The Strathclyde Space Systems Database:
Life Cycle Sustainability Results of the MÌOS Mission

Clean Space Industrial Days

European Space Research & Technology Centre (ESTEC)

Noordwijk, Netherlands

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Aerospace Centre of Excellence, Advanced Space Concepts Laboratory,
University of Strathclyde, Department of Mechanical & Aerospace Engineering

Outline

1. Introduction
2. Update on the Strathclyde Space Systems Database
3. What is the MÌOS mission?
4. Post-mission LCSA of the MÌOS mission
5. Current Work, Future Work & Conclusion

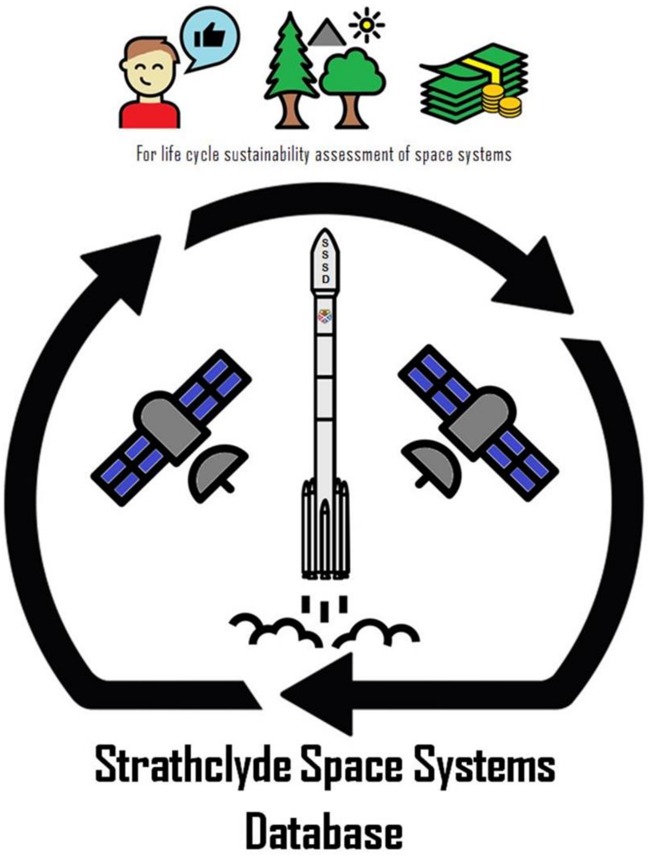
Purpose

- To present a status update on the development of the SSSD database for LCSA of space systems.
- To provide the first ever LCSA results of a space mission using the MÌOS mission (which was run through the SSSD) based on two scenarios;
  (1) full system level results, and
  (2) the impact of switching propellant types on the full system level results.

Introduction

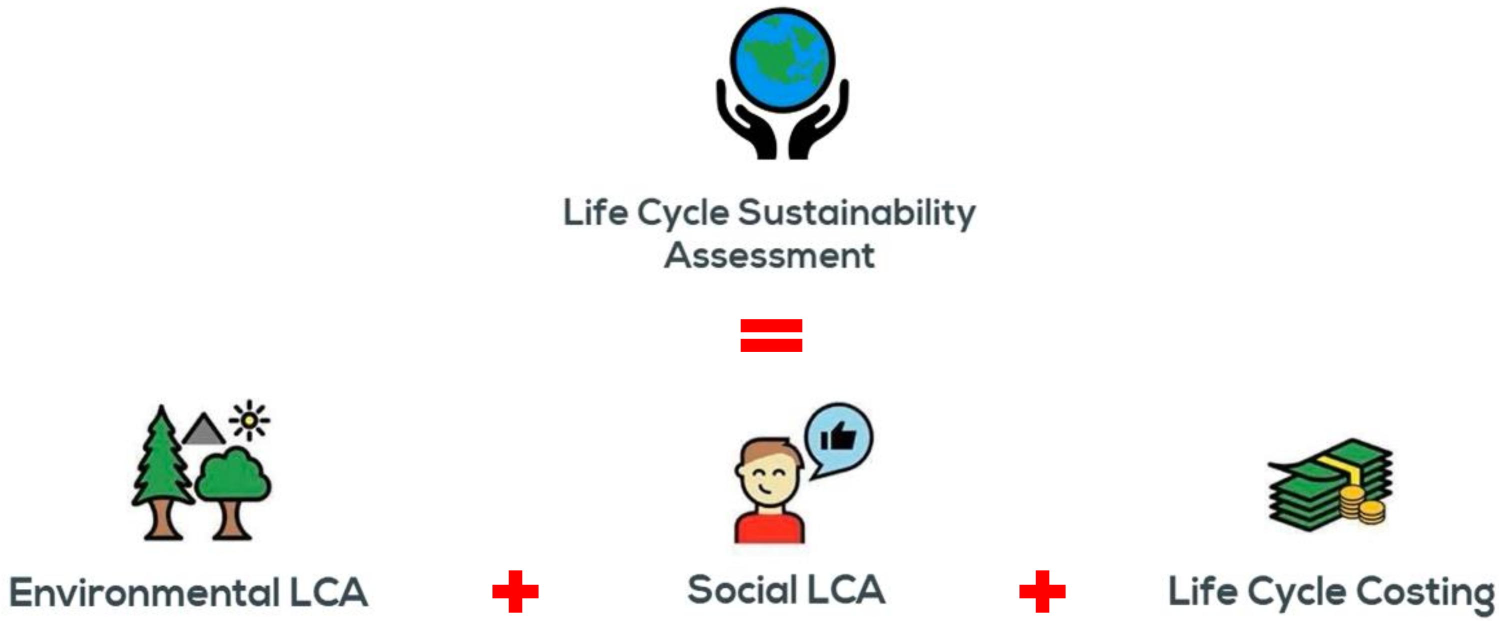
What is the Strathclyde Space Systems Database?

- A new life cycle database for space systems developed independently of the ESA LCA database at the University of Strathclyde.
- It was unveiled in September 2017 at the 68th IAC in Adelaide, Australia.
- The intention is to make the database open-source by mid-to-late 2019.
- It is capable of being integrated into a CDF session for ecodesign.
- It can come to a full life cycle sustainability assessment.



Life Cycle Sustainability Assessment (LCSA)

An environmental management tool used to measure the environmental, social and economic impacts of a product, process or service over their entire life cycle.



