Single-Score Methodology for Space LCA

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Agenda

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    - Towards Greener Propellants
    - Why doing LCA of Propellants
2. Single Score Methodology
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3. Steps of the study
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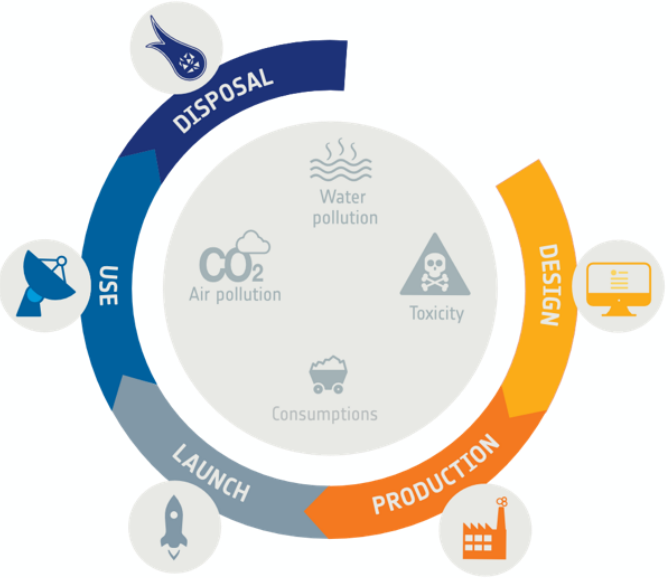
    - Propellants LCA with PEF & AHP Weightings
5. Conclusion

1. Introduction to Propellants LCA

Introduction to propellants LCA

Propellants in launch systems, have an impact on the environment through all their life cycle. Considerably, they “pollute” the most during the **launch event, the production, transport and storage.**



The launch event is the only human activity to “pollute” directly in **all the atmospheric layers**.

Towards using “Greener” Propellants

How can we quantify what is “green”?

- Being **“less toxic”** than legacy propellants is not enough
- Not being on the SVHC should be a **destructive criteria**. But this list does not look only at toxicity
- Even only on toxicity, GHS 1:5 scale doesn’t give a lot of shade for propellants to be greener than the legacy ones.

https://www.aydemperakende.com.tr/en/blog/what-is-energy-class-meaning-of-the-energy-labels-2022

Criteria for SVHC Under REACH

PERSISTENCE: THE SUBSTANCE MUST BE PERSISTENT, MEANING IT DOES NOT READILY BREAK DOWN IN THE ENVIRONMENT, AND IT HAS A LONG-TERM IMPACT.

BIOACCUMULATION: THE SUBSTANCE MUST BIOACCUMULATE, WHICH MEANS IT ACCUMULATES IN LIVING ORGANISMS, PARTICULARLY IN HIGHER TROPHIC LEVELS OF THE FOOD CHAIN.

TOXICITY: THE SUBSTANCE MUST EXHIBIT INHERENT TOXICITY OR POSE A RISK TO HUMAN HEALTH OR THE ENVIRONMENT. THIS INCLUDES TOXICITY TO AQUATIC ORGANISMS, MAMMALS, OR OTHER SPECIES.

WIDESPREAD USE: THE SUBSTANCE MUST BE USED IN A MANNER THAT RESULTS IN WIDESPREAD AND SIGNIFICANT EXPOSURE TO HUMANS OR THE ENVIRONMENT.

RISK TO HUMAN HEALTH: THE SUBSTANCE MUST POSE A RISK TO HUMAN HEALTH, EITHER THROUGH DIRECT EXPOSURE OR EXPOSURE VIA THE ENVIRONMENT.

RISK TO THE ENVIRONMENT: THE SUBSTANCE MUST POSE A RISK TO THE ENVIRONMENT, INCLUDING AQUATIC AND TERRESTRIAL ECOSYSTEMS.

