ECODESIGN: TOWARDS LIFE CYCLE SUSTAINABILITY OF SPACE SYSTEMS

Clean Space Industrial Days

European Space Research & Technology Centre (ESTEC)

Noordwijk, Netherlands

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24th October 2017

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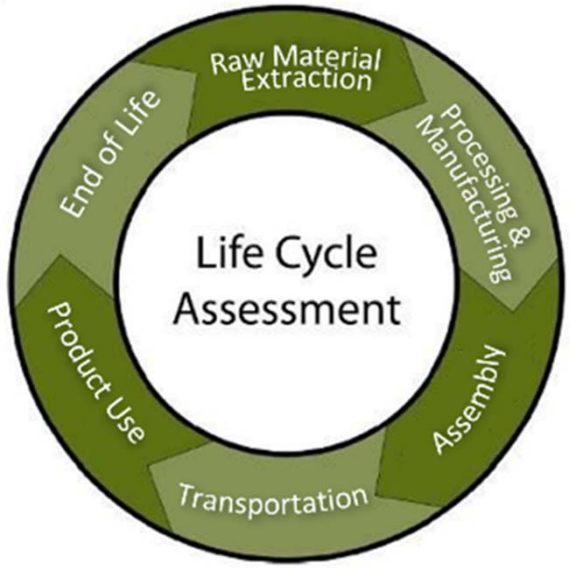
Outline

1. Introduction
2. Life Cycle Sustainability Assessment
3. Process for conducting SLCAs & LCCs
4. Use within the Strathclyde Space Systems Database
5. Discussion & Future Work

Introduction

Context

- Renewed focus on sustainability issues.
- LCA has become embedded within a variety of sectors such as the space industry.
- There is now a growing consensus for a move to a more all-encompassing Life Cycle Sustainability Assessment (LCSA).
- LCA within the space sector should be developed in line with the LCA sector to give parity across the industries.
- Moving towards space-based LCSA is a logical next step which allows for the three pillars of sustainability to be addressed within one assessment.
- Allows the industry to become more accountable and responsible for their operations by taking into account the full spectrum of life cycle impacts and sustainability issues associated with the operation of space systems.



Life Cycle Perspective of a Product System

Purpose

- To introduce the concept of LCSA for space systems.
- To introduce a new open-source LCA platform for space systems which is currently under development at the University of Strathclyde, outlining its inclusion of SLCA and LCC of the next generation green space systems.
  - To use LCSA to assist in defining new optimality criteria for space systems.
  - To help decision-makers choose sustainable technologies and products by determining those that are not only cost-efficient, eco-efficient or socially responsible, but also ones that can easily justify and evidence their sustainability.
  - To act as a crucial first step for the space industry to achieve sustainability by using cutting-edge technological solutions that have both the capability and practical application to mitigate the overall impacts of space programmes and activities during the design process.

Life Cycle Sustainability Assessment

An Overview of Life Cycle Sustainability Assessment

What is LCSA?

An environmental management tool used to measure the environmental, social and economic impacts of products, processes or services over their entire life cycle.

LCSA = LCA + SLCA + LCC

OPTION 1 — 3 separate assessments?

OPTION 2 — SLCA & LCC as LCA impact categories?

Why use LCSA for Space Products?

- The development of LCA is rapidly increasing in for space systems…
- …but LCSA has been described as the future of LCA…
- …so this approach should be adopted in order for the space industry to stay in line with the environmental management sector.