Environmental LCA	Social LCA	Life Cycle Costing
To measure the life cycle environmental impacts	To measure the life cycle social impacts	To measure the life cycle costs

For more info on LCSA, see the UNEP/SETAC Guidelines 'Towards a Life Cycle Sustainability Assessment'

Why Sustainability Assessment?

Guideline 27 of the United Nations Committee on the Peaceful Use of Outer Space's 'Guidelines for the long-term sustainability of outer space activities' calls for promoting and supporting research into the development of ways to support sustainable exploration and use of outer space.

United Nations

General Assembly

Committee on the Peaceful Uses of Outer Space
Scientific and Technical Subcommittee
Fifty-fourth session
Vienna, 30 January-10 February 2017

Why Sustainability Assessment?

Guideline 27 of the United Nations Committee on the Peaceful Use of Outer Space's 'Guidelines for the long-term sustainability of outer space activities' calls for promoting and supporting research into the development of ways to support sustainable exploration and use of outer space.

27.3 "States and intergovernmental organizations should **promote the development of technologies that minimize the environmental impact of manufacturing and launching space assets** and that maximize the use of renewable resources and the reusability or repurposing of space assets to enhance the long-term sustainability of those activities."

LCA?

27.2 "In their conduct of space activities for the peaceful exploration and use of outer space, including celestial bodies, states and international intergovernmental organizations should **take into account,** with reference to the outcome document of the United Nations Conference on Sustainable Development (General Assembly resolution 66/288, annex), **the social, economic and environmental dimensions of sustainable development on Earth**".

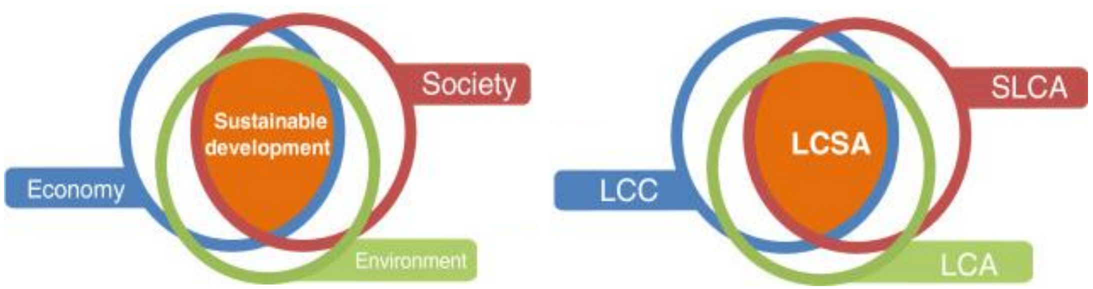
LCSA?

Other Reasons for Sustainability Assessment?

"LCA typically does not address the economic or social aspects of a product, but the life cycle approach and methodologies described in this International Standard [ISO 14040/14044] can be applied to these other aspects."

ISO 14040:2006 & ISO 14044:2006

Source: United Nations DPI (2015)



Source: Schau et al. (2012)

The SDGs promote this three-pillar concept of sustainability through shared economic prosperity, social development and environmental protection

Update on the Strathclyde Space Systems Database

General Overview

- A space-specific process LCSA database.
- Part of the Strathclyde Mechanical and Aerospace Research Toolboxes (SMART) that supports all Concurrent Engineering activities at the University of Strathclyde.
- Conforms to ISO 14040/14044 standards and follows the ESA space system LCA guidelines as closely as possible.
- Built as ZOLCA file within openLCA on top of European Life Cycle Database (ELCD) and Ecoinvent processes (used as background inventories).
- LCI data sources include experimentation, research and work conducted at the University of Strathclyde, literature reviews, LCA databases, collaboration between entities and expert input.

General Overview

Source: Galina (2013)

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Current Status of Database

Environmental LCA

$$IR_c = \sum_s CF_{cs} \cdot m_s$$

Based on ISO 14040 & 14044 and ESA space system LCA guidelines

~75 LCI datasets for space materials, & manufacturing processes

Reference: Process dependent

Midpoint, endpoint or single score (latter in progress)

Social LCA

$$IR_c = \sum_s \frac{RF_{em_s}}{I_{xs} \cdot SS_{cs}}$$

Based on UNEP/SETAC S-LCA Guidelines, SDGs & ISO 26000

105 indicators with associated evaluation schemes

Reference: Social Risk Score

Stakeholder categories, subcategories or single score

Life Cycle Costing

$$IR_c = \sum (TI_{cs} - TC_{cs}) \cdot (CR_{ays_b} [1 - CP_{bys_z}])$$

Based on average market values which account for exchange & inflation rates

35 international currencies

Reference: EUR 2000

Cost categories, mission segments or single score

For fuller methodological descriptions see: https://strathprints.strath.ac.uk/65685/

Coming to a Result

Life Cycle Sustainability Assessment

$$LCSA = LCA + SLCA + LCC$$

OPTION 1: 3 separate assessments?

OPTION 2: SLCA & LCC as LCA impact categories?

BOTH!!

For fuller methodological descriptions see: https://strathprints.strath.ac.uk/65685/

New Features – Quantifying High Altitude Releases

Platform repositioning

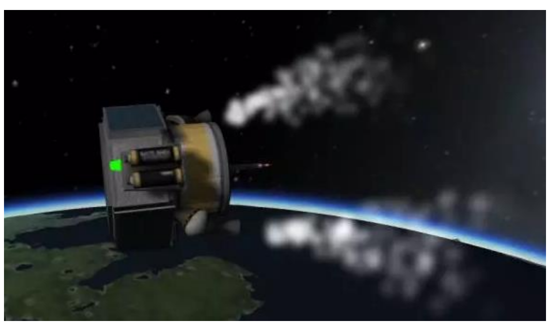
Emitted gas from mono-propellants of nozzle-based systems mixing back into lower layers of the atmosphere.

Platform erosion

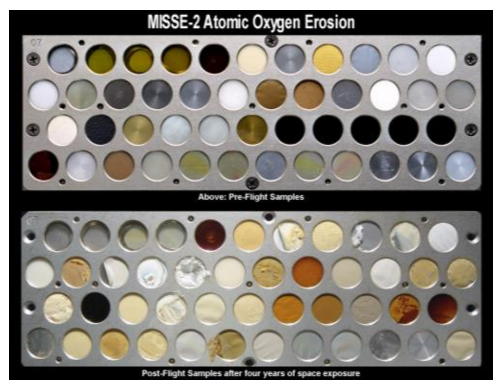
Degradation of hydrocarbon polymers due to the presence of atomic oxygen in LEO to produce volatile oxidation products.

