 processes	14 processes
Level 4: Activity Elements	60 processes	60 processes
Level 5: Background Inventory	250 processes	



Adapted from ESA LCA handbook (2016)

Metrics



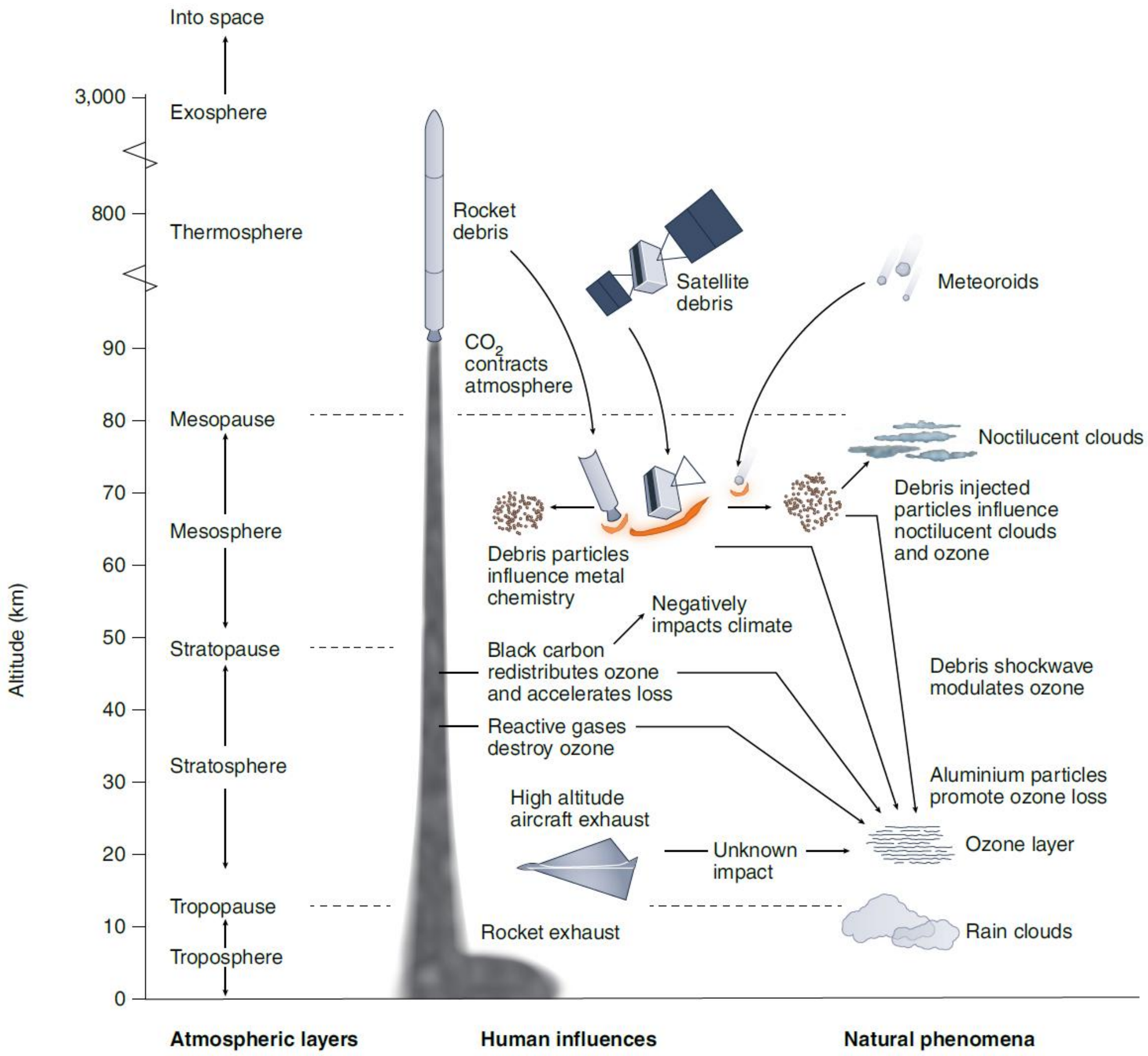
- LCA indicators used by ESA (2016)

