CHALLENGES IN EUROPEAN AEROSPACE
5TH CEAS AIR & SPACE CONFERENCE

Introducing eco-design to ESA – An overview of the activities towards a coherent eco-design approach

Jakob Huesing
RHEA for ESA
Systems and Concurrent Engineer
ESTEC, Keplerlaan 1, NL-2200 AG Noordwijk, NL
Jakob.Huesing@esa.int
Julian Austin (European Space Agency), Tiago Soares (European Space Agency)

ABSTRACT

World leaders from nearly 200 countries participated in the latest UN climate change conference in Lima to discuss the future of the world's climate, human contribution, and possibilities to minimise the effect of human activities on the environment. With the two main contributors to climate change, China and the USA, announcing a bilateral 'climate deal', the responsibility to address challenges such as carbon emissions and resource depletion follow for everyone everywhere. As one of the consequences, an increasing amount of new and upcoming legislative measures address these demands. In the space sector, environmental issues have only recently started to come under closer consideration. Yet through the risks of supply chain disruptions and the increasing environmental awareness of costumers, client operators, employees, and stakeholders, the sector will face new challenges. Aware of its unique position towards the European space sector and industry, ESA is proactively promoting awareness and striving to achieve a deep understanding of environmental impacts. For this reason, in 2011 ESA introduced Clean Space. Branches 1 and 2 of this initiative aim to streamline its activities in the area of environmental impact assessment, eco-design and development of newer and greener technologies. As a by-product, these activities will create a competitive advantage for the European space industry. ESA takes a system level approach to develop a framework to support projects in monitoring their supply chain for compliance with existing and future regulation, evaluating environmental impacts, and identifying possible sustainable alternatives while minimising the overall system level impact to the project. This paper aims to give an overview of the different activities within branches 1 & 2 of Clean Space, how they are organised to build upon and supplement the results and outcomes of the preceding or parallel activities and how these activities feed into a coherent eco-design approach at ESA. Initial studies addressing the environmental impact of the European launcher family established the applicability of Life Cycle Assessment (LCA) to the space sector. Subsequent studies broadened ESA's knowledge about specific methodologies to assess the impact of space activities and helped to define a methodological framework for its application in space. A database with data sets for space specific materials and manufacturing processes and space propellants is being developed in addition to a database that aims to track the use of hazardous materials (e.g. as defined by REACh) throughout the life-cycle of a space product to proactively mitigate supply chain disruption risks. These efforts then culminate in the creation of an ESA handbook on the methodological framework for the use of LCA in space. Based on the assessment of the environmental impact of space activities, the following step aims to introduce eco-design principles into the design of future space missions. A first step in doing so will be the introduction of a preliminary LCA tool into ESA's Concurrent Design Facility (CDF) to enable the environmental impact as an additional design parameter. Furthermore, ESA aims to carry out pilot studies to assess the application of eco-design to space products and will introduce an internal eco-design course to promote the awareness of the environmental impacts of our activities during the design process of space missions. Finally, the eco-design activities are framed by studies on the effective communication of environmental impacts to support European space industry and its stake holders to turn a potential threat into opportunity.