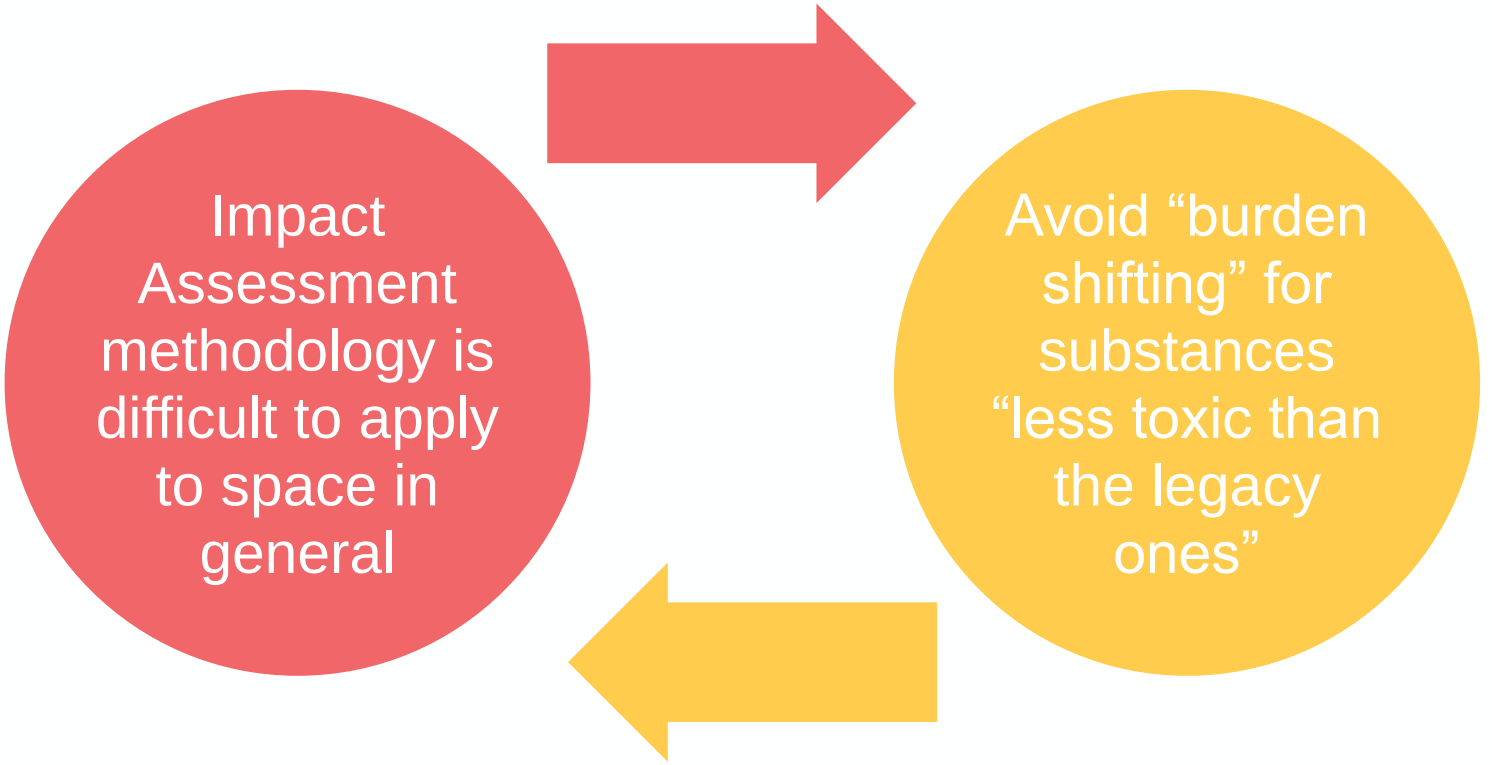
EQUIVALENT CONCERN: EVEN IF A SUBSTANCE DOES NOT MEET ALL THE CRITERIA INDIVIDUALLY, IT MAY STILL BE CONSIDERED AN SVHC IF IT EXHIBITS "EQUIVALENT CONCERN" TO OTHER SVHCS

https://echa.europa.eu/

Why doing LCA of Propellants

Only performing a full Life Cycle Assessment over the different Life Phases can give a **full picture**:

- Avoid **burden shifting**
- Be able to make more **eco-decision early-on**

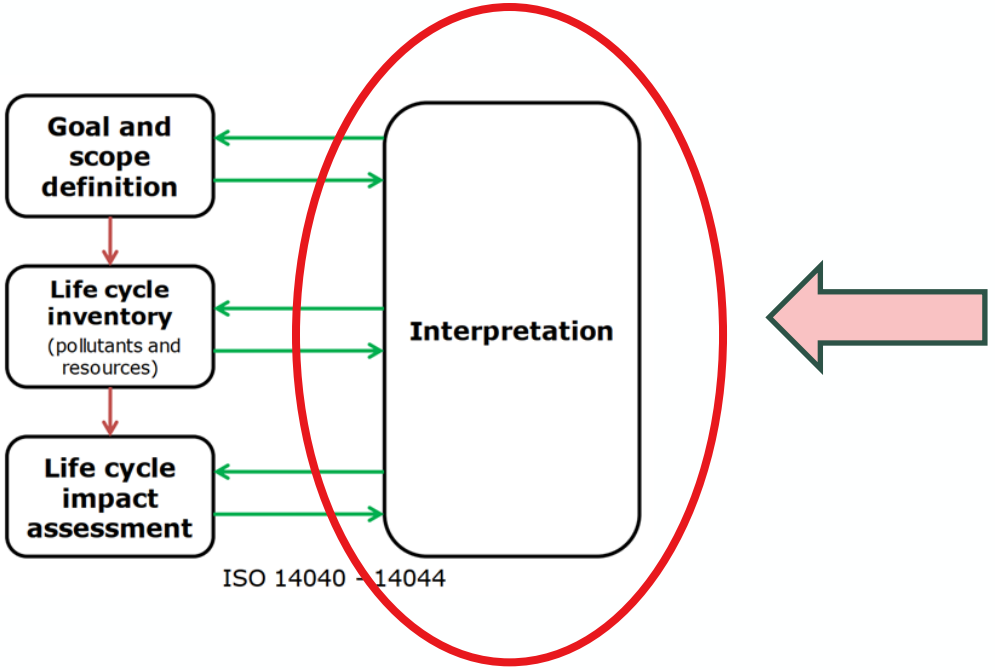


Introduction to propellants LCA

BUT performing an LCA is not straightforward

- Difficult to gather “confidential” data for the LCI especially for propellants
- Difficult to communicate the results due to the high number of impact categories

https://www.thoughtfulleader.com/difficult-decisions/



Single-score can help with direct comparison of LCA outcome & decision-making

2. Single Score Methodology

Single Score Steps in LCA

Characterisation of the different midpoint indicators

Normalisation with a reference case

Weighting

Analytical Hierarchy Process (AHP)

5 Steps to Decision Making with Empathy in Your Business (readytrainingonline.com)

Decision-making Tool

⇩

Single Score Weights Attribution

Analytic Hierarchy Process

- ✓ Structured decision-making through Relative Comparisons
- ✓ Consistency Assessment
- ✗ Time and Focus Demanding

Analytical Hierarchy Process (AHP)

1. **Structured Evaluation**: AHP provides a structured framework for decision-making. It **breaks down complex decisions into a hierarchy of criteria** and alternatives, making the decision process more organized and transparent.

2. **Weighted Evaluation**: AHP enables decision-makers to assign and compare the relative importance of criteria and alternatives. This weighting process allows for the effective prioritization of factors that matter most.

3. **Consistency and Transparency**: AHP ensures consistency in judgments and offers a transparent way to arrive at well-informed decisions.