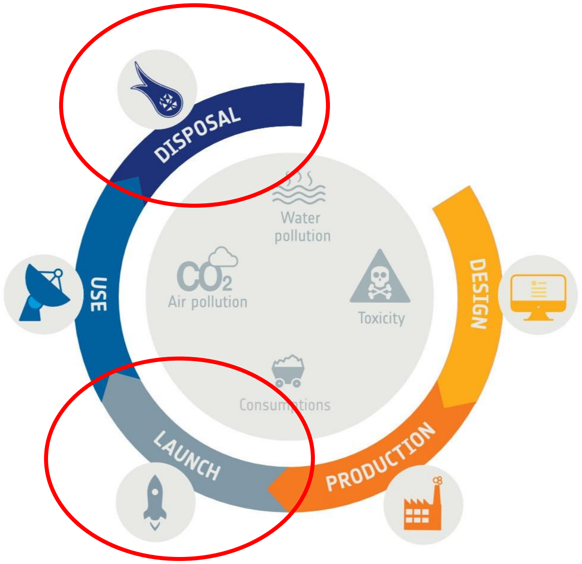
Environmental impact indicator	LCIA method
Global warming potential (100 years)	*For all life-cycle phases except launch event:* Baseline model of 100 years of the IPCC 2007
Ozone Depletion potential	*For all life-cycle phases except launch event*: Steady-state ODPs 1999 as in WMO assessment
Human toxicity potential	USEtox
Abiotic resource depletion potential (fossil and mineral resources)	CML2002
Photochemical ozone formation potential	ReCiPe
Particulate matter formation potential	
Freshwater eutrophication potential	
Marine eutrophication potential	
Metal resources depletion potential	
Ionising Radiation Potential	
Freshwater ecotoxicity potential	USEtox
Marine aquatic ecotoxicity potential	CML2002
Fossil resources depletion potential	
Mineral resources depletion potential	
Air acidification potential	

Flow indicator	Unit	Source
Primary Energy Consumption Potential	MJ	Ecoinvent, Cumulative energy demand
Gross Water Consumption Potential	m3	Ecoinvent, Cumulative energy demand
Mass left in space	kg	Calculated from primary data
Mass disposed in the ocean	kg	Calculated from primary data
Al2O3 emissions in air	kg	Calculated from primary data

ESA LCA handbook (2016)

Crossing all atmospheric layers





https://blogs.esa.int/cleanspace/

J. D. Shutler et al., "Atmospheric impacts of the space industry require oversight," Nature Geoscience, vol. 15, no. 8. Nature Research, pp. 598–600, Aug. 01, 2022. doi: 10.1038/s41561-022-01001-5.

PhD opportunities in 2026

Space Launch Impact on Climate and Environment

- **30+ partners** (TUD, ISAE, DLR, CNRS, PSI, EPFL, PMOD, PoliTo, Uni Stuttgart, ULB, and also industries)

- **18 PhD positions** funded through a MARIE SKŁODOWSKA-CURIE ACTIONS
  1. Launch Vehicle Emissions (incl. 1 at EPFL LPAC: “End of life emissions of composite materials upon re-entry”)
  2. Atmospheric Interaction & Climate Impact
  3. System Design & Analysis

- Hiring process will start ~early 2026, to start in 2026Q3

Ecodesign

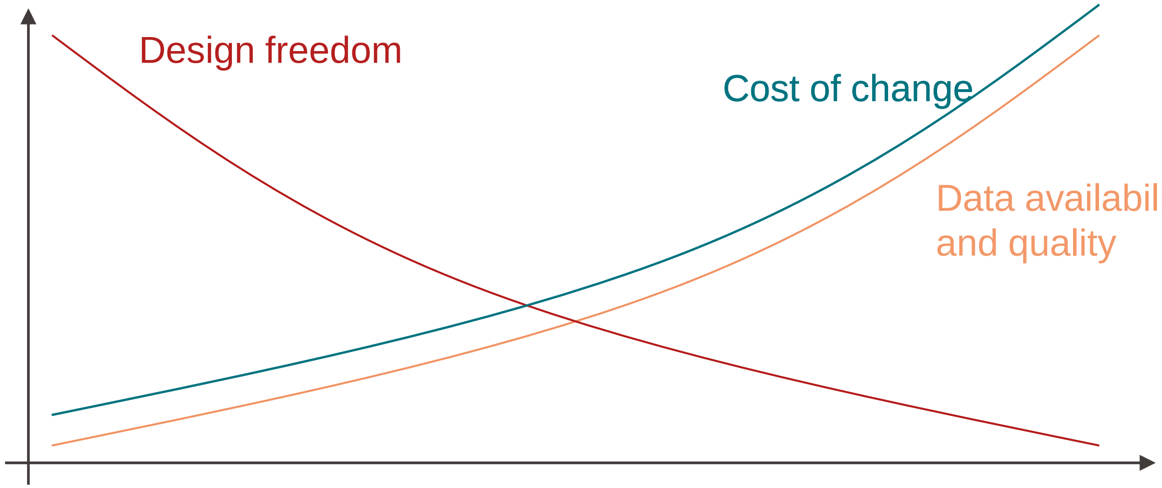
Done early in the design phase !