1 INTRODUCTION

Space flight has revolutionised our views and understanding of the Earth, its environment, our atmosphere, and their interrelations as Earth orbiting scientific missions enabled an unprecedented insight to our planet, its eco-sphere, its climatic interrelations and the impact of human actions to it. But also by providing strong and captivating visuals, such as the iconic Earthrise or the Pale Blue Dot, which helped carrying the awareness of the necessity of preserving this fragile environment into mainstream public opinion. Many initiatives and efforts have come forth from this and world leaders from nearly 200 countries participated in last year's UN climate change conference in Lima to address challenges such as carbon emissions and resource depletion. With the two main contributors to climate change, China and the USA, announcing a bilateral 'climate deal', it becomes apparent that environment-friendly policies and regulations and sustainable development will in some way or another influence all of us in the future. In fact, environmental laws and regulations are among the fastest evolving areas of law, particularly within the EU, with the directives and regulations RoHS[1] and REACh[2] as prominent examples also impacting on European space activities. In Europe there is already a number of applicable environmental legislation, which cover various phases of a space mission such as: launch of the satellite, launcher and satellite production, production and disposal of ground segment, components design and testing, office work etc.
But despite the strong link between the environmental movement and space and the fast developing legislation, environmental issues of the space sector itself have only recently started to come under closer consideration. ESA has started to develop new processes and technologies to shape and comply with future regulations in these areas, while, at the same time, minimising possible disruption of qualified materials and processes in the European supply chains. By being a pioneer in adopting eco-design and green technologies, ESA supports European industry to ensure a competitive advantage. In that respect, resource efficient technologies also contribute to reduce costs by decreasing material inputs, energy consumption and waste.
After briefly introducing Clean Space, this paper will give an overview of the different eco-design activities within ESA, how they are organised to build upon and supplement the results and outcomes of the preceding or parallel activities and how ESA, with the selection and organisation of activities, moves from the assessment of environmental impacts to the application of eco-design principles.

2 CLEAN SPACE

In 2011, ESA's Agenda 2015 action plan recognised the need to guarantee the future of space activities by protecting the environment, which is affected by our activities both on Earth and in space. Thus in 2012 the cross-cutting Clean Space initiative was founded, organised along three distinct braches, addressing eco-design, space debris mitigation and space debris remediation as shown in Figure 1. The eco-design branch distinctly addresses the environmental impacts of space activities on Earth and looks into methods of assessing and reducing them, while the other two branches look into ways space debris and active space debris removal. Clean Space takes a system level approach to establish technology development roadmaps for each branch and builds on ESA's technology programmes such as TRP and GSTP for their implementation.

[1] EU Directive (2002/95/EC) pertaining to the **R**estriction **o**f **H**azardous **S**ubstances in Electrical and Electronic Equipment (EEE). It was adopted by the EU in February 2003 and brought into force 1st of July 2006.
[2] EC Regulation (EC 1907/2006), **R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emical substances. The law entered into force on 1 June 2007.

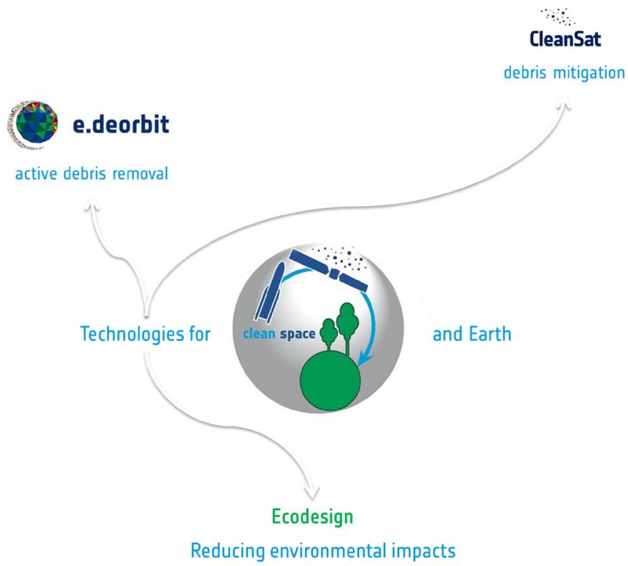

Figure 1: Clean Space's three branches

ESA, with its Clean Space initiative, will devote increasing attention to the environmental impact of its activities in the frame of ESA programmes, through the implementation of specific technology roadmaps. Since its creation in 2012, Clean Space has accumulated more than 100 activities under its umbrella, streamlining activities to give a pro-active answer to the environmental challenges both on ground and in space, including its own operations as well as operations performed by European space industry in the frame of ESA programmes.