Dimensions of Sustainability & Life Cycle Sustainability Assessment (Source: Schau et al, 2012)

Brief History of Life Cycle Sustainability Assessment

- **1987:** Brundtland Report and 'Life cycle thinking' grows in importance throughout the 1990s.
- **1998:** Anderson et al suggests that environmental impacts within LCA should not be separate from societal and economic impacts.
- **2000:** Upham expanded on this, highlighting the need for a perspective that was wider than LCA.
- **2002:** 'Life cycle thinking' concept mentioned at the World Summit on Sustainable Development.
- **2005:** Hunkeler & Rebitzer proposed that in order to have a sustainability approach to LCA, social aspects (although not naming SLCA specifically) and LCC must also be considered.
- **2008:** Walter Klöpffer formalised efforts of linking environmental, societal and economic principles as they relate to product life cycle by creating a new kind of sustainability framework called LCSA.
- **2011:** In an evaluation of LCA evolution, Guinée et al suggested that the future of LCA lies with a move towards LCSA.
- **2011:** UNEP/SETAC release "Towards a Life Cycle Sustainability Assessment" Guidelines.
- **To date:** No known space-related LCSAs which encapsulate the sustainability triad of environmental, social and economic concerns has never been conducted.

Key Aspects of Each Assessment:

Life Cycle Assessment	***Social Life Cycle Assessment***	***Life Cycle Costing***
• Quite well-defined and frequently used.	• Poorly understood/defined and not used often.	• Reasonably well-defined and occasionally used.
• ISO 14040 & 14044 standards.	• Non-standardised.	• Only standardised for buildings & constructed assets (ISO 15686-5:2017).
• Numerous supporting documents and guidance papers.	• UNEP/SETAC guidelines used as a benchmark.	• Several supporting documents and papers.
• Impacts broken down into midpoints or endpoints.	• Impacts broken down into stakeholder or impact categories.	• Impacts broken down into cost categories or a single monetary value.
• Globally accepted characterisation factors for substances.	• Subjective implementable indicator criteria and no characterisation factors.	• No characterisation required.

Life Cycle Assessment Framework

When conducting an LCSA, both SLCA and LCC should still follow the LCA Framework as closely as possible for consistency in addition to the UNEP/SETAC LCSA Guidelines (& ESA's Space System LCA Guidelines when conducting a LCSA of space systems)!!!

Goal & Scope

- Functional Unit
- System Boundary

Life Cycle Inventory Analysis

- Data Collection & Calculation

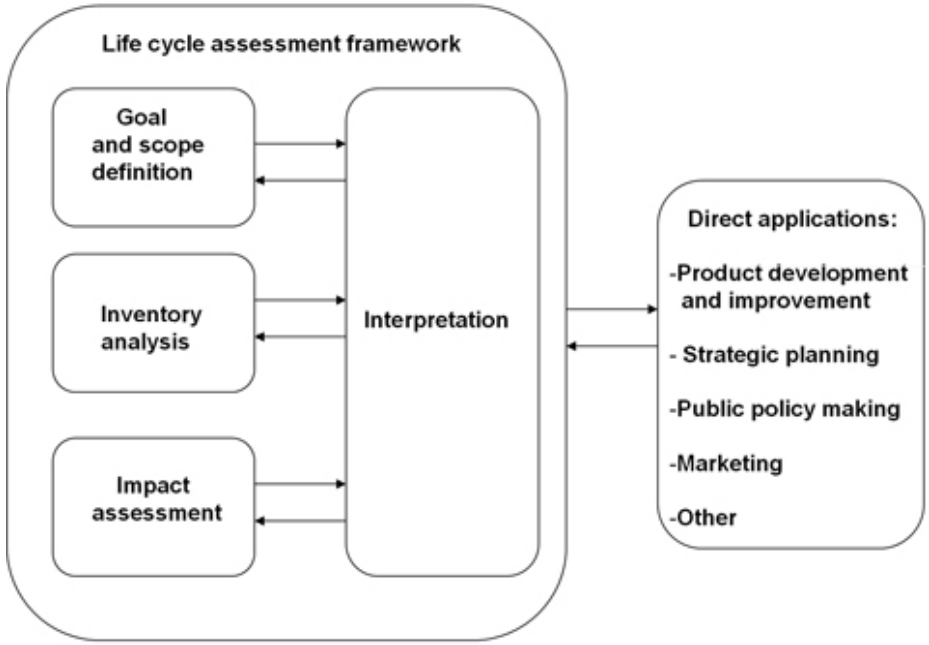
Life Cycle Impact Assessment

- Selection of Impact Categories, Indicators & Characterisation Models

Interpretation

- Completeness, Sensitivity & Consistency Checks
- Conclusions, Limitations & Recommendations

"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."