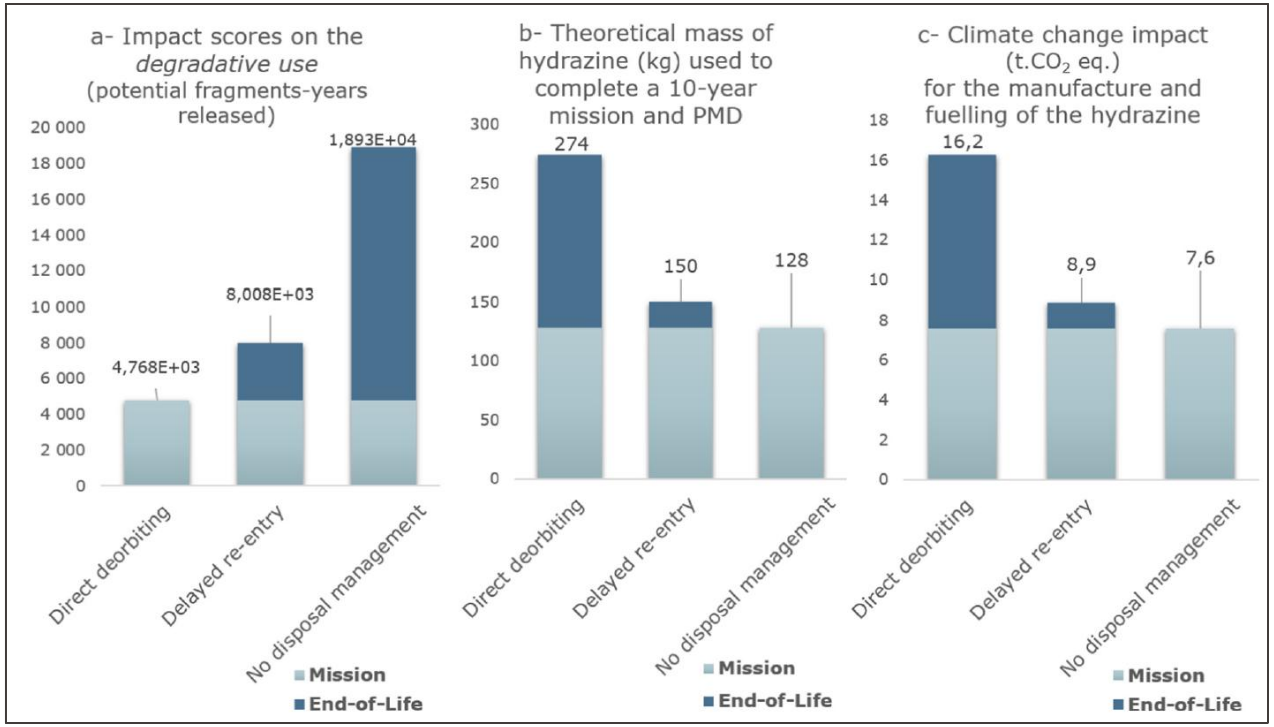
Iterative

- Perform LCA
- Identify hotspots
- Eco-design (with same performance)
- Re-assess

Avoid burden shifting !
- By phase
- By indicator
- By (sub)system

Adapted from https://innovativedelta.com/approach/

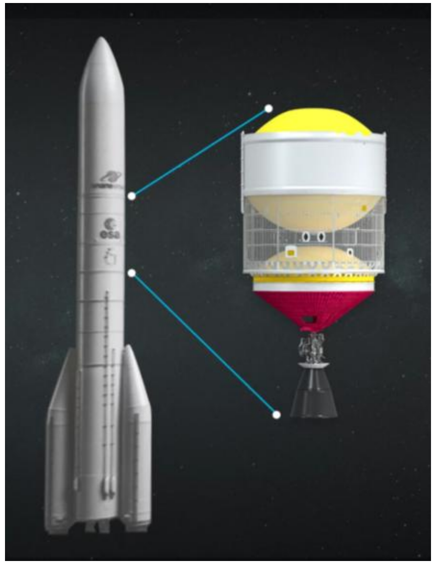




Example from T. Maury et al., "Assessing the impact of space debris on orbital resource in life cycle assessment: A proposed method and case study", Science of the Total Environment 667 (2019) 780–791