3 ECO-DESIGN BRANCH

The objective of the eco-design branch is to implement the use of eco-design in space projects to mitigate supply-chain disruption risks, increase the efficient use of resources and reduce environmental impacts by promoting life-cycle awareness.
Existing environmental legislation is already impacting on the European space sector, such as REACh, which registers and restricts the use of certain chemicals or RoHS, which regulates the use of certain substances for electronics or EU targets on greenhouse gas emission reductions. And with environmental legislation being among the fastest evolving areas of law, future legislation is certain to impact the space industry as well. Therefore, ESA is taking a "pro-active approach towards this area of legislation", to "bring a competitive advantage to European industry by a) preventing supply chain disruptions and b) anticipating, assessing and mitigating effects of legislative measures." [1]
Legislation as REACh and RoHS often targets specific substances that are used in up-stream processes such as, e.g. cleaning or surface treatment processes, and might not even appear in the final product itself. Due to this, even the prime contractors often have not a complete visibility of all substances used within their suppliers and cannot entirely anticipate the impact of new legislation to their overall supply chain. It is therefore one of the objectives of the Clean Space eco-design branch to develop tools and

methodologies to provide a visibility into the supply chains and to develop and promote alternatives to potentially targeted substances and processes in the future.

Another aim of Clean Space's eco-design branch is to assess the impacts of space activities on our terrestrial environment[3]. Despite the increased public awareness towards global environmental challenges and the strong link that the space sector (as provider of captivating visuals and enabler of multiple Earth observation missions) and environmental research share, there is currently no systematic methodology existing to assess the environmental performance of space activities. In general, assessments of environmental impacts have scarcely been performed in the space sector, at all. However, priorities are starting to shift and the demand is growing. Customer requests to Arianespace about the environmental impact of Ariane 5 launches show an increasing attention to the environmental impact of the launch service. And several distributed, non-coordinated initiatives on environmental impact assessment can be observed. Arianespace performed a bilan carbone and CNES carried out a Life Cycle Assessment (LCA) on the Ariane 5 launcher. Finally, Airbus has established a dedicated eco-design office, the so-called Design for Environment (DFE) department.

As a third pillar, next to supply chain monitoring and environmental impact assessment, Clean Space's eco-design branch aims at the reduction of these impacts and a more efficient use of resources. This objective is complementary to the first two, as an analysis of the complete life-cycle of a product, which includes its whole supply chain, also provides visibility into the use of resources. And an assessment of the overall impacts related to the resource consumption opens the potential to increase the efficient use of these resources, such as raw materials, heat, energy or water, by identifying hot-spots of use and benchmarking the consumption against alternatives.

4 LCA, THE TOOL OF CHOICE

With the objectives defined, the question of implementation and subsequently the definition of an appropriate set of tools arose. Tools and methodologies that provide visibility of a product's supply chain; allow assessing its environmental impacts; and that establish practical advice for future impact reduction and more efficient resource use in a technical, science-based, objective and quantifiable way.
ESA made its first experiences with environmental impact assessment in 2009 with a preliminary study called ECOSAT, carried out in the ESA's Concurrent Design Facility (CDF). This first attempt of applying impact assessment methodologies on space systems established LCA as the tool of choice.

Life Cycle Analysis (LCA) is a ISO standardised [2] model based tool, widely used in other industrial sectors. It provides a science based overview of the environmental aspects throughout the product's life cycle, from the extraction of the materials required, to the treatment of these materials at the end-of-life (from cradle to grave). Thus LCA was identified as suitable tool complying with the defined requirements: It is an approach looking at the complete life cycle, also considering supply chains and resources extraction; it allows to study effects of possible environmental legislation by observing the complete life cycle and monitoring its environmental impacts as a whole, without simply shifting burdens from one stage of the product to another; and by aggregating different effects into environmental impact indicators, it allows to assess and compare different legislative measures.

[3] As opposed to our orbital environment, the problem of space debris, which is being addressed by the other Clean Space branches.