Re-entry

The heating, melting and vaporisation of re-entering materials before turning to re-entry smoke particles (RSPs).



Source: Kerbal Space Program (2015)



Source: McCarthy et al. (2010)

Source: ESA-D. Ducros (2014)

Quantification of High Altitude Releases

A good first assumption for the characterisation of these high altitude releases within LCA can be made through the following equation:

$$IRHAR_c = \sum_s \left(\frac{CF_{cs_o} \cdot m_{s_a}}{AD_o} \right) \cdot AD_a$$

Characterisation factor that connects intervention *s* released at sea level *o* with impact category *c* (CF_{cs_o})

Size of intervention *s* released at altitude *a* (m_{s_a})

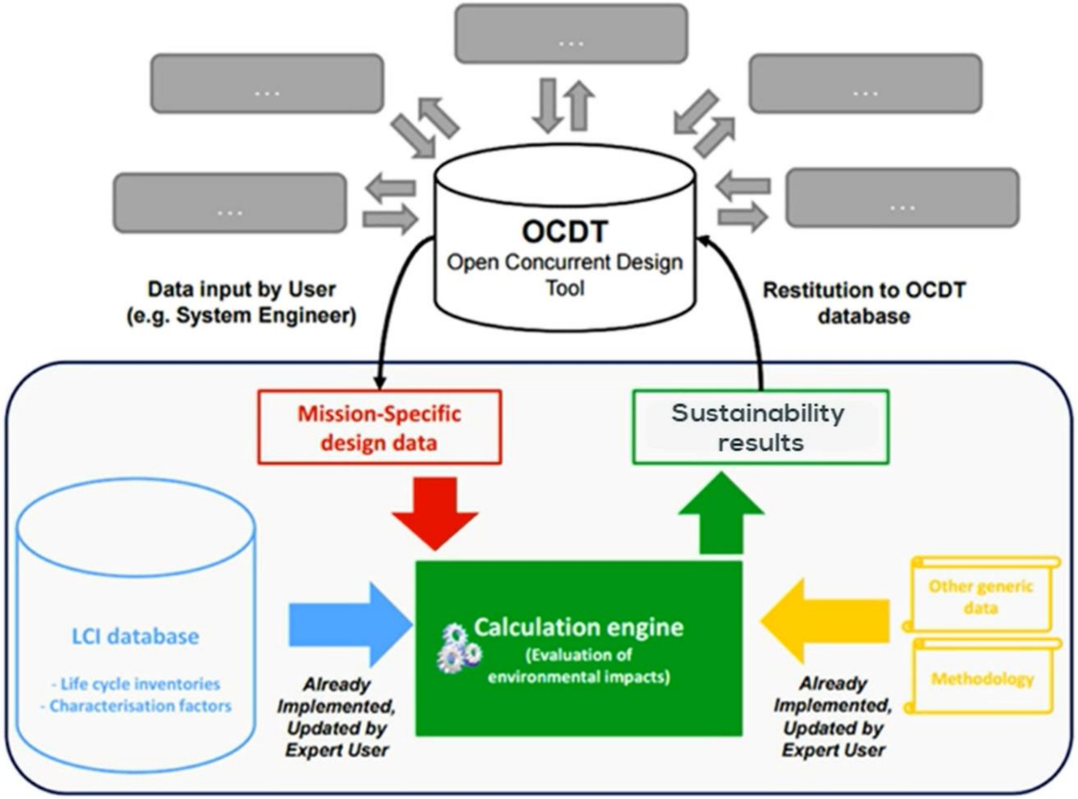
Indicator result for high altitude releases for impact category *c* ($IRHAR_c$)

Atmospheric density at altitude *a* (AD_a)

Atmospheric density at sea level *o* (AD_o)

But more study is required!

Integration into the Concurrent Design Process



Source: Adapted from Chanoine et al. (2014)

What is the MÌOS Mission?

ESA Concurrent Engineering Challenge

ESA Academy's First Concurrent Engineering Challenge:

- Tue 12th - Fri 15th September 2017.
- Strathclyde participated from the Concurrent & Collaborative Design Studio, TIC Building, University of Strathclyde.
- Purpose: For students to learn how ESA assesses technical and financial feasibility of space missions through concurrent engineering.

Four teams:

- University of Strathclyde
- Politecnico di Torino
- Universidad Politecnica de Madrid
- ESA Academy's Training and Learning Centre

Meet the Strathclyde Team!

All Masters/PhD Students from:

- Mechanical and Aerospace Engineering
- Design, Manufacture & Engineering Management
- Electronic & Electrical Engineering
- Physics

Covering the following disciplines:

- Instrument/Optics
- Propulsion
- OBDH
- Power
- Structures
- Configuration
- Thermal
- Mechanisms
- Telecom/Telemetry
- AOCS
- Mission Analysis

The Task:

A Phase 0/A design of a small satellite mission to the Moon in order to collect data on the micro-meteorite and radiation environment and detect the presence of water/ice on the Lunar South Pole in view of a future Moon base.

Source: Adapted from Psychedelic Resonances From Infinite Possibilities Digital Track "Road Moon" (2014)

Mission Objectives & Requirements

MIS-OBJ-01	The mission shall take pictures of South pole areas with high expected water/ice content, with a resolution of 10m/pixel.
MIS-OBJ-02	The mission shall observe the lunar radiation and micrometeorite environment.
MIS-OBJ-03	The mission shall observe the water/ice content of the Lunar South pole.
MIS-R-01	The mission shall consist of a single satellite or a single plane constellation.
MIS-R-02	The mission shall stay in Lunar orbit for 2 years.
MIS-R-03	The mission shall be launched using an Ariane shared GTO.
MIS-R-04	The mission shall be compatible with any launch date.
MIS-R-05	The total combined mass of the whole system shall be 300 kg.
MIS-R-06	The mission should use COTS components.
MIS-R-07	The mission shall have a end of life disposal manoeuvre.
MIS-R-08	The mission shall use direct to earth communication.
MIS-R-09	Applicable documents: CDF margin philosophy.