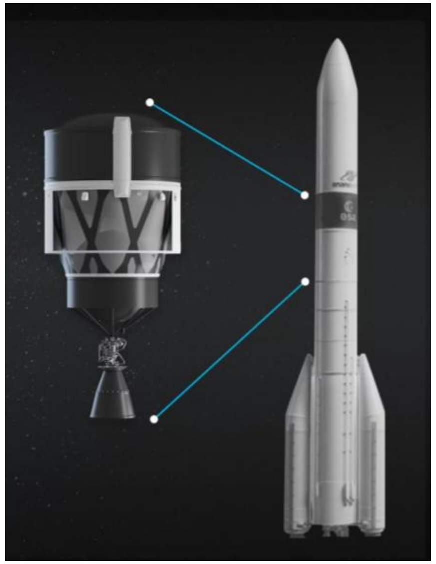
Assessment and Comparison Tool

Introduction

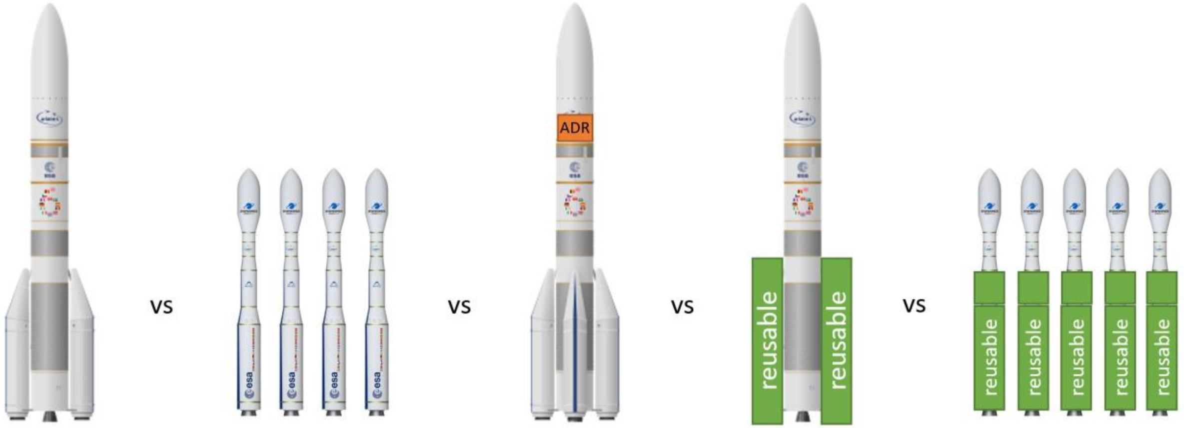


<u>More or less</u>:
Performance ?
Cost ?
Availability ?

Risks ?
Environmental impacts ?



ArianeGroup, Phoebus article, 2022



Context

Development of the Assessment and Comparison Tool (ACT)

2022 | Green Space Logistics (1y) | REACT (2y) | Nov. 2025

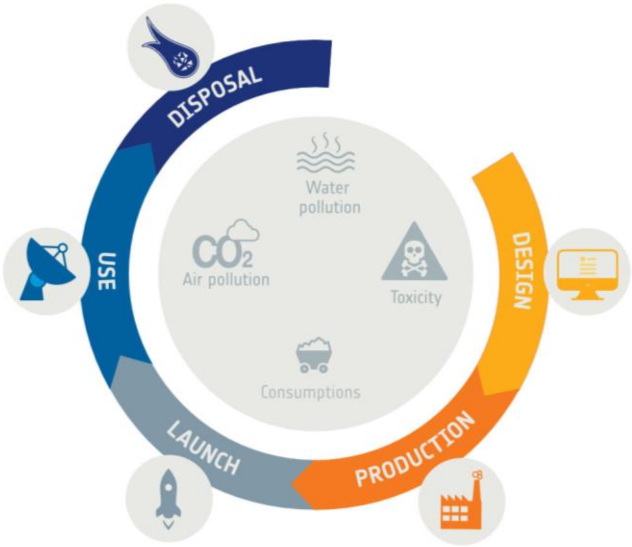
Preparation (9m) | Implementation (15m)

Nov. 2023 now

"Integrate **environmental** criteria in the **design** process of space transportation **system**"

↳ Space-specific
Simplified
Prospective
Life Cycle Assessment (LCA)

↳ Support ecodesign



https://www.esa.int/ESA_Multimedia/Images/2020/08/EcoDesign_infographic

Impacts computation

Precalculated impact **scores** ·	material/energy/etc. **amount**	= **final impact score**
(background databases)	*(specified in ACT)*	*(environmental impacts of configuration)*

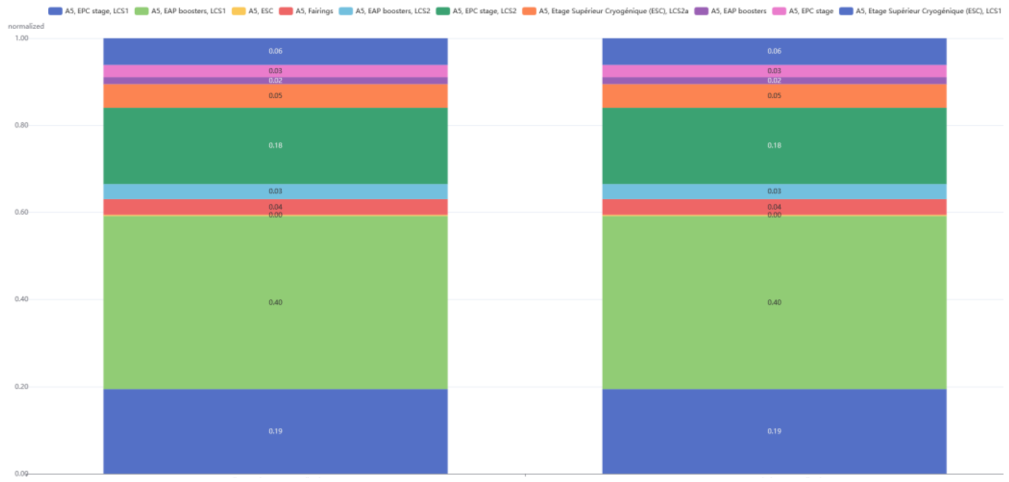
Prospective data

Parameters:

- Dry mass
- Volume
- Recoverable ?
- Reusable ?