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 space mission.
All incoming and outgoing flows (materials and energy, both extracted from the environment and released into it) are inventoried for each life-cycle phase. Then, they are aggregated to quantify a set of environmental impact indicators.
LCA is a multicriteria approach: no single environmental score is given on its own, but results are presented through several environmental impact indicators. The LCA methodology allows to compare multiple scenarios (such as different design options) and to identify pollution transfers from one type of impact to the natural environment to another, or from one life cycle step to another, between two different scenarios of the same system, or between two different systems. Thus, LCA can also be used in the context of an eco-design approach or for support to decision-making. The multi-step and multicriteria attributes of LCA are illustrated in Figure 2 [3].
While LCA is used in many industrial sectors and identified by the European Integrated Product Policy as the "best framework for assessing the potential environmental impacts of products," [4], the applicability of the LCA methodology to the space sector had not been assessed. It has mainly been used to model products in mass production. The translation to the space sector required a response to some inherent questions [5]:

- For mass produced items, the impacts of R&D and infrastructure are usually insignificant, while they make up a large part of a space missions life cycle.
- Impacts are related to a functional unit (e.g. per litre produced or per passenger kilometer) to quantify the impacts in a comparable way, identification of an independent comparable functional unit for space missions is difficult.
- In an usual LCA, about 80% of the data and the processes exist in databases, while in the space industry innovative and dedicated processes and materials are used, thus requiring an extraordinary effort in data collection and modelling
- The life cycle of a space mission is distributed around the whole world with parts being transported at all different stages, thus requiring elaborate transport models to account for these impacts.
- Emissions occur at unique locations specific to the space sector and not covered by the current models (launcher emissions during its ascent).

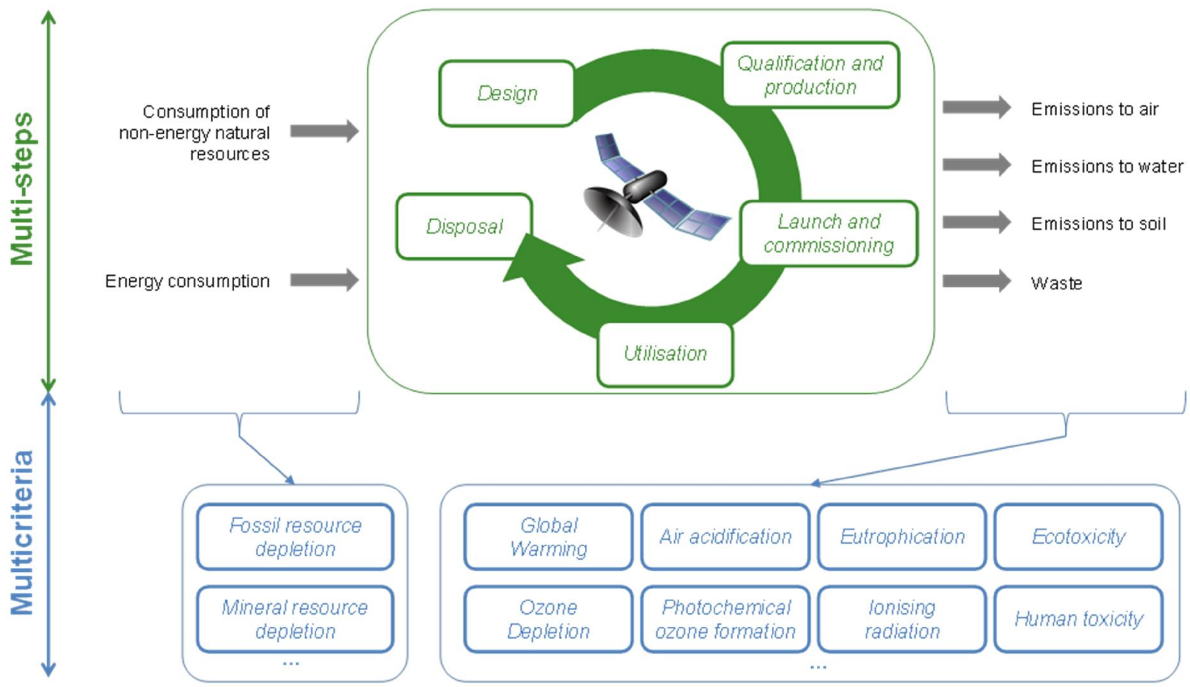

Figure 2: Multi-step and multicriteria attributes of life-cycle assessment [3]

