# Developing a standardised methodology for space-specific Life Cycle Assessment

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## 1 ABSTRACT

Environmental protection has become an extremely prominent subject resulting in rapid development of environmental legislation. European industries, particularly those in consumer goods, are being called by the European Commission through the Joint Research Centre to evaluate their environmental impacts. This is done through the use of life cycle thinking, and more specifically Life Cycle Assessment (LCA), an internationally standardized tool (ISO 14040 and 14044 [1]) widely accepted as the best way to assess one's environmental footprint. The use of Life Cycle Thinking (analysing a product from cradle to grave) avoids burden shifting; transferring impacts from one part of the life cycle to another, from one region to another, from one generation to the next etc. The European Commission, through the Joint Research Centre, is implementing standardised LCA methodologies called 'Product Environmental Footprints' with specific 'Category Rules' (http://ec.europa.eu/environment/eussd/smgp/product_footprint.htm) for several industries but as of yet the space sector has been exempt. Performing LCA in the space sector is unique, due to many specificities of the industry and therefore the ISO standards do not suffice as a rigorous methodology to follow. At ESA, these difficulties have been tackled and LCAs have been carried out on the European launcher family (Vega, Ariane 5 ECA/ES) as well as four complete space missions (Earth-observation, telecommunications, meteorological and science). Studies are also currently underway on LCAs of materials and processes and space propellants specific to the space sector. Furthermore, industry has begun work in the area, with Airbus DS, CNES and Arianespace all performing environmental impact studies. In order to aid communication in the area, and to be able to exchange and understand results, it is important to establish a standardised LCA methodology for the space sector, from an early stage. The European Space Agency is performing this role, developing a handbook titled 'Space System Life Cycle Assessment (LCA) Guidelines'. This internal handbook will provide the methodological framework for users to perform LCAs in the space sector, at either system or component/equipment level, as well as guidelines on how to communicate on the results. Such a methodology will harmonise and encourage future LCA studies from both ESA and industry, and provide a necessary step towards the longer term goal of eco-design, where a product is designed in such a way as to reduce the environmental impacts.

# 2 LIFE CYCLE ASSESSMENT OF SPACE MISSIONS

## 2.1 Brief presentation of Life Cycle Assessment (LCA)

LCA is a powerful method, standardised at international level by ISO [1], to evaluate the environmental performance of products (i.e. either goods or services) in a comprehensive and objective manner: an LCA aims at assessing the quantifiable environmental impacts of a product throughout its whole life-cycle, from the extraction of the materials required to the treatment of these materials at the end-of-life stage, i.e. from cradle to grave. In 2003, the European Integrated Product Policy [2] identified LCA as the "best framework for assessing the potential environmental impacts of products". Since then, LCA has been increasingly used both in policy development and business. The methodology consists in carrying out exhaustive assessments of natural resources consumption, energy consumption and emissions into the environment (waste, emissions to air, water and ground), for each process involved in the life-cycle of a product or service [3]. They are then categorised per life-cycle phase and aggregated to give the full set of environmental impacts.

LCA is a multicriteria approach as it looks at all quantifiable environmental issues related to either resource consumption (e.g. energy consumption, mineral resource depletion, water consumption), air pollution (e.g. climate change, acidification, ozone depletion), or soil or water pollution (e.g. eutrophication, toxicity towards the ecosystems). LCA and LCT help to avoid resolving one environmental problem while creating another, avoiding the so-called burden shifting i.e. transferring impacts from one part of the life cycle to another, from one region to another, from one generation to the next or between different types of environmental impacts (e.g. reducing Climate Change Potential while increasing Human Toxicity Potential). LCA is a powerful tool that can be used to map the supply chain, support the identification of areas of main environmental impact or concern(hot-spots) and compare different design options from the environmental standpoint. Consequently, LCA can be used in the context of a "design for the environment" approach, or as a support tool for decision making. Figure 1 illustrates the main principles and concepts of LCA.