LCA datasets:

Material / Component	Value
Aluminium	760
Cork	100
…	…

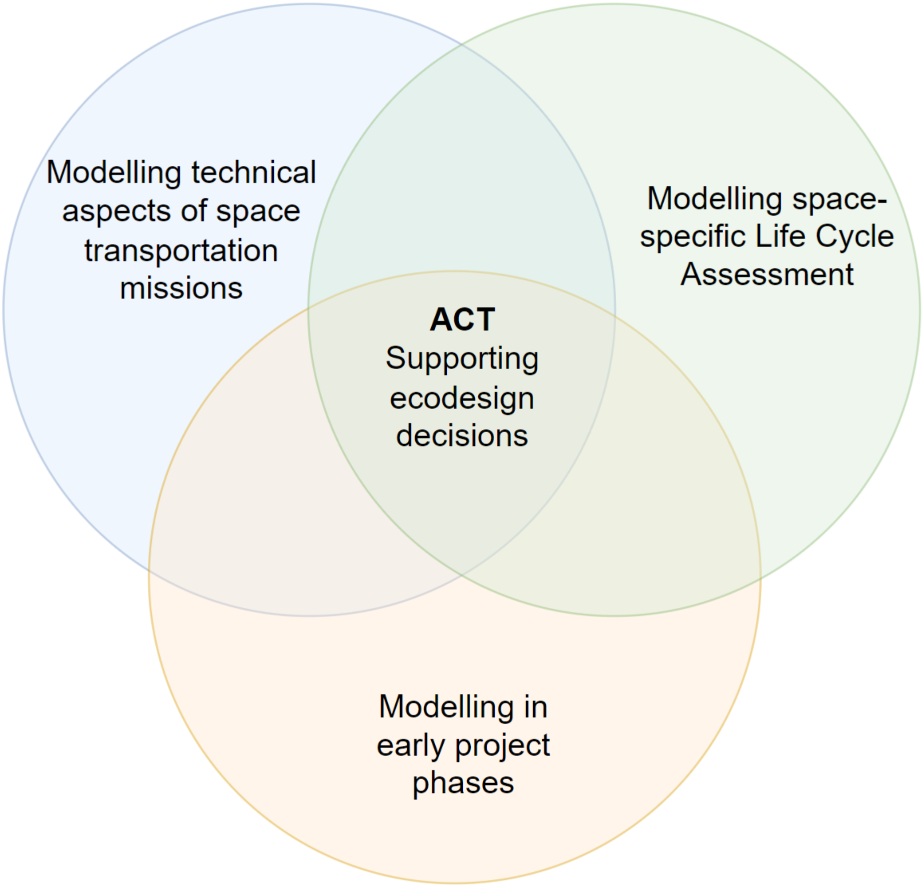


Climate change (normalized)

Ozone depletion (normalized)