LCA Framework (Source: ISO 14040:2006)

Process for conducting SLCAs & LCCs

Social Life Cycle Assessment

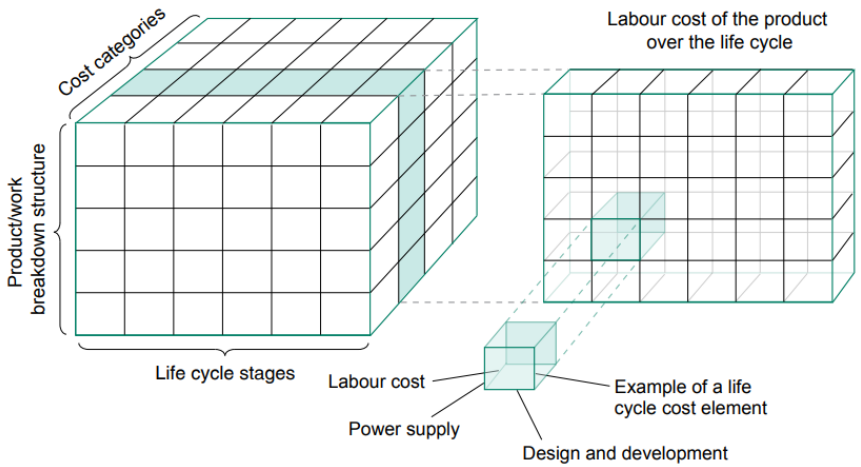
SLCA Stakeholder Categories & Subcategories (Source: UNEP/SETAC, 2009)

Stakeholder categories	Subcategories
Stakeholder "worker"	Freedom of Association and Collective Bargaining Child Labour Fair Salary Working Hours Forced Labour Equal opportunities/Discrimination Health and Safety Social Benefits/Social Security
Stakeholder "consumer"	Health & Safety Feedback Mechanism Consumer Privacy Transparency End of life responsibility
Stakeholder "local community"	Access to material resources Access to immaterial resources Delocalization and Migration Cultural Heritage Safe & healthy living conditions Respect of indigenous rights Community engagement Local employment Secure living conditions
Stakeholder "society"	Public commitments to sustainability issues Contribution to economic development Prevention & mitigation of armed conflicts Technology development Corruption
Value chain actors* not including consumers	Fair competition Promoting social responsibility Supplier relationships Respect of intellectual property rights

Social Life Cycle Assessment

- The UNEP/SETAC "Guidelines for Social Life Cycle Assessment of Products" should used as baseline for conducting SLCAs.
- Should follow ISO 14040 Framework with some adaptions.
- Goal and Scope should be aligned to the study and/or other studies involved in the LCSA, including functional unit and system boundary.
- LCI has a range of different Stakeholder Categories and Subcategories (shown on the left) with a number of social indicators each for which data should be collected and calculated.
- LCIA is not always mathematical as the inventory usually contains a mix of qualitative and quantitative data meaning that the results can often be very subjective which causes problems. This makes characterisation difficult.
- Interpretation should follow the same process as documented within the ISO 14040 Framework.

Life Cycle Costing



Cost categories and the share if labour costs in LCC (Source: IEC, 1996)

Life Cycle Costing

- Various different types of LCC exists for different industrial sectors and products (see The UNEP/SETAC “Towards Life Cycle Sustainability Assessment” Guidelines for more details).
- Should follow ISO 14040 Framework.
- Goal and Scope should be aligned to the study and/or other studies involved in the LCSA, including functional unit and system boundary whilst considering potential discount rates.
- LCI is concerned with gathering data for the different unit processes as cost flows.
- LCIA should aggregate costs by cost categories. These cost categories will highly depend on the product system and supply chain (see left).
- Interpretation should follow the same process as documented within the ISO 14040 Framework.