The Strathclyde mission design - MÌOS

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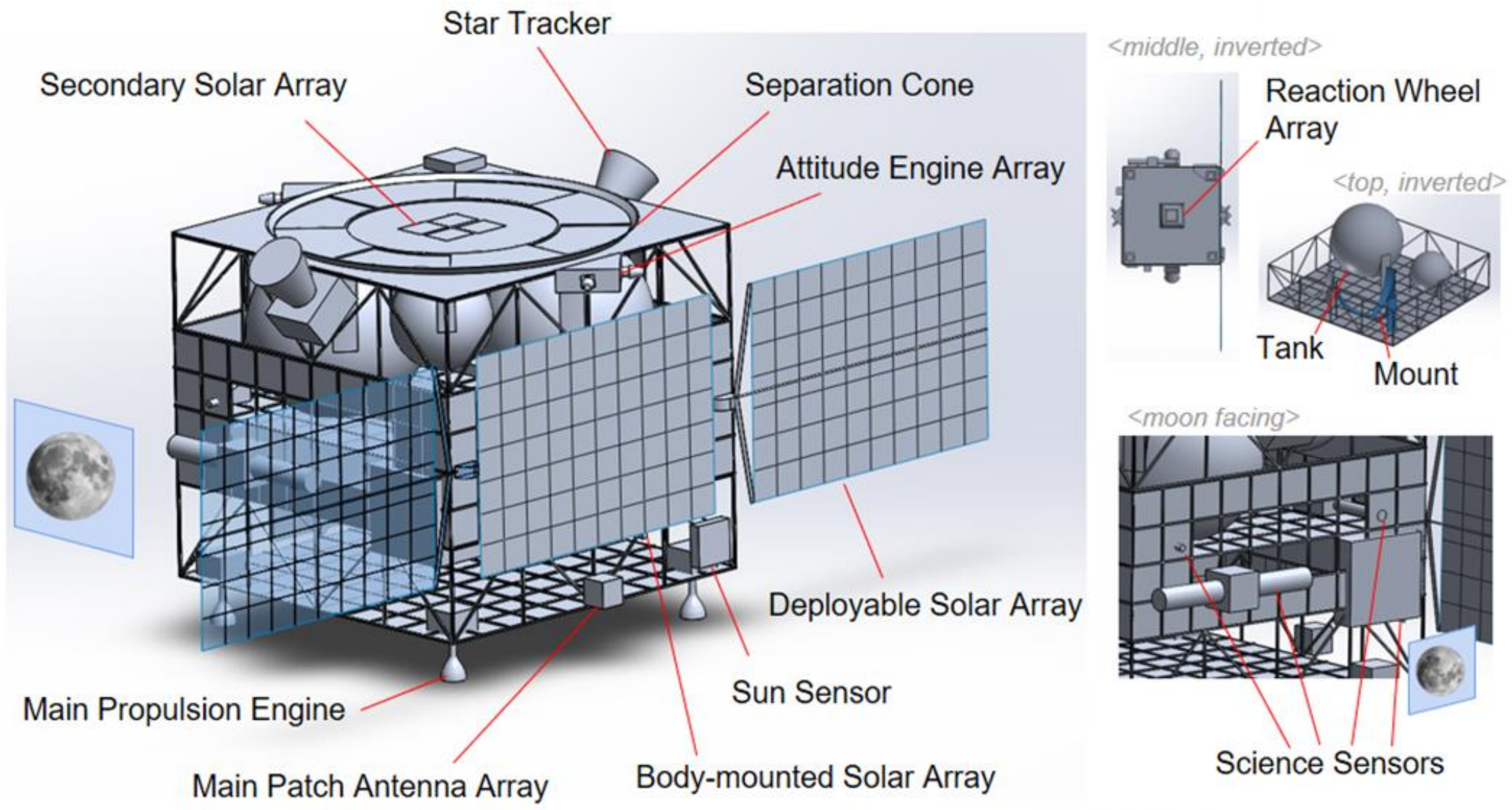
The Strathclyde mission design - MÌOS

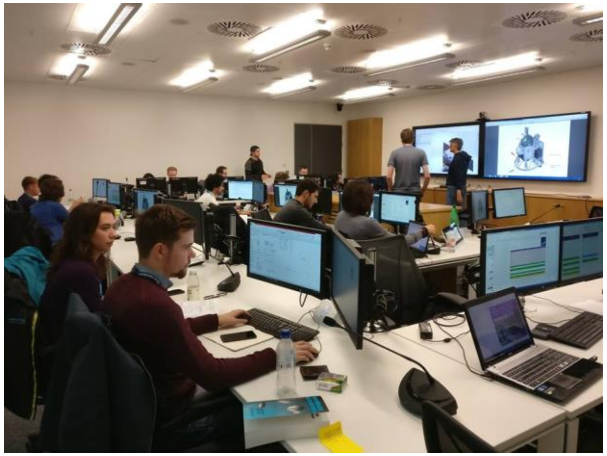


Mass Budget

Subsystem	Current Mass (kg)	Mass Margin (%)	Maximum (kg)	% of Dry Mass
Instrument/optics	11.91	12%	13.32	10%
Propulsion	27.50	9%	29.90	22%
OBDH	0.60	100%	1.20	1%
Power	19.49	20%	23.39	17%
Structures	14.82	20%	17.78	13%
Configuration	-	-	-	-
Thermal	8.27	20%	9.92	7%
Mechanisms	1.78	20%	2.136	2%
Telecom/Telemetry	4.00	20%	4.80	3%
AOCS	10.50	20%	12.60	9%
Mission Analysis	-	-	-	-
SPACECRAFT DRY TOTAL	98.87	16%	115.04	-
System Mass Margin	-	20%	23.01	-
DRY TOTAL (incl. System Mass Margin)	-	-	138.05	-
Propellant	140.10	2%	142.90	-
SPACECRAFT WET MASS	-	-	280.95	-
Launch Adapter	4.24	20%	5.09	-
WET MASS + LA	-	-	286.04	-
Mass Margin	-	-	13.96	4.65%

Study Outcomes

- A robust design capable fulfilling all objectives & requirements with good margins.
- No major design flaws at the final review.
- Potential improvement of design with further iterations.
- Taught students about concurrent engineering, mission design and how to use the OCDT & data sharing.
- But no information on the environmental, social or economic life cycle impacts of the mission.



Why was LCSA not Integrated to the CDF study?

1. LCSA (or even E-LCA) was not included as one of the required disciplines within the study.
2. At the time of the study, the SSSD was not yet at a point where it could be used within concurrent design.
3. The only Ecodesign expert at Strathclyde already was participating in the study as:
   - CDF Team Leader
     - Managing the study
     - Providing support to all disciplines
   - Part of the propulsion team
     - Defining a propulsion system
     - Calculating the total amount of propellant
   - Systems Engineer
     - OCDT site administrator
     - Manager of the system mass budget
     - Manager of the system power budget
   - Project Engineer
     - Organising the challenge
     - Providing students with training
     - Running of the challenge
     - Follow-up to the challenge

Source: Sasek (2017)

So why do a LCSA now?