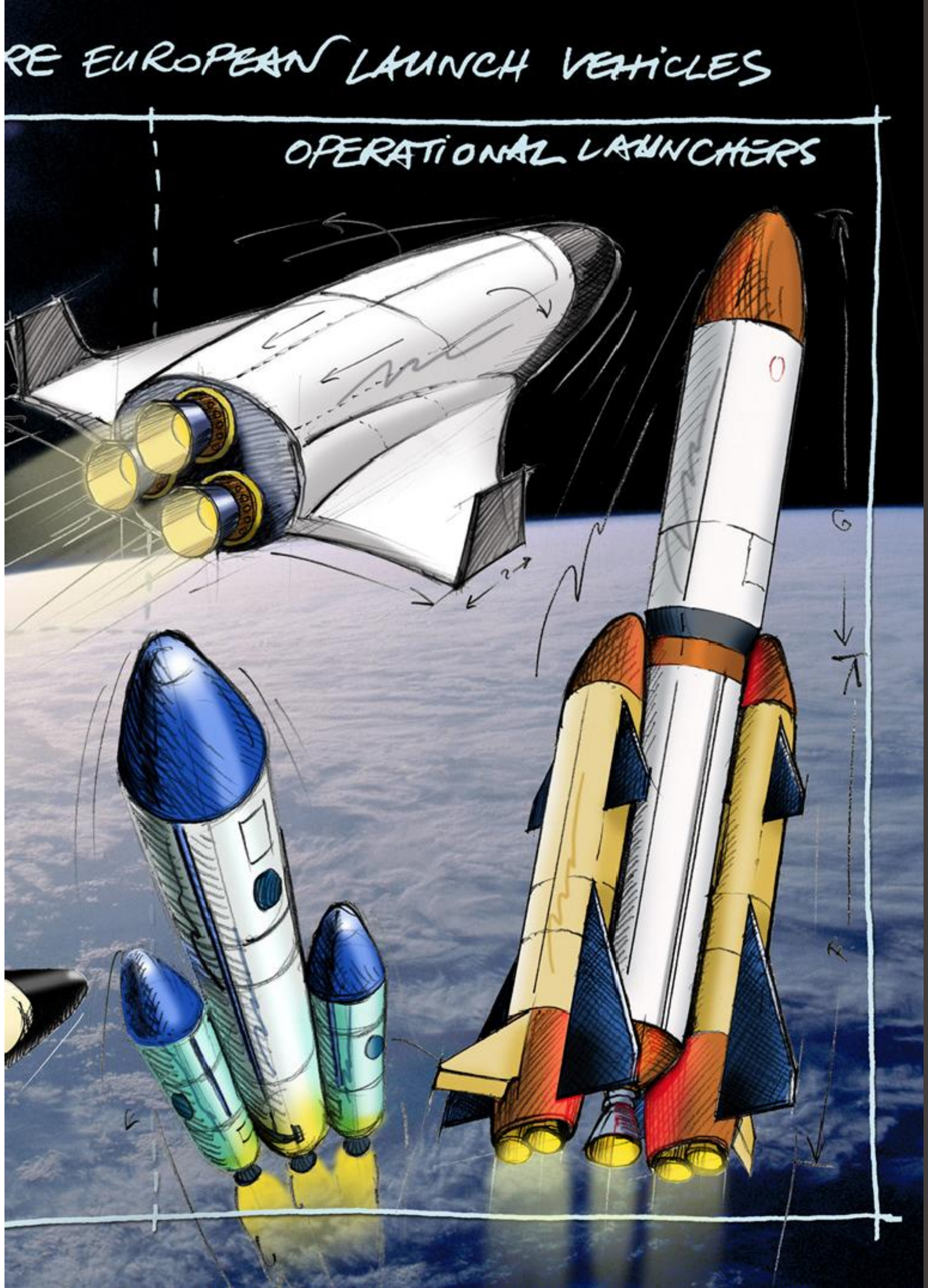
ACT - Unique Selling Point

- Understanding users' requirements
- Internal needs and external constraints
- Describe new features for the v2



Used:

- In ESA projects
- With industries (~research and student projects)
- With industries (subcontracts)
- With the EPFL Rocket Team and other student teams

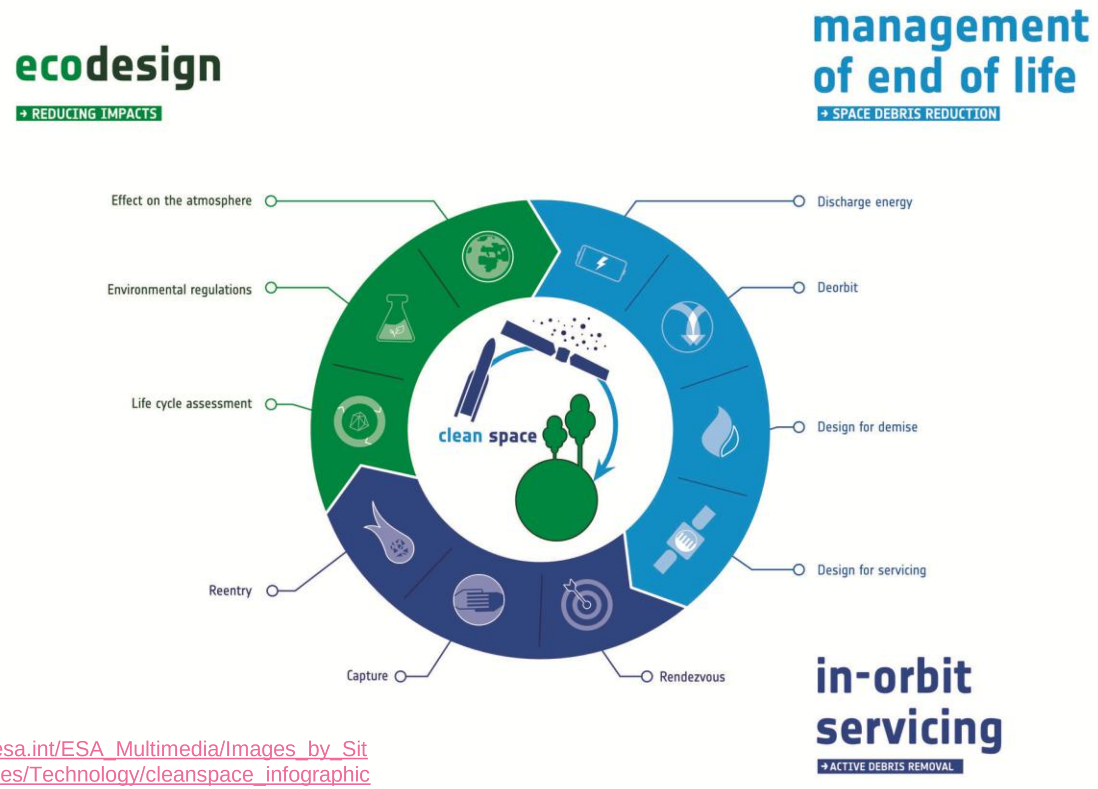


Conclusion

Motivation

Take-aways

More motivations for LCA in space



https://www.esa.int/ESA_Multimedia/Images_by_Site/Our_activities/Technology/cleanspace_infographic

ESA, academia, and industries are looking for talents in these topics !

e.g from SE job position: *"Duty: monitoring the implementation of life cycle analysis and the Zero-Debris Policy in accordance with the initiatives of the ESA Clean Space Office"*
https://jobs.esa.int/job/Noordwijk-System-and-Verification-Engineer/962521601/