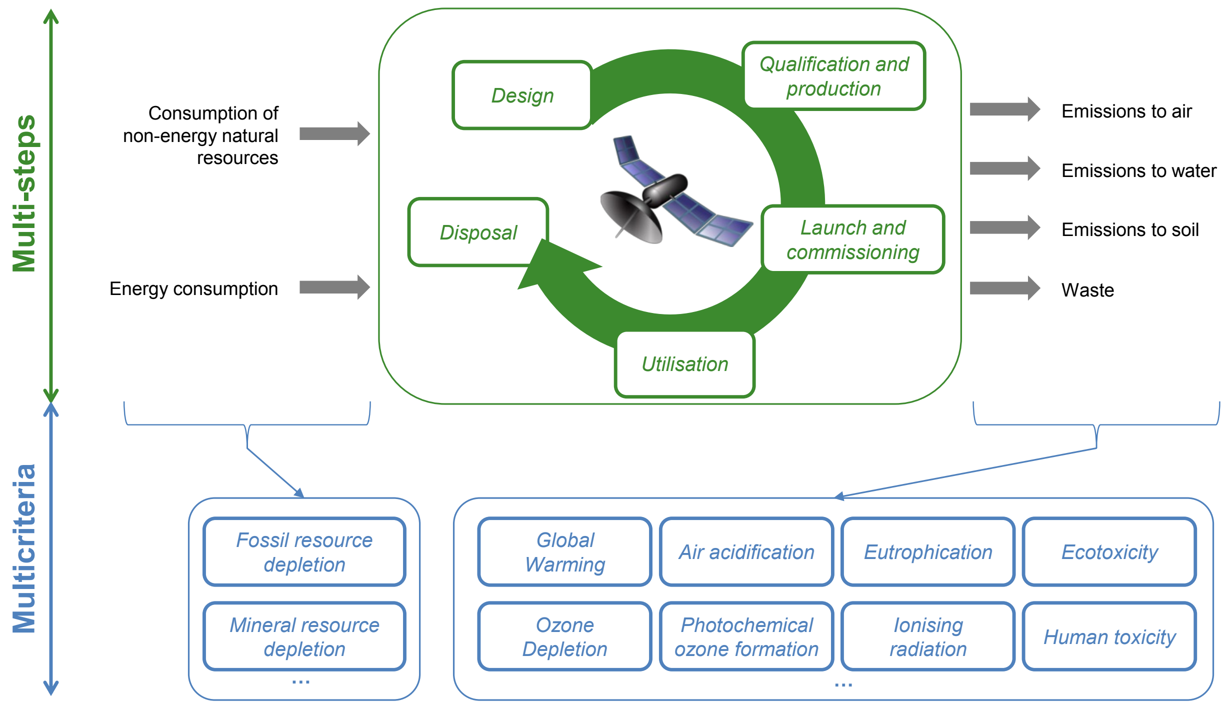


**Figure 1: Illustration of the multi-step and multicriteria attributes of LCA**

In order to perform quantitative analysis of environmental impacts, specific tools have been developed and are widely used in various industrial sectors (e.g. aeronautic, automotive, defence, etc.). The concept of Life Cycle Thinking (LCT) and the related quantitative tool Life Cycle Assessment (LCA) are used in the development, implementation, and monitoring of environmental policies globally.

## 2.2 LCA use at ESA

Work begun looking at the environmental impacts of space missions in 2009, with a pilot Concurrent Design Facility Study called Ecosat, looking at applying eco-design to space systems through the use of LCA techniques and both Cradle-to-Cradle and Cradle-to-Grave methodologies. Following a call from the directorate of Launchers to understand better the environmental impacts of launch vehicles, in 2011 a study was carried out by Bio-IS, where a full LCA of Vega and Ariane 5 ES/ECA was performed over their entire life cycle. Data was collected extensively: primary data via industrial workshops with the major companies in supply-chain of A5 & Vega, a preliminary questionnaire was sent to all companies before detailed and customized questionnaires to collect quantitative data. NDAs were also signed between ESA, Bio-IS and the companies. This process was complemented by secondary data collection, through ESA documentation of Ariane 5 and Vega and an extensive literature review.