1. Requested by the Director of the Aerospace Centre for Excellence to allow all space mission designed at the University of Strathclyde to be as environmentally, socially and economically responsible as possible.

2. To inform decision-makers of the sustainability impacts of the MÌOS concept before the potential of any further iterations/design sessions were to occur.

3. As a first test case for the SSSD (now that it is ready) to assess the sustainability impacts of a space mission.

Source: PresenterMedia (2018)

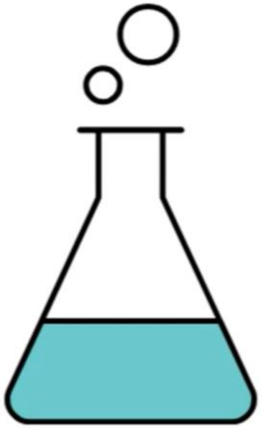
Post-mission LCSA of the MÌOS mission

Scenarios

The post-mission LCSA for the MÌOS mission was used as a test case for the SSSD and considered two options:

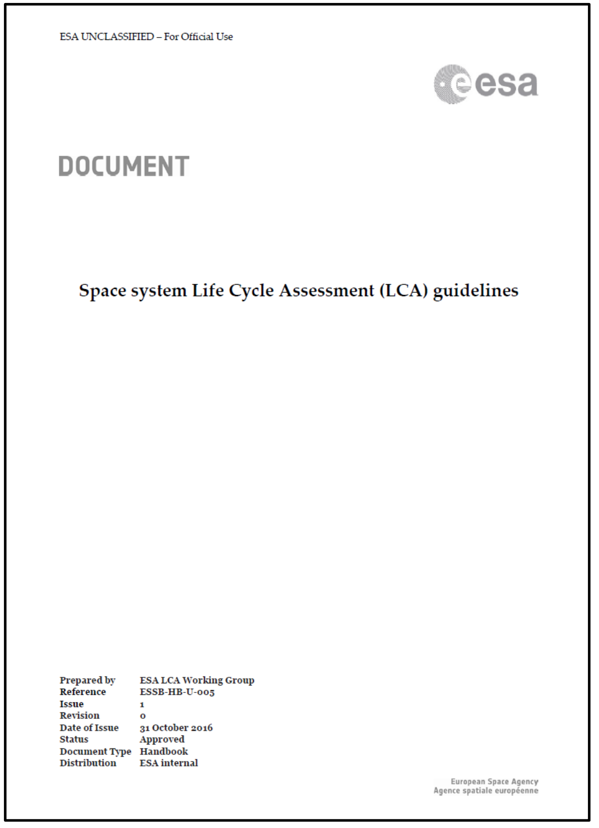
(A)
MÌOS system level life cycle sustainability assessment results

(B)
The influence of changing mono-propellants from hydrazine to LMP-103S on MÌOS system level results



Required Assets for the Assessment

- The Strathclyde Space Systems Database.
- Access to the OCDT model and final presentation of the MÌOS mission.
- ISO 14040:2006, 14044:2006 & 15686-6:2017 standards.
- IEC 60300-3-3:2017 standard.
- UNEP/SETAC S-LCA & LCSA guidelines.
- ESA Space system Life Cycle Assessment (LCA) guidelines.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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

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University of Strathclyde Engineering

Goal & Scope

Goal:

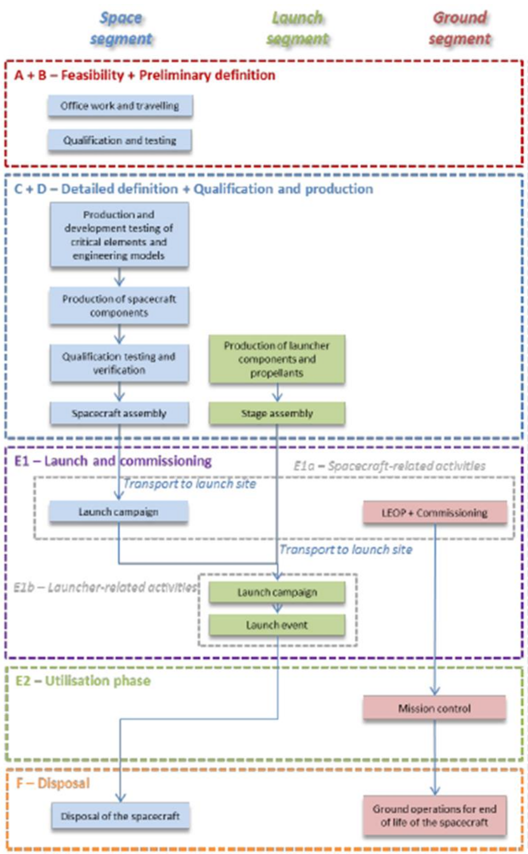
Scenario A: To assess the full system level life cycle sustainability impacts of the MÌOS mission through a post-CDF LCSA study.

Scenario B: To assess the direct & indirect life cycle sustainability impacts of changing mono-propellants from hydrazine to LMP-103S on MÌOS system level results from Scenario A*.

Scope:

FU: “One space mission in fulfilment of its requirements”.

System Boundary: See figure on right.



*Based on a previous SSSD study which found that the overall direct environmental impact of 1 kg of LMP-103S was generally lower than 1 kg of hydrazine.

Life Cycle Inventory

Data Collection:

- LCI used is the SSSD.
- Dynamic elements (i.e. space systems) based on information contained within the OCDT and final presentation of the MÌOS mission.
- Non-dynamic elements (i.e. man-hours) based on typical values for mission type.

Data Calculation:

- Data is calculated in terms of spacecraft wet mass plus the launch adapter (including system and subsystem mass margins).
- Validation of data collected for dynamic elements was confirmed at final review.
- The relating of data to unit processes and the reference flow of the functional unit is already implemented within the SSSD.

Allocation:

- Allocation already implemented within the SSSD.