In a pro-active initiative ESA, with strong industrial support, answered these questions, established the applicability of LCA to space systems, and responded to the growing interest in the topic, when it used LCA in a pilot study to assess the environmental impact of the European launcher family. The study, which system boundaries are illustrated in Figure 3, confirmed a high potential of a coherent LCA framework for a number of applications, also for sectors with relatively small production volumes [6]:

- Have a better understanding and monitoring of the supply chain and support pro-active and coordinated measures to avoid potential disruptions due to environmental legislation;
- Identify processes that represent environmental hot-spots in the products life-cycle and provide a consistent and effective basis for environmental impact mitigation;
- Perform technology trade-offs, as a support to eco-design approaches and avoid burden shifting from one environmental impact to another or from one life-cycle stage to another;
- Provide a consistent and science based tool to support communication on environmental issues.

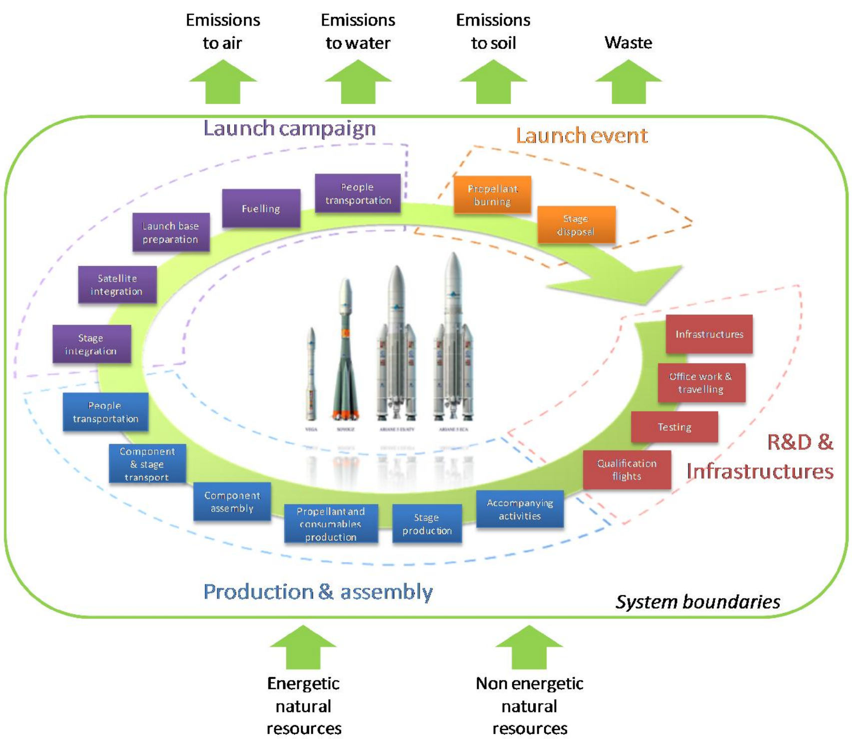

Figure 3: European Launchers life-cycle system boundaries representation

But it also concluded a number of milestones on the way to apply this framework in a systematic way by the space industry [6]:

1. Databases must be enhanced to cope with the specificities of space systems manufacturing processes;
2. Methodological frameworks shall be set up establishing the modelling rules to be applied;
3. Specific impacts related only to the space activities must be understood and modelled (e.g. space projects are the only anthropogenic activity crossing all the layers of the Earth's atmosphere).