This launcher study in turn led to the question of satellites, and in 2012 three independent contracts were placed, analysing the impacts of four entire space missions (Earth-observation, telecommunications, meteorological and science). Using the results from the launchers study, it was possible to have an insight into the comparative impacts of the launch, space and ground segment, although the ground segment models need refinement as they remain highly simplified.

Internally, an LCA study was performed on the former Ariane 6 PPH configuration (solid first and second stage, liquid upper stage). This was achieved despite the early stage of the project, based on a scaling from the existing results and data for Ariane 5 and Vega. Since then, the Ariane 6 configuration has changed to PHH (solid boosters, liquid central and upper stages) and a similar activity will likely be undertaken for the latest, and now fixed, configuration.

A small contract was carried out to investigate the communication of LCA results in the space sector. It advised ESA on the necessary considerations when deciding on whether to communicate results and the appropriate ways to communicate in the event of a communication.

Furthermore, ESA continues its efforts with follow-on studies, based on these system level LCA studies, addressing the environmental impacts of space specific materials & processes and propellants and is furthermore working on developing a methodological guideline for the application of LCA to the space sector.

### 2.3 Difficulties Encountered

Given the complex supply chain in the European space sector, collecting primary LCA data is a difficult task. For the launchers LCA study, primary data was collected from companies via the following approach:

1. Industrial workshop held with all companies in supply-chain of A5 & Vega
2. NDAs signed between ESA, Bio-IS and companies
3. A preliminary questionnaire was sent to all industrials
4. Detailed and customized questionnaires to collect quantitative data

When primary data was unavailable, secondary data was acquired via ESA documentation and literature review. For the space missions LCA, data was collected from the satellite primes in addition to through interviews with ESA experts.

One problem that was encountered was a discrepancy between primary and secondary data. Regularly, it was observed that for an equivalent process, primary data brought much higher environmental impacts than secondary data. This could be due to a number of reasons, such as the fact that secondary data often uses inventory datasets which are formed by averaging industrial activity where economies of scale are present (not the case in space). Furthermore, often the granularity on obtained primary data is lower, for example, the annual electricity consumption of a factory may be acquired but allocating the correct percentage to a specific process or part produced can be complicated.

The LCA study underway on "Space specific materials & processes and propellants" aims to fill data gaps where inventory data is unrepresentative of the space sector. Furthermore, the discrepancy in primary and secondary data will be investigated in further detail, through a future study to see whether a systematic approach can be applied to compensate for the 'underestimate' of secondary data when applying to the space sector.

Lastly, through the experience gained within ESA, it was clear that LCA results are very sensitive to the methodology followed, and thus for a new and growing topic such as LCA in space, it is important to ensure that a standardised and well defined methodology is implemented.

## 2.4 Justification of the need

The European Union is placing significant importance on environmental protection, having set in place the European Platform of Life Cycle Assessment in order to address the "need for more consistent data and consensus LCA methodologies" (referenced in section 6.2). European industries, particularly those in consumer goods, are being called by the European Commission through the JRC (Joint Research Centre) to evaluate their impacts using standardized LCA methodologies called "Product Category Rules" (referenced in section 6.2). As of yet though, the space sector has been exempt, being considered as a 'niche'. This will not remain the case however, ESA is therefore preparing for the future by developing a handbook containing guidelines on how to carry out LCA in the space sector.

Within the frame of previous Clean Space activities, databases have been created to establish background data-sets of the collected information for future use in combination with available data-sets on terrestrial products. The models, which were created in the activities, have been translated into inventory data-sets to populate these databases. The experience gained in the past activities has been formulated into methodological frameworks for the conduct of life cycle assessments on launcher and space missions, respectively, which serve as input to the handbook 'Space system Life Cycle Assessment (LCA) guidelines'.