Score	Definition
9	Extreme more importance
7	Much stronger importance
5	Essential or stronger importance
3	Moderate importance of one over another
1	Equal importance
2, 4, 6, 8	Intermediate Importance for compromises between values

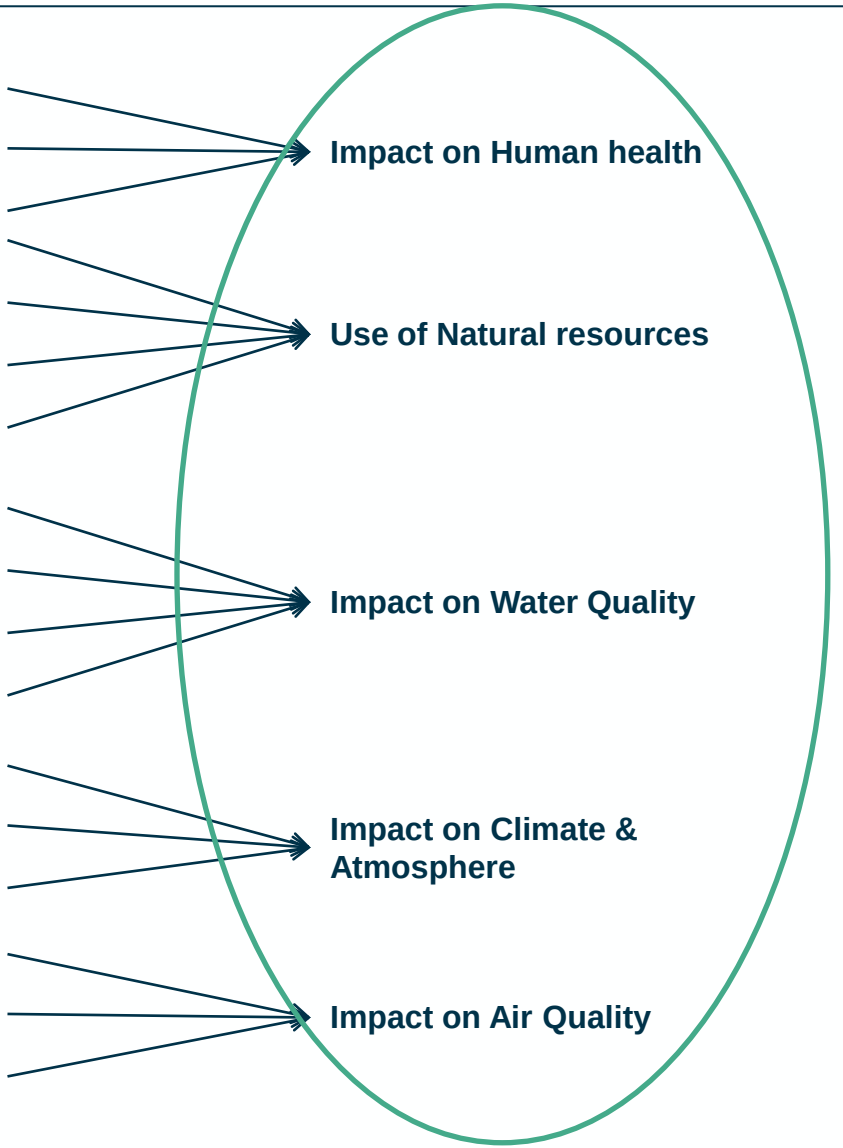
1. • Define Problem and Hierarchy
2. • **Pairwise Comparison**
3. • Consistency Check
4. • Weights Computation
5. • Best Alternative Selection

3. Steps of the Study

Groups of Impact Indicators

Midpoint Indicators

- Human Toxicity Potential Non-Cancerous
- Human Toxicity Potential Cancerous
- Use of Restricted Substances
- Water Use
- Land Use
- Use of Fossil Fuel resources
- Use of Metals & Minerals
- Freshwater Eutrophication Potential
- Freshwater Ecotoxicity Potential
- Marine Eutrophication Potential
- Marine Ecotoxicity Potential
- Global Warming Potential
- Ozone Depletion Potential
- Ionizing Radiation Potential
- Air Acidification Potential
- Photochemical Ozone Formation Potential
- Particle Matter Formation Potential