Use within the Strathclyde Space Systems Database

An Overview of the Strathclyde Space Systems Database

- A space-specific process database capable of determining the life cycle sustainability impacts of a variety of space systems which has been constructed to address these problems.
- Aim is to improve upon space LCA methodology by providing a robust open-source LCA platform which can be integrated into the concurrent design process.
- Part of the Strathclyde Mechanical and Aerospace Research Toolboxes (SMART) that supports all Concurrent Engineering activities at the University of Strathclyde.
- It should be noted that it is by no means the intention to compete with or replicate the SPACE OPERA tool created at ESA.

SMART
STRATHCLYDE MECHANICAL AND AEROSPACE RESEARCH TOOLBOXES

Life Cycle Assessment Methodology

- Still under development but conforms to ISO 14040/14044 standards and follow the ESA guidelines as closely as possible with the view of improving the methodology used.
- Built as ZOLCA file within openLCA on top of European Life Cycle Database (ELCD) and Ecoinvent processes in a tier-style approach with 5 levels for calculation to determine a singular unit of output per process.
- Data sources include experimentation, research and work conducted at the University of Strathclyde, literature reviews, LCA databases, collaboration between entities and expert input.
- Midpoints indicators used to comprise of a wide range of potential environmental impact areas and are considered to be representative of a space mission.

SSSD Levels for Calculation

Level	Name
1	Analysis of whole mission
2	Analysis of mission phases
3	Analysis of mission phase categories
4	Analysis of singular activities (Underlying assumptions & transitioning into easy-to-understand units)
5	Background LCI Inventories & Databases

Social Life Cycle Assessment Methodology

- Uses Stakeholder Categories & Subcategories from the UNEP/SETAC SLCA Guidelines.
- A range of space- and non-specific indicators were created for each Stakeholder Subcategory with a suggested evaluation scheme to obtain a social risk factor.
- Evaluation schemes are merely suggestions and primarily concentrate on European and UK based evaluation criteria and are not intended to represent geographical regions, organisations or stages along the supply chain.
- The evaluation scheme puts the LCI result into performance-based bands and these bands are attributed a risk factor and score of between 0 and 100.
- Once a risk factor has been assigned to the 'social aspects' tab of the relevant Level 2 process, the user can then input a flow into Level 2 process which is linked to the LCIA.
- Impact category results calculated by; $IR_c = \sum_s \frac{RF_{em_s}}{I_{xs} \cdot SS_c}$
- As characterisation uses risk factors, a social score is obtained which can be used to come to a single score result.

SSSD Social Risk Factors

Performance Band	Risk Factor
No Risk	0
Very Low Risk	20
Low Risk	40
Medium Risk	60
High Risk	80
Very High Risk	100

Life Cycle Costing Methodology

- A very simplistic assessment type which allows the user to add unit flows for process input.
- Splits monetary flows into costs and revenues across all life cycle phases for a variety of different cost categories for the space segment, launch segment, ground segment and infrastructure.
- No characterisation or risk factors are required as all results have a single unitary value.
- Can be input to Level 2 or 3 processes.
- Impact category results calculated by; $IR_c = \sum_s TR_{cs} - TC_{cs}$
- As this assessment type uses a single monetary value, a single score can be obtained.

Example of SSSD LCC Cost & Revenue Categories

Costs	Revenues
Assembly & Integration	Deductions
End of Life	Investment
Energy & Fuel	Other
Exchange & Transfer Losses	Proceeds
Extraction & Processing	Residual Value
Insurance	Trade & Sales
Labour	
Maintenance & Service	
Manufacturing & Production	
Material, Component & Resource	
Operating	
Other	
Procurement	
Replacement	
Tax & Licensing	
Testing	
Training, Consultations & Meetings	
Transportation	
Utilities	
VAT	