Take-aways

- The space sector generates very specific types of impacts
- LCA is multi-step, multi-criteria, and aims to be comprehensive
  - All processes required for the complete life cycles of products & services are included
  - It allows a complete accounting of environmental burdens
- Ecodesign for impact reduction, to start early
- ACT = tool for simplified, space-specific, (prospective) LCA
- Some gaps still exist and require R&D

“ If you love space, you must love Clean Space ”

--- Former ESA Director General
Jean-Jacques Dordain

Testing your learning

Instructions

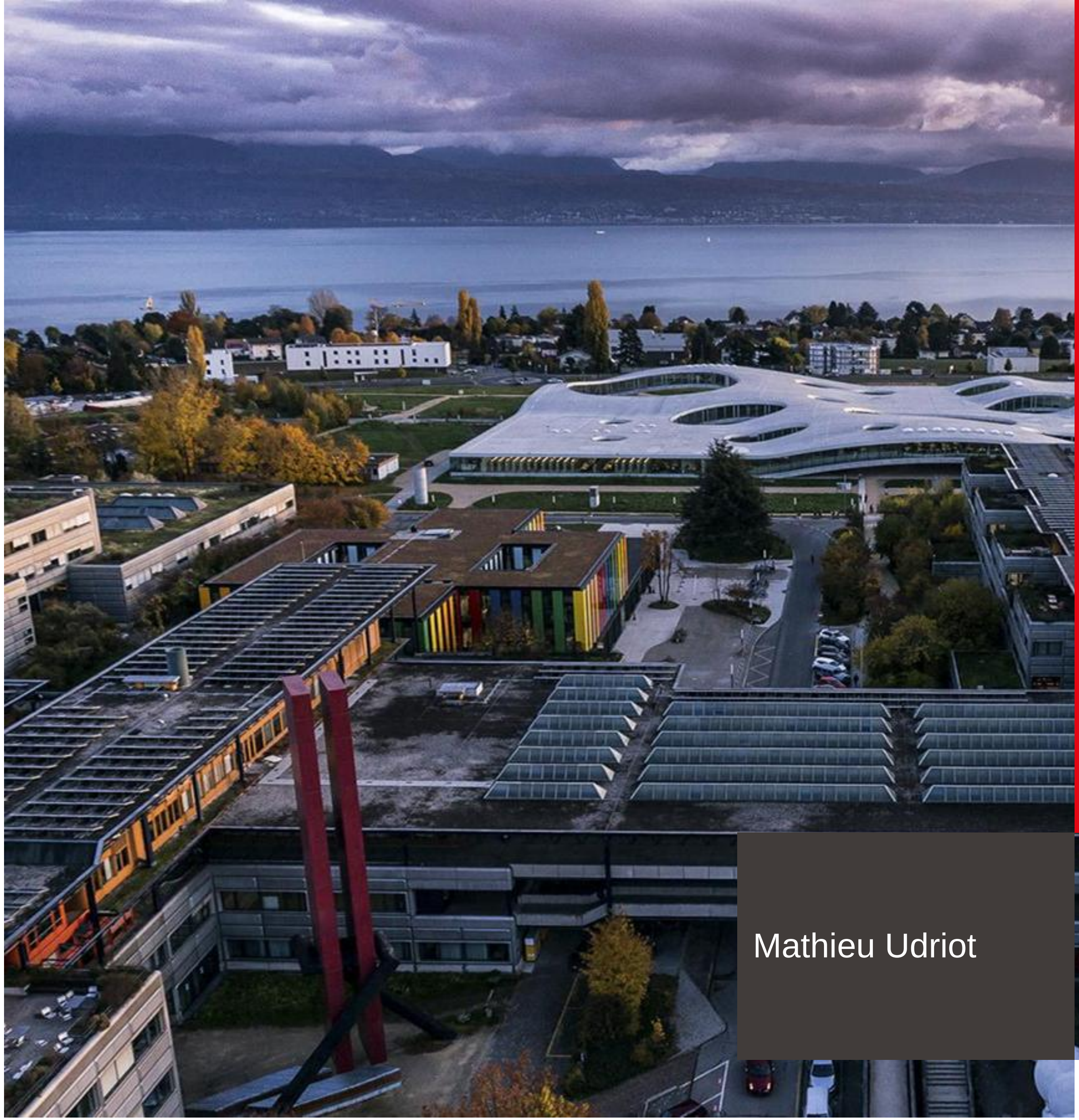
Go to

www.menti.com

Enter the code

5289 2960

Or use QR code



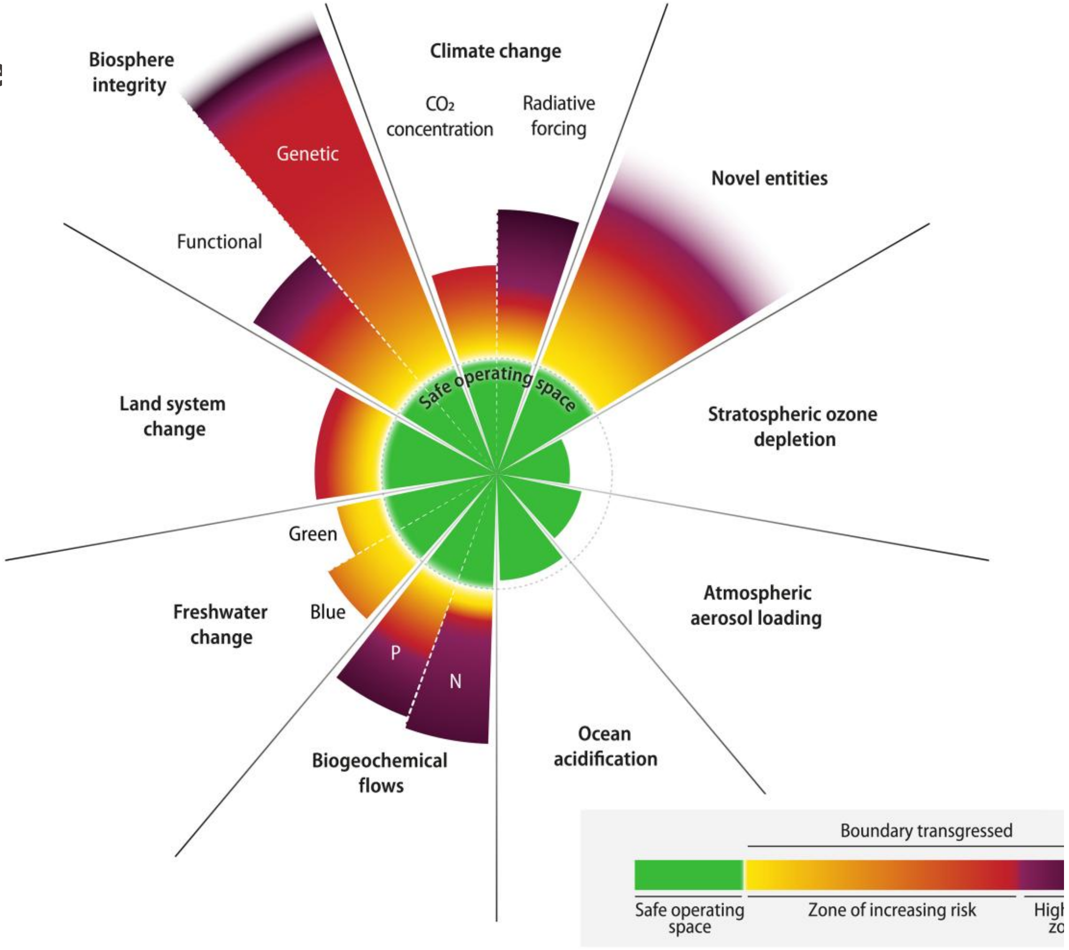
Introduction to Life Cycle Assessment in an eco-design perspective

Mathieu Udriot

Spring 2025

LCA context:
Planetary boundary (PB) concept

- Thresholds for **biophysical processes** considered crucial for the **stability of Earth**
  - → to depict **how much environmental disturbance the world can sustain** without reaching a state that is considered unsafe from a precautionary point of view
  - → “Which environmental burdens are acceptable for society to stay within the safe operating space?”
- **Nine global PB thresholds**, with biosphere integrity (biodiversity loss) and climate change as core boundaries
- Latest evaluation: *“…finds that six of the nine boundaries are transgressed, suggesting that Earth is now well outside of the safe operating space for humanity.”* (https://www.science.org/doi/10.1126/sciadv.adh2458)



Data quality and uncertainties

Data quality rating (DQR):

- Precision
- Completeness
- Representativeness (temporal, geographical, technolog
- Consistency
- Reproducibility

→ "Pedigree matrix"

Uncertainty distribution →
Monte Carlo

Local/Global Sensitivity Analysis

Indicator score	1	2	3	4	5 (default)
Reliability	*Verified data based on measurements*	*Verified data partly based on assumptions or non-verified data based in measurements*	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial export)	Non-qualified estimate
Completeness	*Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations*	*Representative data from >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations*	*Representative data from only some sites (<50%) relevant for the market considered or >50% of sites but from shorter periods*	Representative data from only one site relevant for the market considered *or* some sites but from shorter periods	Representative-ness unknown or data from a small number of sites *and* from shorter periods
Temporal correlation	Less than 3 years of difference to the time period of the dataset	Less than 6 years of difference to the time period of the dataset	Less than 10 years of difference to the time period of the dataset	Data from area with slightly similar production conditions	Age of data unknown or more than 15 years of difference to the time period of the dataset
Geographical correlation	*Data from area under study*	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown or distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)
Further technological correlation	*Data from enterprises, processes and materials under study*	Data from processes and materials under study but from different technology	Data from processes and materials under study but from different technology	Data on related processes or materials	Data on related processes on laboratory scale *or* from different technology

See also https://indico.esa.int/event/516/contributions/9939/ for latest developments in the space sector