The Strathclyde Space Systems Database:
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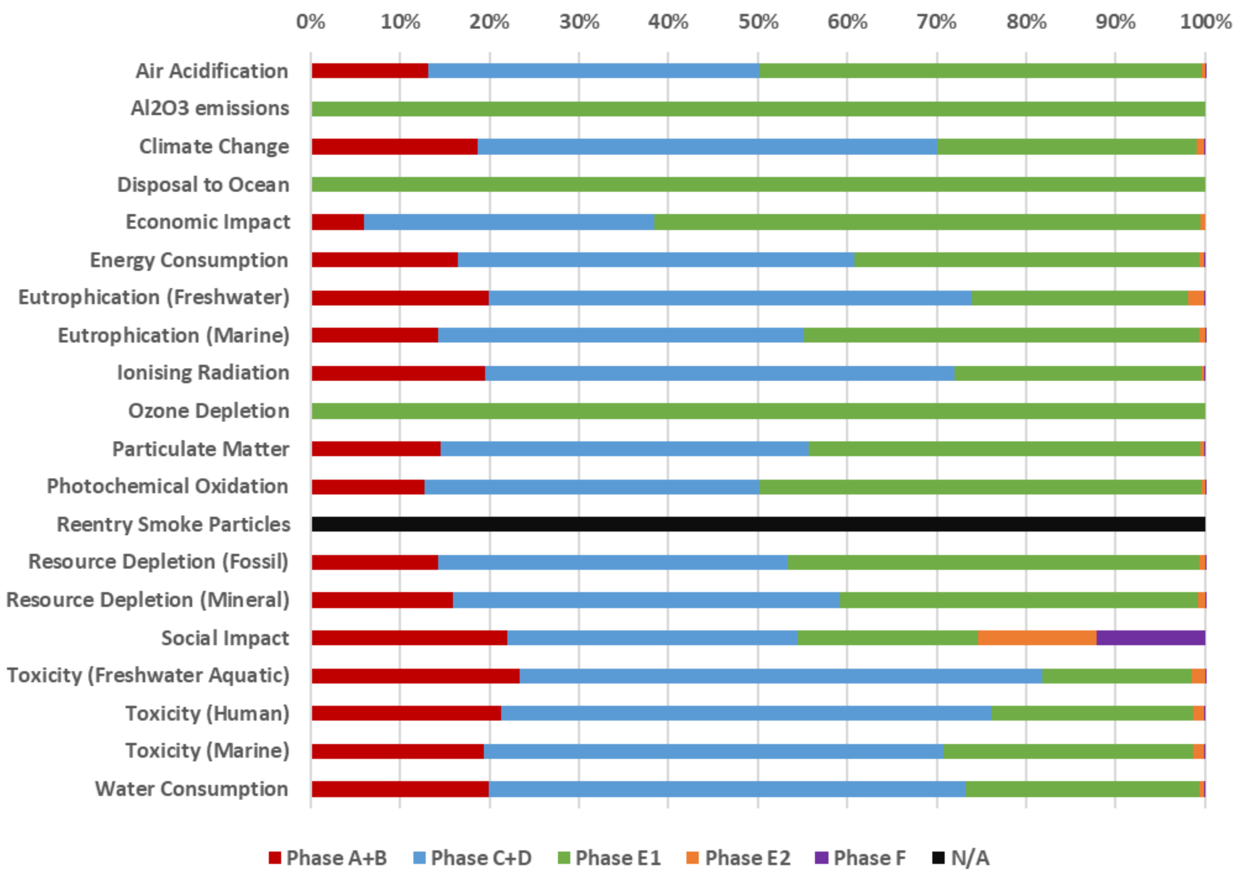
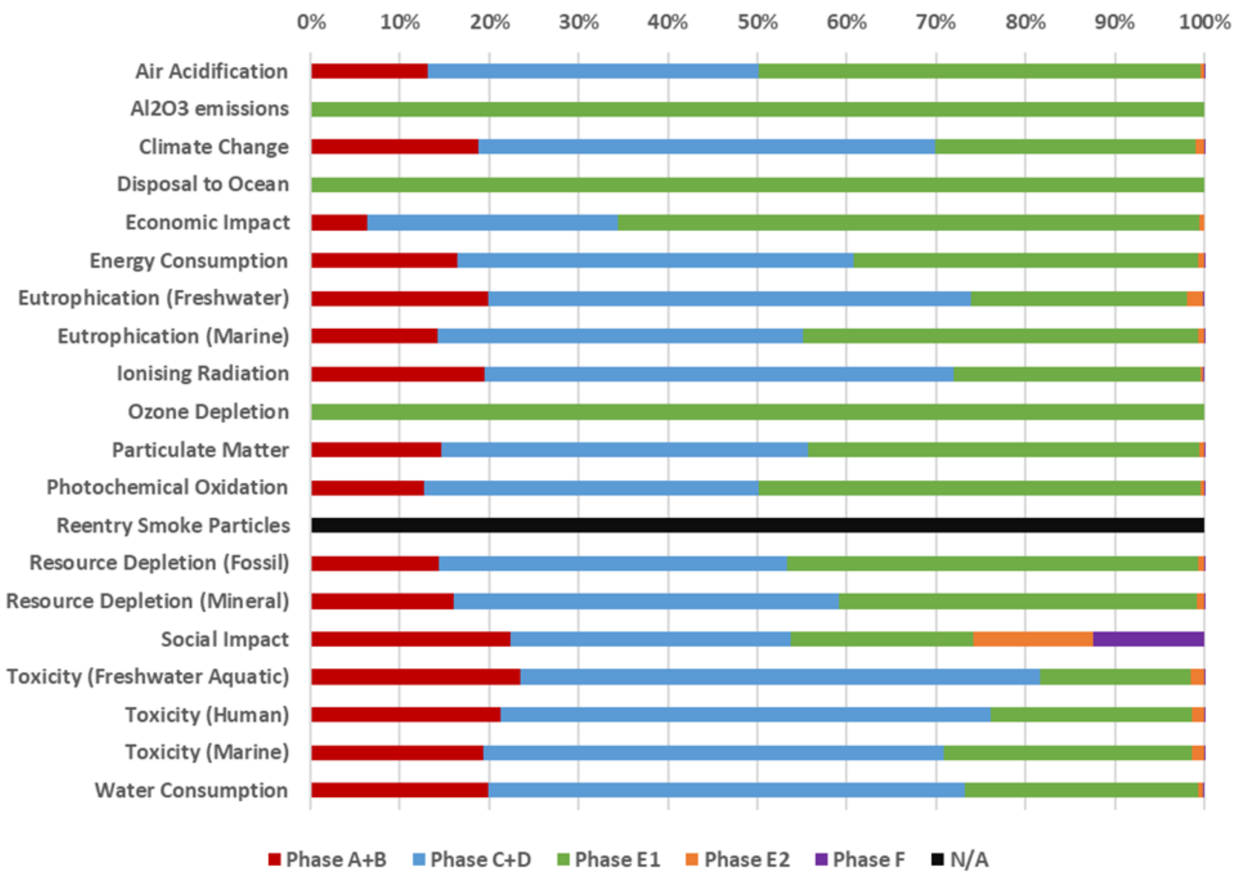
A: Life Cycle Impact Assessment