Outside ESA, Airbus DS has founded its Design for Environment (DFE) office and CNES has also performed an LCA on the Ariane 5 launch vehicle. Several space and non-space sector industrials have participated in the aforementioned ESA studies, and for the on-going activities on materials and processes and space propellants, the 'Eco-design Alliance for Advanced Technologies' has been founded to extend the industrial base of contributors. In addition, Arianespace has communicated a growing sensitivity of its customers to the launch service impacts.

With the development of the European legislation amongst many industries, one must also prepare for users of satellites to call for quantification of their environmental impacts. This context means the situation is set to change and therefore, experience from other sectors shows that it is important to define rules and guidelines from the beginning that allow the whole sector to carry out LCAs and communicate in a consistent way. This shall promote the constructive exchange across the sector on this subject and the correct dissemination of the methodology and of the results. ESA, aims to keep industry informed throughout the development of the handbook. The risk of inaction, resulting in an uncoordinated approach would create the potential for 'green washing', where false claims can be made on the environmental benefits of a product for marketing purposes.

The fast evolving environmental legislation, together with public pressure, is turning environmental impact more and more into a criterion for design and product selection. In order to prepare for the future and have effective communication tools, the capacity of an organisation to comprehensively quantify the environmental impact of its activities and products is of major importance and of strategic interest.

The space sector is a unique domain: it has rather low production rates, impacts on environments so far not considered in the traditional LCA (e.g. direct emissions into the high atmosphere), uses specialised materials and industrial processes, and has long development cycles. For all this the application of LCA to space projects requires the development of dedicated databases and methodological rules. LCA for the space sector is a new area of development, and therefore it is vital to establish guidelines for good practice as early as possible.

The development of the ESA handbook 'Space system Life Cycle Assessment (LCA) guidelines' will benefit the space industry, allowing them to reduce their environmental impacts, see potential breaks in the production chain and potential cost savings. Furthermore, Clean Space activities can provide a push for technology development, which will stimulate European industry, could justify start-ups of companies and put Europe at a competitive advantage on the topic of green technologies.

## 3 ESA HANDBOOK: SPACE SYSTEM LCA GUIDELEINES

### 3.1 Objective

The goal of the ESA handbook is to provide a common LCA methodology to be followed when performing Life Cycle Assessment within the space sector. It will be an effective tool to enable the analysis of the space industry from an environmental footprint point of view. As an understanding of the origin of one's environmental impacts is a fundamental step to reducing them, this handbook will in turn provide the basis for performing eco-design. The handbook also gives guidelines on how to communicate on LCA results.

### 3.2 Scope

This handbook aims to establish the methodological rules on how to correctly perform space-specific LCAs at the following levels:

- Level 1: Space system
    - Entire space mission
    - Launcher, satellite or ground segment
- Level 2:
    - Equipment/component/technology

For Level 1, the methodology has been adapted from that which was defined during the course of prior ESA studies. For Level 2, generic guidelines are provided. For certain pieces of equipment/components where models were developed in the frame of previous ESA studies, specific LCA models which have been verified by ESA experts can be found in the Annexes.

The set of methodological rules given in the handbook provides the framework for performing comprehensive quantitative assessments and consistent environmental declarations for complete space systems and subsystems as well as individual hardware equipment, components and technologies.
LCA methodology has been developed to quantify environmental impacts on the earth eco-sphere. Therefore, the analysis of the impacts from space debris is excluded from the scope of the handbook. Specific requirements for Space Debris Mitigation are applicable to all ESA projects.

The methodology described in the handbook does not deal with the obsolescence management due to environmental regulations such as REACh, this is addressed by the European space industry in the frame of a dedicated working group. Nevertheless, the proposed LCA guidelines can be used to identify the potential use of hazardous substances in the product supply chain in order to inform the user of possible risks or future concerns at any phase of the product development.

Finally this handbook defines guidelines for the communication of the results of environmental impact assessments in a consistent way across the different levels.