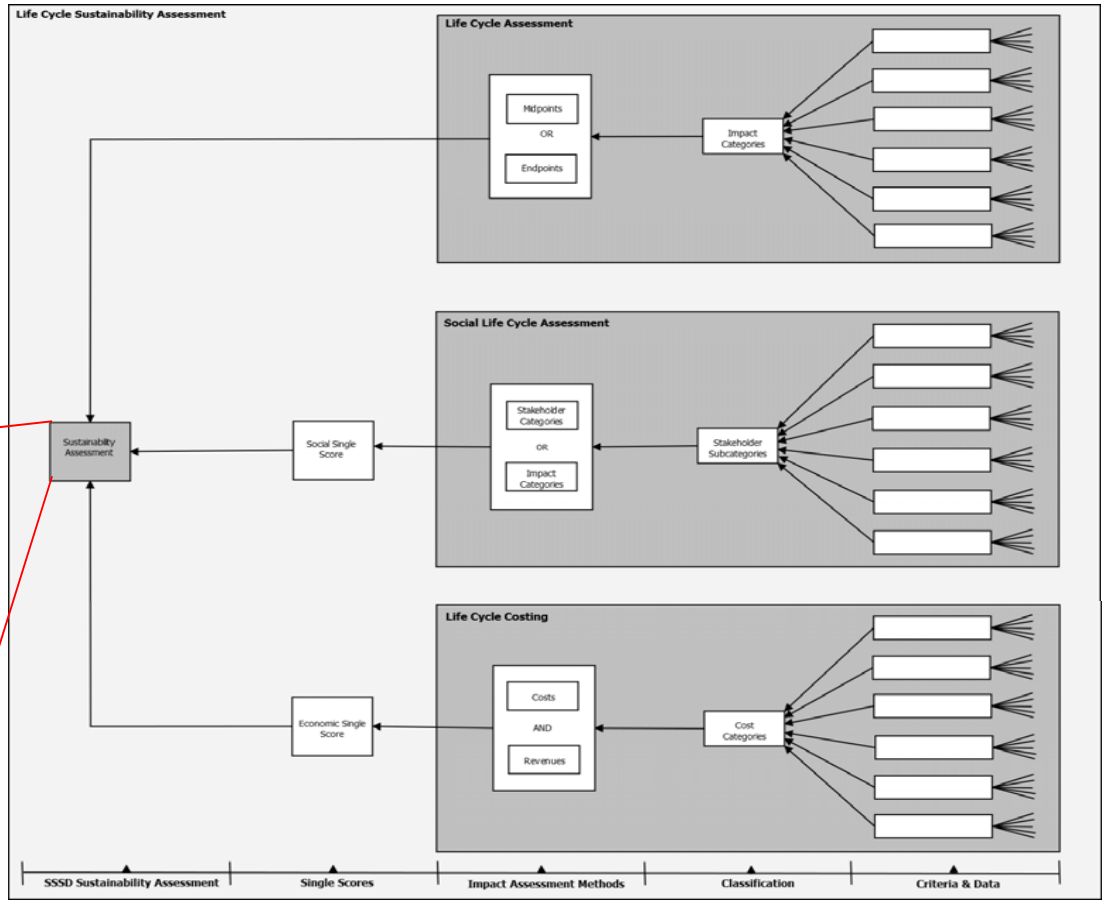
Coming to a Life Cycle Sustainability Assessment

So now we have three separate life cycle studies… now what?

They can either be viewed as entire assessments in their own right or SLCA and LCC can be included as single score impact categories within LCA

SSSD Impact Categories

Impact Category	Unit	Source
Acidification	kg SO_2 eq.	CML
Climate Change	kg CO_2 eq.	IPCC
Eutrophication - Freshwater	kg P eq.	ReCiPe
Eutrophication - Marine	kg N eq.	ReCiPe
Ionising Radiation	kg U-235 eq.	ReCiPe
Ozone Depletion	kg CFC-11 eq.	CML
Particulate Matter Formation	kg PM10 eq.	ReCiPe
Photochemical Oxidation	kg NMVOC	ReCiPe
Resource Depletion - Fossil	MJ fossil	CML
Resource Depletion - Mineral	kg Sb eq.	CML
Toxicity - Freshwater Aquatic	PAF.m^3.day	USEtox
Toxicity - Human	cases	USEtox
Toxicity - Marine	kg 1,4 DB eq.	CML
Water Consumption	m^3	ReCiPe
Social Impacts (SLCA)	**Social Score**	-
Economic Impacts (LCC)	**Currency**	-