Impact Category	Result	Unit
Air acidification	4.60655E4	kg SO2 eq
Al2O3 emissions	4540	kg
Climate change	9.49483E6	kg CO2 eq
Disposal to ocean	96595	kg
Economic impact	2.92116E8	EUR 2000
Energy consumption	2.10155E8	MJ
FW eutrophication	5169	kg P eq
Marine eutrophication	1.03660E4	kg N eq
Ionising radiation	4.55751E6	kg U235 eq
Ozone depletion	2126	kg CFC-11 eq
Particulate matter	1.24884E4	kg PM10 eq
Photochemical ox.	2.89205E4	kg NMVOC
Fossil res. depletion	1.51309E8	MJ fossil
Mineral res. depletion	8.08236E4	kg Sb eq
Social impact	14.51	Social score
FWA ecotoxicity	4.95064E7	PAF.m3.day
Human toxicity	3.12	Cases
Marine ecotoxicity	1.11356E10	kg 1,4-DB eq
Water consumption	4.52780E7	m3

The Strathclyde Space Systems Database:
Life Cycle Sustainability Results of the MÌOS Mission

B: Life Cycle Impact Assessment



Impact Category	Result	Unit
Air acidification	4.60523E4	kg SO2 eq
Al2O3 emissions	4540	kg
Climate change	9.49137E6	kg CO2 eq
Disposal to ocean	96595	kg
Economic impact	2.74462E8	EUR 2000
Energy consumption	2.10095E8	MJ
FW eutrophication	5164	kg P eq
Marine eutrophication	1.03616E4	kg N eq
Ionising radiation	4.55628E6	kg U235 eq
Ozone depletion	2126	kg CFC-11 eq
Particulate matter	1.24833E4	kg PM10 eq
Photochemical ox.	2.89121E4	kg NMVOC
Fossil res. depletion	1.51269E8	MJ fossil
Mineral res. depletion	8.07981E4	kg Sb eq
Social impact	14.25	Social score
FWA ecotoxicity	4.93200E7	PAF.m3.day
Human toxicity	3.12	Cases
Marine ecotoxicity	1.11260E10	kg 1,4-DB eq
Water consumption	4.52611E7	m3

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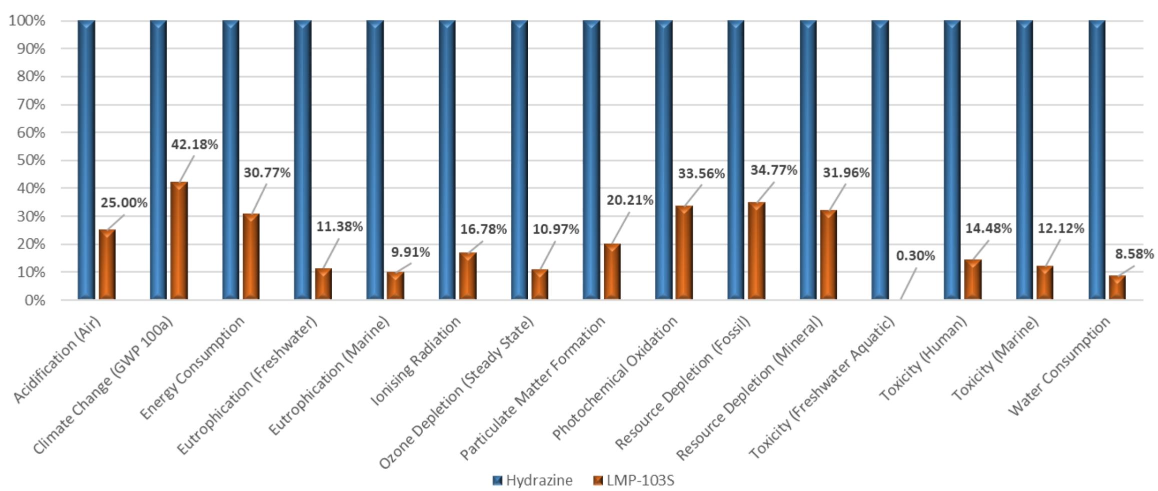
B: Life Cycle Impact Assessment

Direct impacts from the production and manufacturing of 1 kg of LMP-103S compared to the production and manufacturing of 1 kg of hydrazine for selected impact categories