5 LCA ACTIVITIES

In several subsequent activities, ESA set out to systematically address these milestones.
Specific impacts only related to space activities and not yet covered by the methodology are addressed in multiple ways: In two studies, the effect of launcher plumes in higher layers of the atmosphere were modelled and translated into LCA impact categories, to take into account the effects of the most visible of impacts during the actual launch event in the launcher's unique working environment. [look for references] In-situ measurements for model validation are planned in the current roadmap. Furthermore assessments of the impacts to the marine environment from metallic pieces falling back into the ocean from used launcher stages are planned. The results will then feed back into the overall impact assessment of a launcher's lifecycle. Also studies are foreseen to assess the potential implementation of re-entering space debris into the models underlying the LCA methodology.
To enhance existing databases, further broaden its knowledge on the environmental impact of its activities and improve the existing models of space systems, three studies on the environmental impact

of space mission were carried out, assessing the environmental performance of four different space missions. These pilot LCA studies were performed on a representative selection of space projects, including scientific, earth observation, meteorological and telecommunication missions. The results provided detailed insight on the environmental profile of space missions: in particular, activities mainly contributing to the environmental impacts, sources of these impacts, areas where improvements can be made, etc. were identified. The simplified system boundaries of these studies are illustrated in Figure 4.

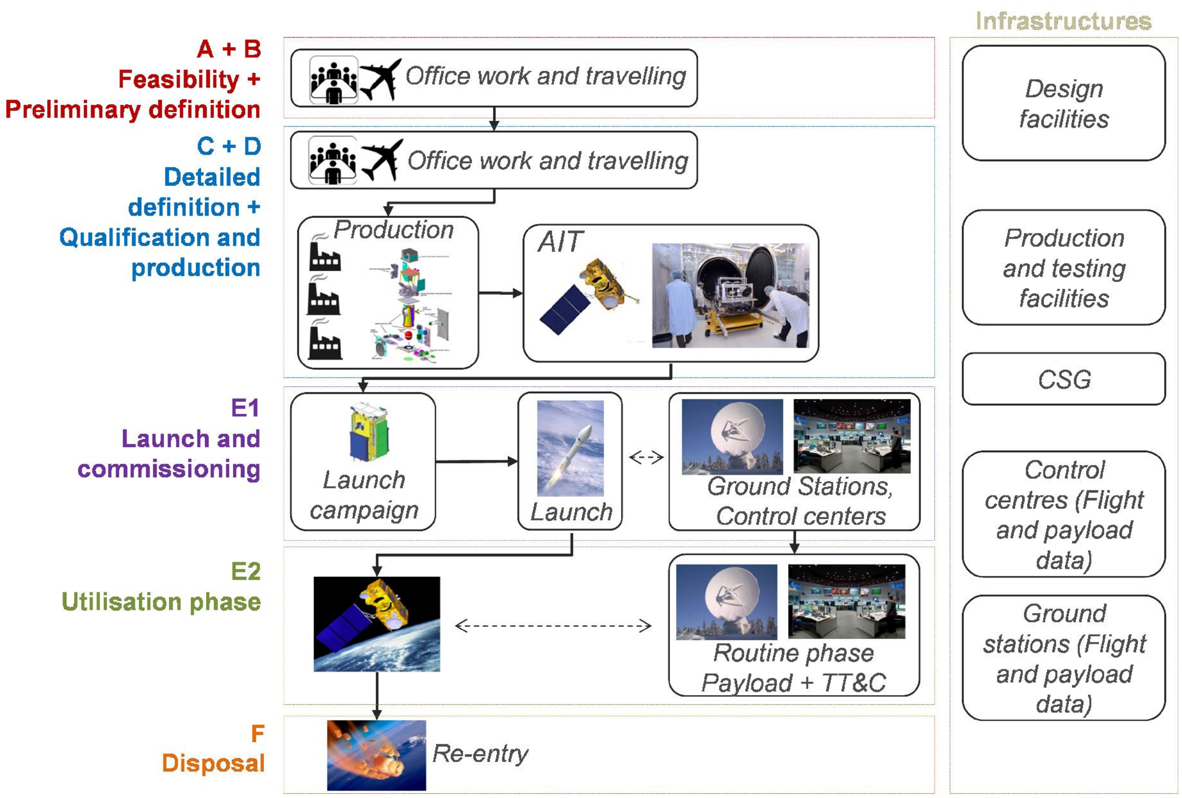

Figure 4: LCA of space missions system boundaries

Based on the results of the space mission studies, hot spots and areas of insufficient data quality were identified and fed into two new studies, addressing these areas: The on-going studies to assess the impacts of space specific materials & manufacturing processes and space propellants. The objectives are multifold: To assess hot-spots of the previous studies in more detail, to provide visibility of the overall supply chain and assess disruption risks, to assess the environmental performance of the products and processes in study, to allow comparison to suitable alternatives, to populate space specific LCA databases with high-confidence data and to address specificities of the space sector, not covered in commercially available LCA databases. Future studies will further broaden ESA's knowledge in these areas, focusing on more specific items, as e.g. specific launcher parts, equipment and components, or areas covered with less detail in the previous studies, e.g. the ground and user segments.