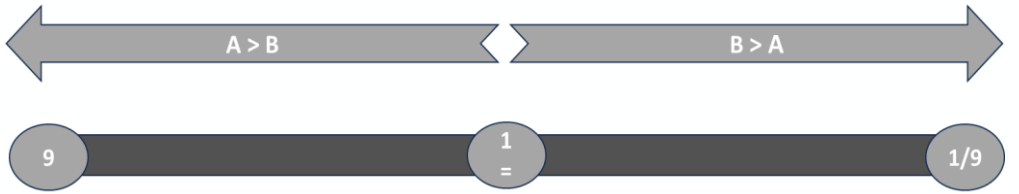
Endpoint Indicators

Questionnaire – Part 1 & Part 2

1. Weighting of Endpoint indicators: https://forms.gle/PYRfn8uxsGqupf438
   - Collected **50 answers** so far
   - Your inputs is very much welcome

2. Weighting on Midpoint Indicators within each group:
   - Excel sheet available on demand:
     - lily.blondel@ing.unipi.it
     - cleanspace@esa.int
   - Collected **10 answers** so far
   - Your inputs is very much welcome

3. The next section shows the preliminary output of the study



Comparison Matrix

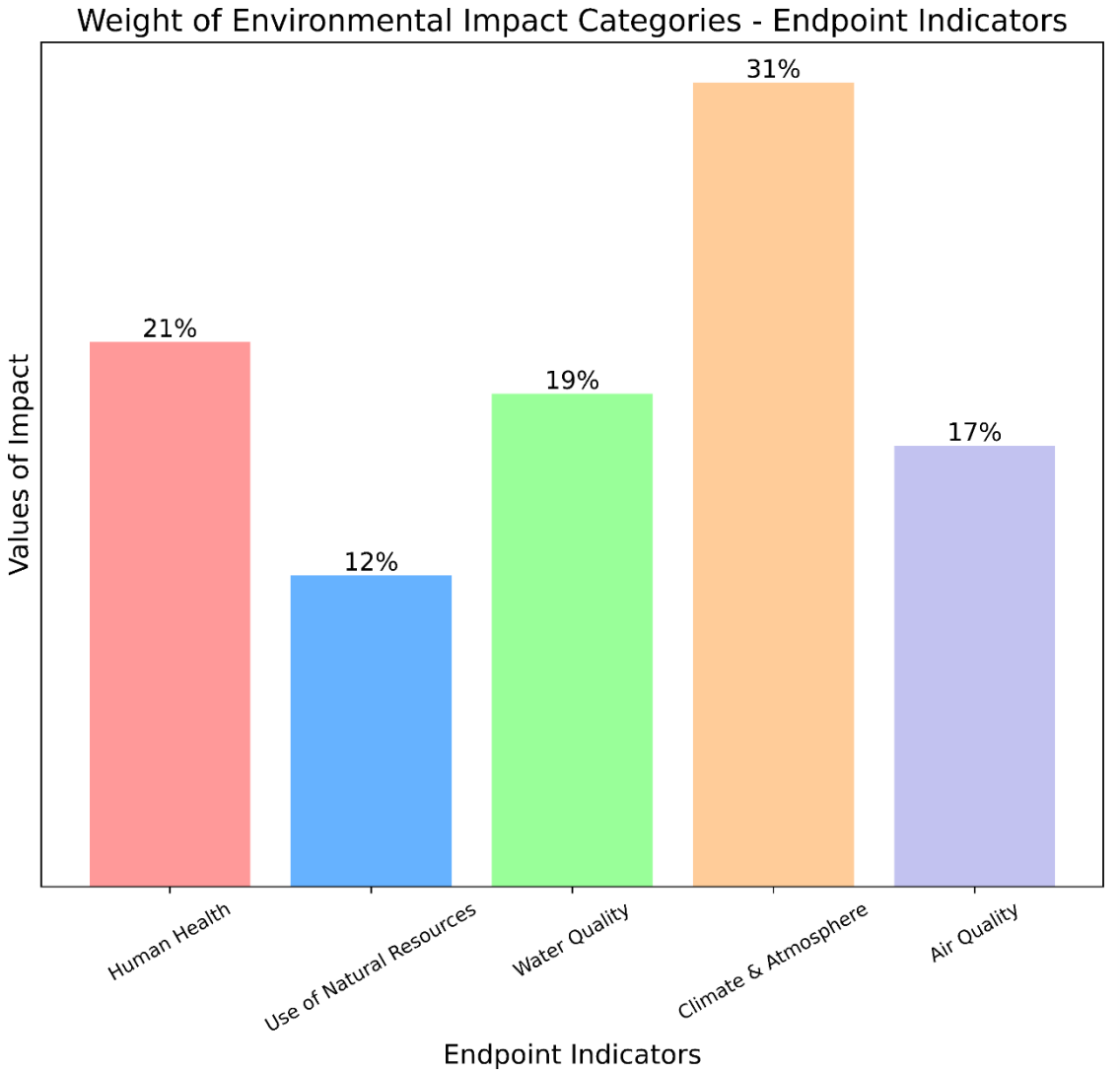
A / B	Human Health	Use of Natural Resources	Water Quality	Climate & Atmosphere	Air Quality
Human Health	1	input	input	input	input
Use of Natural Resources		1	input	input	input
Water Quality			1	input	input
Climate & Atmosphere				1	input
Air Quality					1