Social

Hydrazine: 100%

LMP-103S: 77.37%

Economic

Hydrazine: 20.03%

LMP-103S: 100%

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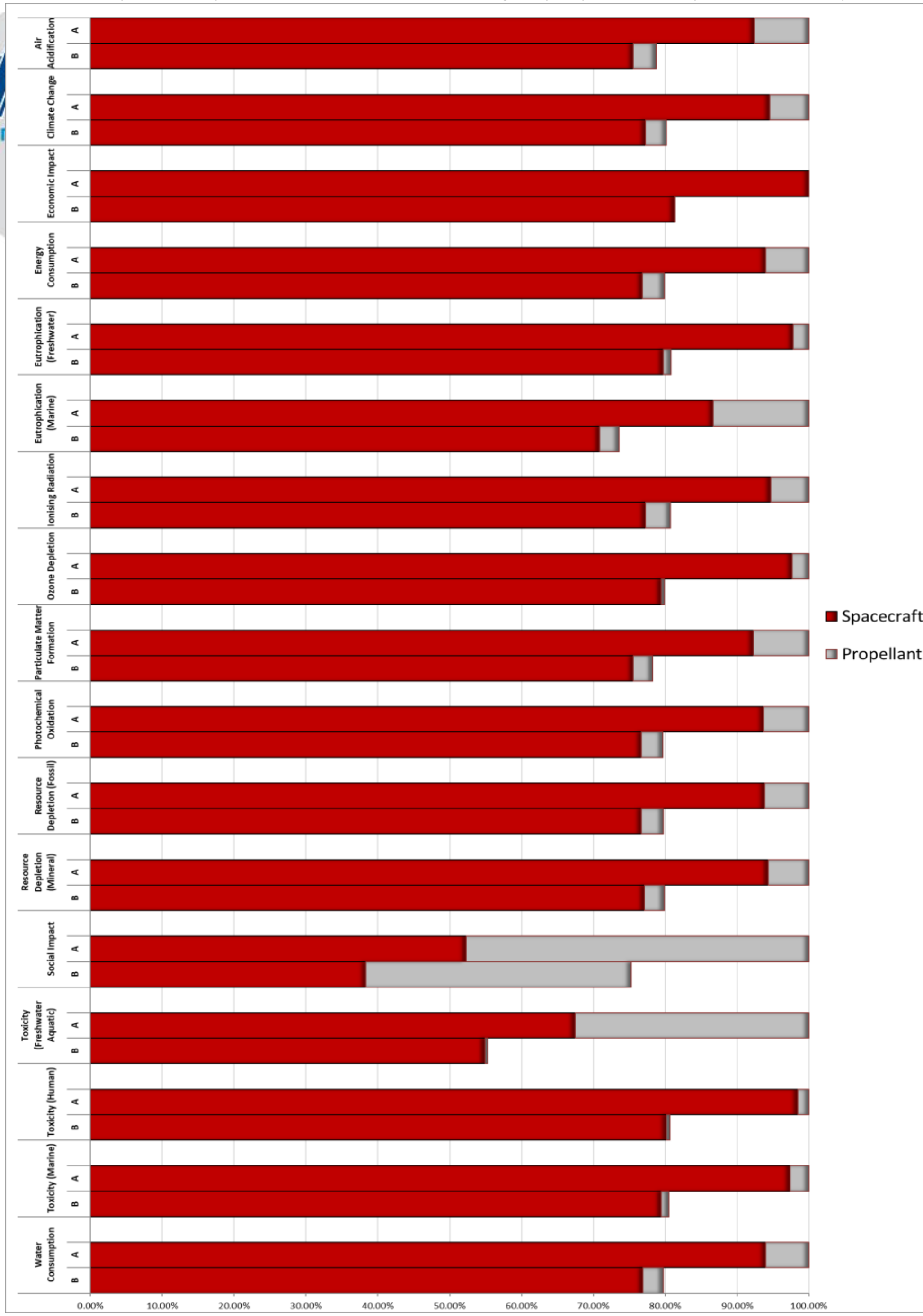
Water consumption	4.52611E7	m3

Indirect impacts on production & manufacturing of propellant & spacecraft components



B

...ems Database:
...f the MÌOS Mission

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Water consumption	4.52611E7	m3

Interpretation

Scenario A

- The LCSA study has identified the potential hotspots of the MÌOS mission and fulfilled its intended goal with respect to the FU and system boundary.

Scenario B

- The change from hydrazine to LMP-103S barely affects the system level results due to how small the spacecraft is (<300kg).
- However LMP-103S can be considered as a better option than hydrazine:
  - 32% higher density impulse and 8% higher Isp (values based on observations from the PRISMA mission, launched 15 June 2010).
  - 26% less propellant required.
  - 39% smaller propellant tank required.
  - 18.7% ‘waterfall’ mass savings.
  - 22.15% average saving per environmental impact category during space segment.
  - 0.03% average saving per environmental impact category at system level.
  - 24.73% reduction in social impact during space segment.
  - 1.77% reduction in social impact at system level.
  - 18.65% cost savings during space segment.
  - 6.05% cost savings at system level.
  - Hydrazine is REACH restricted whereas LMP-103S is not.

Evaluation

Successes

- First ever LCSA conducted for space systems.
- Demonstrated the important role of economic and social considerations in decision-making.
- The SSSD integrates LCSA into concurrent design to allow the space sector to be more accountable for their actions based on globally accepted policies and guidelines.

Problems

- At system level the relative impacts of ecodesign changes seem small.
- Many impact categories are confusing for non-LCA experts and the amount devalues social and economic issues.

Recommendations

- Focus ecodesign on dynamic elements (i.e. spacecraft + propellant production & manufacturing).
- Reduce LCA impact categories to simplify decision-making despite being less scientific.
  - **Endpoints:** Human health, Ecosystem damage, Resource consumption, Social, Economic
  - **Single Score:** Environment, Social, Economic
  - **Sustainability Single Score:** Sustainability

Current Work, Future Work & Conclusion

The Strathclyde Space Systems Database:

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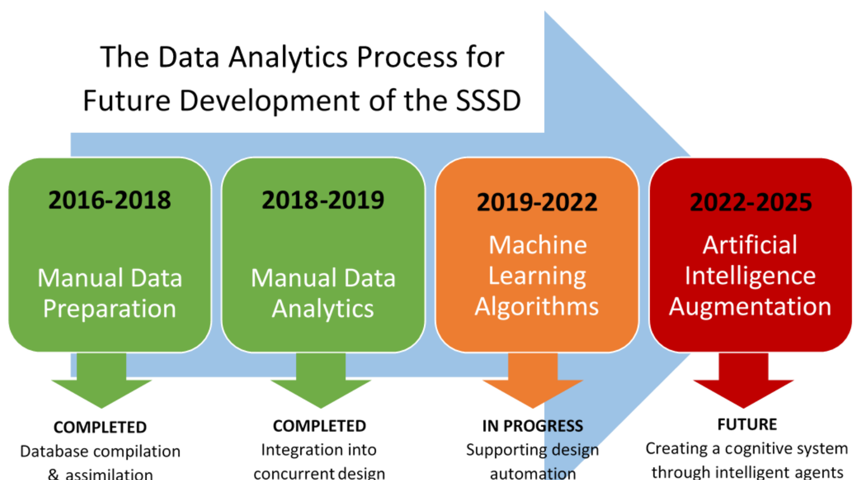
Current & Future Work

Current Work

- The SSSD is currently undergoing validity testing with the ESA LCA database & Space Opera ecodesign tool from September 2018 to December 2018.
- The SSSD is being gradually integrated into concurrent design as an ecodesign tool.

Future Work

- The SSSD will be used within a concurrent design session to generate sustainability results for a SPACE Canada mission concept in February 2019.
- The SSSD Proposed Roadmap shows how the SSSD will become part of SMART for future CDF studies at the University of Strathclyde.



Proposed SSSD Roadmap by June 2019

Conclusion

The benefits of using sustainability criteria in mission design has been demonstrated. It is hoped that the SSSD will contribute to the global sustainability agenda by assisting decision-makers to design space missions that are not only cost-efficient, eco-efficient and socially responsible, but also ones that can easily justify and evidence their sustainability.

Acknowledgments:

Any Questions?

University of Strathclyde Glasgow

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