Based on the extensive work already performed and the knowledge and experience gained, ESA also thrives to set up methodological frameworks for environmental impact assessment modelling rules in the space sector. While, as a consequence of the fast evolvement of environmental legislation in multiple areas, the European Commission (EC) is running LCA harmonisation activities across several industries, such as the European Platform of Life Cycle Assessment and the establishment of Product and Organisation Environmental Footprint Category Rules, it has however indicated that it sets its first priorities on mass produced consumer goods. ESA still believes, in order to enable exchange on the topic, that guidelines need to be established from an early stage. This will reduce the risk of 'green washing', where companies make false claims on their product or service being 'green' or modify impact assessment methodologies to improve their results and it will promote the use of LCA, keep industry informed and encourage and enable the exchange between the stakeholders and actors. Due to the increasing interest in the topic and the work that has been started in the field, ESA decided to take the lead to avoid the use of different methodologies, currently being implemented by the space industry. In coordination with the EC's Joint Research Centre (JRC), that is welcoming ESA's initiative in the field of LCA for space applications, ESA initiated an internal working group, aiming to produce a handbook to provide methodological guidelines on how to perform LCA studies on space activities. These guidelines will address specificities of applying LCA to the space sector, apply existing ISO standards, collect existing experience, give modelling guidelines for future applications, as well as provide recommendations on the ways to communicate environmental results. It aims to be all encompassing, covering LCA at system, segment, subsystem and equipment level.

6 FROM ASSESSMENT TO APPLICATION

The next step is to evolve from an assessment based environment to actual eco-design applications, aimed at reducing the environmental impacts and increasing the efficiency in the use of available resources. Since the environmental performance of a space system (as any other product) is mainly driven by design choices, which are defined at an early stage of the design process, a first activity addresses the assessment and comparison of early stage design choices in the space mission design process. While environmental performance should be continuously assessed throughout the mission's design process in order to refine the LCA based on updated design data and to ensure validity and consistency of early eco-design choices, an eco-design approach should nevertheless start as early as possible in the design process, where design choices are still open. This is illustrated in Figure 5 [3].