### 3.3 Content

The handbook "Space system Life Cycle Assessment (LCA) guidelines" aims to provide a methodological framework for any LCA practitioner wanting to perform an LCA within the space sector. It contains guidelines for LCAs performed at the two 'levels' defined in Section 3.2. The methodology is consistent with ISO standard 14044 [1], and should be seen as an extension of the methodology with space-specific guidelines rather than an alternative to it. For both level 1 (space mission, launch, space or ground segment) and level 2 LCAs (equipment/component/technology), guidelines are given on the following LCA elements:

- Goal and Scope
- System Boundaries
- Functional Unit
- Cut-off criteria
- Rare Materials
- Assembly, Integration and Testing

For level 2 LCAs, ESA made use of internal expertise by setting up a working group. In the working group, experts were used to cover the following areas:

- Propulsion
- Manufacturing Processes and Materials
- Obsolescence and M&P
- Electronic Components
- Mechanical and Structures
- Electrical Subsystems/Harness/Power
- Solar Array
- Avionics
- Thermal
- Mechanisms
- Testing and AIV
- RF Payload (Telecomms Payload)
- Optical Payload
- Batteries
- Communications

Existing models, created primarily through the previous space missions contracts were then analysed by the experts, who through the scope of the activity, were given training in LCA. Their feedback allowed the quality of the models to be evaluated. For those models considered of good quality, the models will be included in the handbook as Annexes to be used as 'off the shelf' models for use in future LCAs. In addition to these models, the experts provided insight on their area of expertise on the following areas.

- Mass breakdown and materials used

- Loss rates
- Assembly
- Testing and Inspection

Where the models were not considered of a sufficient standard for inclusion in the handbook, guidelines were provided based on the feedback given on the above points, in order to aid an LCA practitioner building an LCA model.

Guidelines were also provided on how to communicate on LCA results. Miscommunication or communication in a misleading way can result in 'Green Washing'. This is when the 'green' label is used for marketing purposes without substantial evidence. It is often quickly noticed by green activist groups and can damage an organisation's reputation. The chapter aims to reduce this possibility and increase the clarity of results.

Discussion is also presented on the pros and cons of using mid-point or end-point indicators and suggestions on when one or the other (or a mixture) might be most appropriate. For mid-point indicators, a short list of the most relevant indicators for space was chosen, although this list is still under discussion. This will allow a greater focus and interpretability when presenting LCA results.

## 4 FUTURE VISION

ESA foresees that LCA will become more widespread both inside the agency and in industry. Already, new technology developments inside ESA are calling for contractors to perform an LCA of the technology in order to have a holistic view of the environmental impacts. With this understanding, eco-design can be performed in order to create green technologies. A common adoption across Europe of eco-design will allow the space sector to significantly reduce its environmental impacts, which may have other benefits as well such as cost reductions due to savings in material/energy usage. It could also position Europe with a competitive advantage as the world leader in green technologies.

As performing LCA is a pre-requisite to performing eco-design, the ESA handbook is an important step in harmonising the European approach to LCA and facilitating eco-design. Whilst initially the handbook will remain ESA-internal, in the future there is potential for coordination with industry/other actors in order to create a Product Environmental Footprint (PEF) or an ECSS standard.

Lastly, in order to increase awareness and understanding of eco-design in ESA projects, a tool is being developed which will integrate environmental performance as a design criterion within concurrent design facility studies.

## 5 CONCLUSIONS

The ESA handbook will provide guidelines for performing space LCAs. It will provide a methodology which incorporates the specificities of the space sector for LCA studies performed at system and equipment level. It will also provide guidelines on the communication of LCA results. The project, carried with the advice of ESA experts in a dedicated working group, will produce an ESA internal handbook to be used when LCA is performed within the agency. In the future, the handbook could form the basis of a wider guideline or standard, in order to continue ESA's goal of increasing the prevalence of LCA and eco-design, in order to create green technologies and reduce the environmental impacts of the European space sector.

## 6 REFERENCES

[1] ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines

[2] Communication from the Commission to the Council and the European Parliament - Integrated Product Policy - Building on Environmental Life-Cycle Thinking - COM/2003/0302 final

[3] Y Le Guern, A. Chanoine, F. Witte, J. Huesing, T. Soares – "Integrating environmental assessment in the Concurrent Design of Space Missions", 2014