- Consistency Check
- Weight Computation

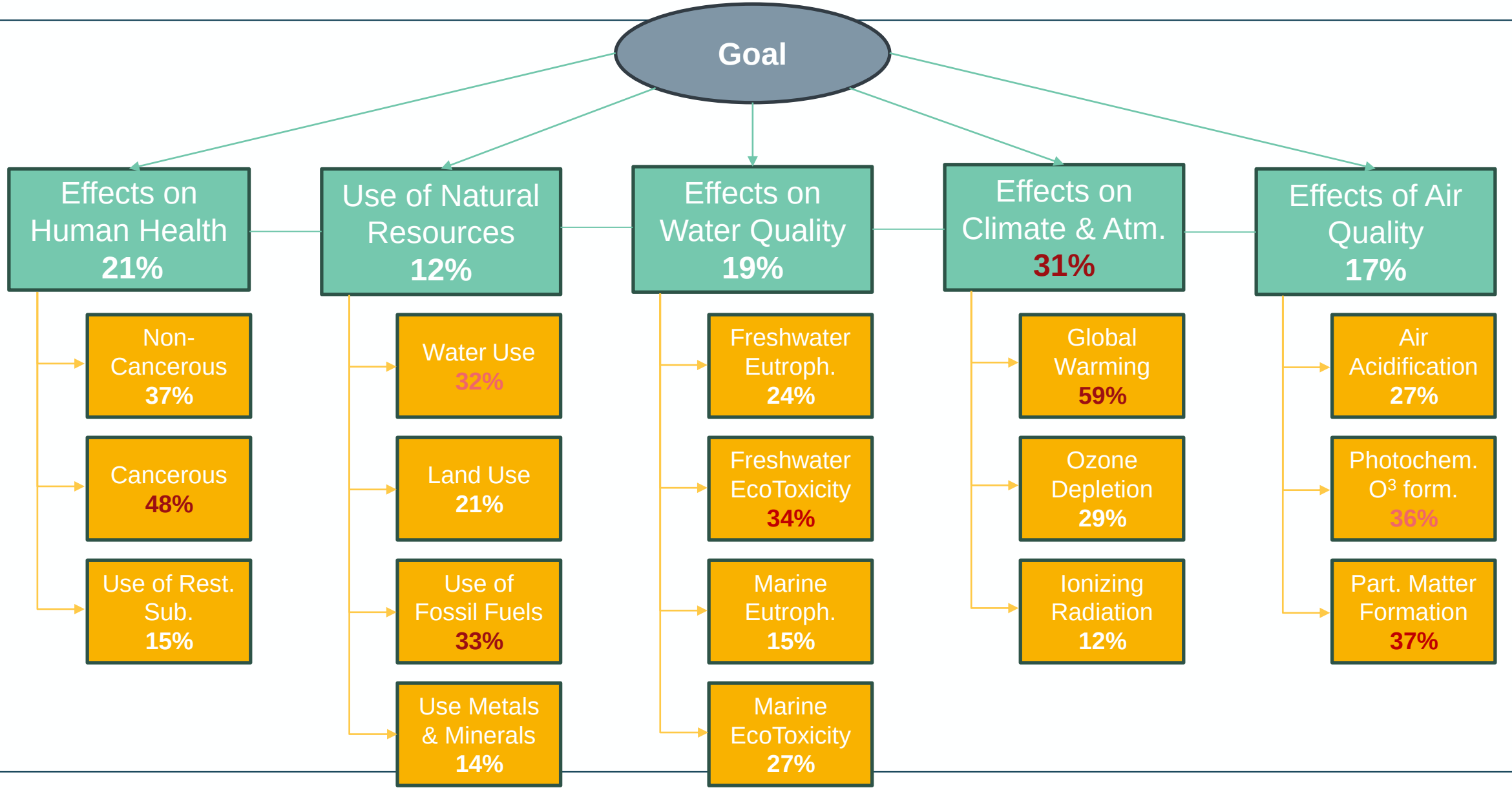
4. Preliminary Results

Preliminary AHP Weights – Endpoint Indicators

- Weight Attribution to the Impact Categories or Endpoint Indicators
- Weights computed from the **30 answers** that passed the Consistency Check
- **Impact on Climate & Atmosphere** is a clear concern among all other categories



Preliminary AHP Weights – Midpoint Indicators



Comparison of PEF and AHP weights

Single Score examples of some Propellants

Preliminary **single-score of propellant LCA** for in-space transportation:

Oxidizers

	98% Hydrogen Peroxide	Nitrous Oxide	Nitrogen Tetroxide
PEF single score	126	288	228
AHP single score	119	273	214

Fuels

	Ethanol	Methanol	Monomethylhydrazine (MMH)	RP-1
PEF single score	0.12	0.07	5.58	0.16
AHP single score	0.10	0.05	6.01	0.16

High Vap. Fuels

	Acetylene	Ethane	Ethene
PEF single score	292	125	148
AHP single score	258	92	103

Much closer score

Maybe Ethylene is a good alternative if better on other aspects

Monopropellants

	AF-M315E	FLP-106	Hydrazine	98%-Hydrogen peroxide (HTP)	LMP-103S
PEF single score	1.34	12.49	6.69	0.13	12.16
AHP single score	3.01	17.43	15.68	0.12	16.98

Hydrazine scores much higher with AHP

- Functional Unit: All results are per kg loaded into a space system.
- System Boundaries: Cradle-to-gate for chemicals production, adding processes up to launch.

Work Ongoing: need to account for the overall propulsion system impact (and its performance, therefore accounting for the quantity needed)

5. Conclusion

Conclusion

- For the moment, it is difficult to assess which propellants are "**greener**" without a full LCA study
- LCA is challenging to apply for Space
- AHP methods gives a **rigorous framework of evaluation.** **With more answers we have a more representative outcome**
- Weighting based mostly on **inputs from the space community** could give another valuable perspective, compared to PEF, to consider environmental-friendly decision-making of future space missions.

Hard choices,
easy life.
Easy choices,
hard life.

Open Points:

- Solution to limit single-score subjectivity ?
- Propagation of uncertainties in LCA ?
- Further work needed

References

[1] A. Sarritzu, L.Blondel Canepari, R.Gelain, P. Hendrick, A. Pasini, *Analytical Hierarchy Process-based trade-off analysis of green and hybrid propulsion technologies for upper stage applications,* January 2023 International Journal of Energetic Materials and Chemicals.
DOI:10.1615/IntJEnergeticMaterialsChemProp.2023047590

[2]
https://indico.esa.int/event/416/contributions/7321/attachments/4916/7536/Environmental%20Impact%20of%20Propellants%20%5BCSID%5D.pdf

Thank you for your attention !