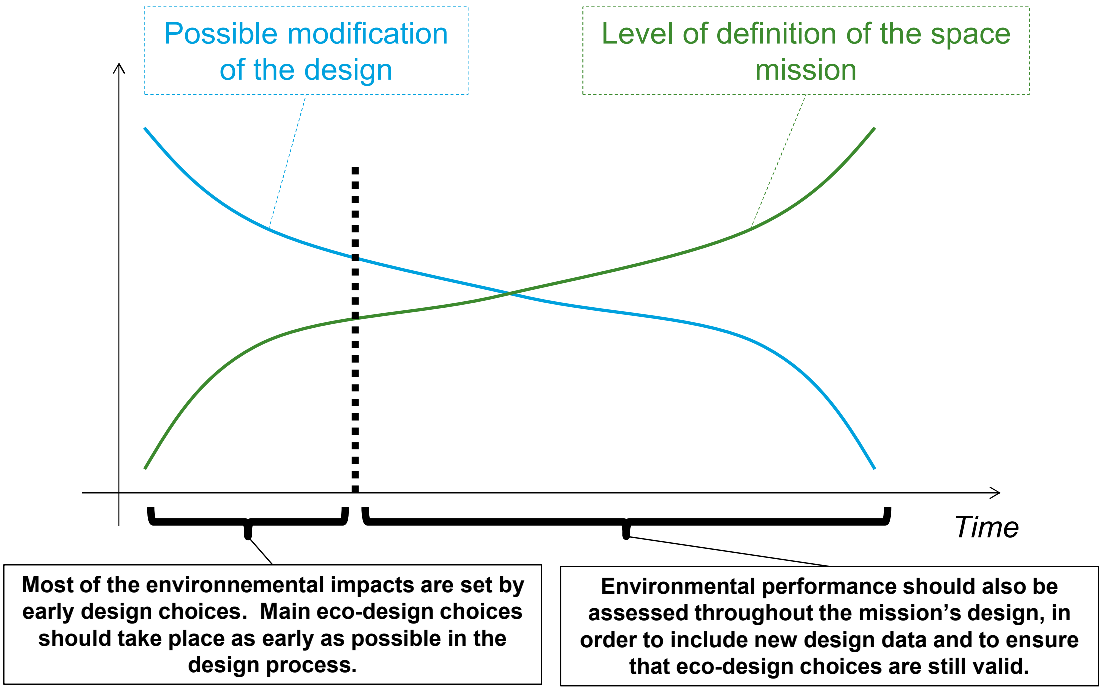

Figure 5: Eco-design impacts in space mission's design process [3]

Based on this knowledge, an environmental impact analysis tool is being developed to be used in ESA's Concurrent Design Facility in pre-phase A studies in a very early design stage. The tool will be implemented in ESA's Open Concurrent Design Tool (OCDT) design framework employed in the CDF. The results can then be used to assess and compare the environmental impact of preliminary design choices and give an additional decision parameter at hand for project study manager. It will be consecutively enhanced through user experience and feedback and further LCA database population.
Furthermore ESA is going to use eco-design methodologies in a well-defined industrial pilot case to broaden its knowledge and gain experience and it has implemented an internal LCA training, to raise awareness among its own staff and teach the basics of LCA for space.

7 CONCLUSIONS

ESA, together with the European space industry, is pioneering the field of environmental assessment for space. While ESA is committed to further evolve the work on the impact assessment framework and to evolve the assessment into eco-design application, the work cannot be successful without Europe's industry. That is why one of the most important developments will be to establish a network to further evolve, validate and publish existing space LCA data sets, and to collect primary data to create new additional data sets where necessary, involving all levels of the supply chain of the European space industry. This will support the on-going activities in industry and at ESA, to further establish eco-design in the entire European space sector.

8 REFERENCES

[1] T. Soares, J. Huesing, I. Carnelli, A. Galvez, L. Innocenti – "Clean Space from the beginning; a Description of Systems and Concurrent Engineering Aspects of ESA's Clean Space Initiative for Earth", SECESA 2012
[2] ISO 14044:2006, Environmental management – Life cycle assessment – Requirements and guidelines
[3] A. Chanoine, Y. Le Guern, F. Witte, J. Huesing, T. Soares – "Integrating environmental assessment in the Concurrent Design of Space Missions", SECESA 2014
[4] A. Chanoine, Y. Le Guern, F. Witte, J. Huesing, T. Soares, L. Innocenti – "Integrating sustainability in the design of space activities: development of eco-design tools for space projects", CEAS 2015
[5] J. Huesing, T. Soares, L. Innocenti – "Environmental Impact Assessment – The Application of the LCA Methodology for Space Missions at ESA", IAC 2013
[6] T. Soares, L. innocent, A. Cucci – "LCA for Environmental Impact Assessment of Space Systems – ESA's assessment of European Launchers", International Workshop on Environemnt and Alternative Energy, 2012