Discussion & Future Work

Evaluation of the Strathclyde Space Systems Database

- Will offer a preliminary LCA tool for space systems which can be built upon to become a robust technique for calculating life cycle impacts of space-specific products.
- Capable of being integrated into the concurrent design process in order to determine life cycle impacts of the next generation of green space systems.
- The inclusion of LCSA gives more depth and showcases how a sustainability assessment can be reached rather than purely an environmental one.
- Gathering data is to create the platform is challenging and time consuming.
- Demonstrating the integration of LCSA may allow for its eventual inclusion within space mission design.

SSSD Motives & Expected Outcomes

- To become part of SMART for use within future CDF studies at the University of Strathclyde.
- To advance and compliment environmental sustainability in the space sector.
- To facilitate technological development/move with the times whilst complying with current and future legislation.
- To contribute to the global environmental sustainability agenda.
- Because it is morally the right thing to do.

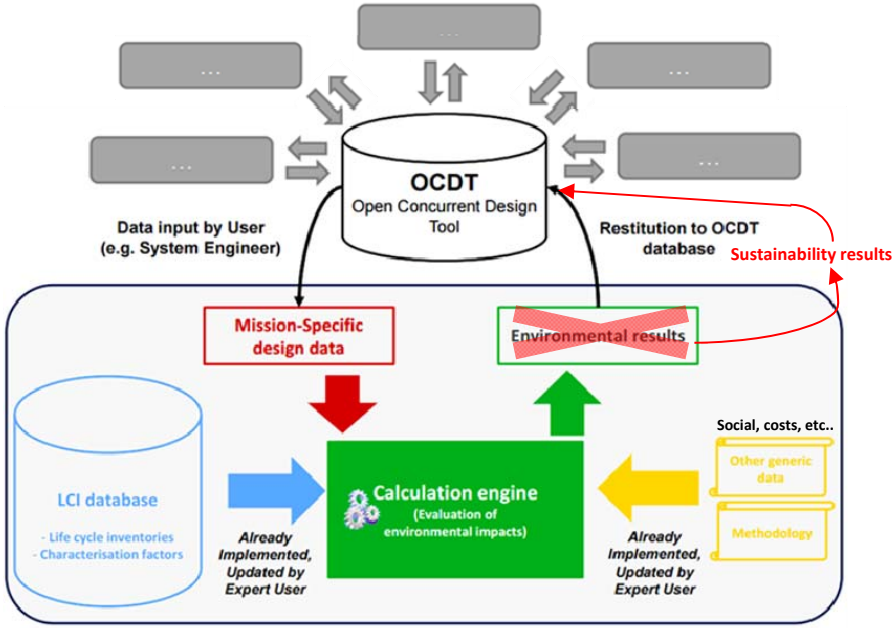
Future Work & Conclusion

Future Work

- Continue building up SLCA & LCC and include these flows in the underlying assumptions (which can be changed by user).
- Integration of LCSA into the concurrent design process.
- First results are expected to be generated by early 2018.
- Inclusion of uncertainty analysis will be pursued in the near future.

Conclusion

- We have presented an open-source LCA platform currently under development at the University of Strathclyde.
- Shown how it can be used to calculate the life cycle sustainability impacts of space systems.
- Planned public release by mid-to-late 2019 where it is hoped to contribute to the global sustainability agenda by assisting in creating a more sustainable world through the mitigation of adverse sustainability impacts of space programmes and activities during the design process.



Connecting LCSA with the OCDT (adapted)
(Source: Chanoine et al, 2014)

Any Questions?

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