SPACE AND SUSTAINABILITY MODELS

Toulouse Business School, Professional Program Aerospace Management
Research Supervisor: Sophie d'Armagnac

<u>WHY APPLYING LIFE CYCLE THINKING AND GENERAL SUSTAINABILITY PRINCIPLES IS CRITICAL FOR THE SPACE INDUSTRY</u>

Sophie Quintana and Louis Serinet
February 5th, 2018

Why applying Life Cycle Thinking and general sustainability principles is critical for the space industry

Summary

Given the growing interest in the space industry, it is crucial to achieve sustainable development, combining the social, environmental, economic and all stakeholders. International entities of the sector, such as ESA through its guidelines for a Life Cycle Assessment adapted to space, initiated this dynamic. After a review of the research carried out on the Life Cycle Thinking, we sought to explain why and how to apply this tool to the space sector. It appears that adapted to an industrial context, the Life Cycle Management can only bring added value, in addition to benefiting all stakeholders. We even go so far as to identify this approach as indispensable for the space sector. Indeed, by the example of SpaceX reusable launchers, we show that isolated sustainable initiatives can be harmful. The application of Life Cycle Management in the space industry could be done easily, practical methods of sustainable development being intuitive. But managing change in the industry as a whole and in business is less obvious. For the approach to succeed, all stakeholders must participate, and the adoption of new sustainable business models can be considered and optimized through the growing number of startups in the sector.

Keywords: sustainable development, sustainability, Triple Bottom Line, stakeholders, Life Cycle Thinking and Management, competitive advantage, Eco-Growth, business models.

Face à l'intérêt croissant pour l’industrie spatiale, il est crucial de parvenir à un développement durable, combinant les dimensions sociale, environnementale, économique, et impliquant toutes les parties prenantes. Des entités internationales du secteur, telles que l’ESA à travers ses directives pour une Analyse du Cycle de Vie adaptée au spatial, ont initié cette dynamique. Après un bilan des recherches réalisées sur la Pensée Cycle de Vie, nous avons cherché à expliquer pourquoi et comment appliquer cet outil au secteur spatial. Il apparaît qu’adaptée à un contexte industriel, la Gestion du Cycle de Vie ne peut qu’apporter de la valeur ajoutée, en plus de bénéficier à toutes les parties prenantes. Nous allons même jusqu’à identifier cette démarche comme indispensable pour le secteur spatial. En effet, par l’exemple des lanceurs réutilisables de SpaceX, nous montrons que les initiatives durables isolées peuvent se révéler néfastes. L’application de la Gestion du Cycle de Vie dans l’industrie spatiale pourrait se faire de manière aisée, les méthodes pratiques du développement durable s’avérant intuitives. Mais la gestion du changement dans l'industrie dans son ensemble et dans les entreprises est moins évidente. Pour que la démarche réussisse, toutes les parties prenantes doivent participer, et l'adoption de nouveaux modèles économiques durables peut être envisagée et optimisée grâce au nombre croissant de startups du secteur.

Mots-clés : développement durable, durabilité, Triple Bilan, parties prenantes, Pensée et Gestion du Cycle de Vie, avantage concurrentiel, Éco-Croissance, modèles économiques.

CONTENTS

INTRODUCTION

Between March 20 and April 21, 2017, a major social movement paralyzed French Guiana. Nearly 15,000 people, out of the 250,000 in the territory, marched in the big cities and set up dams on the road axes. Their demands: to incite political leaders to act against the glaring inequalities and social problems observed in French Guiana, such as unemployment, insecurity, lack of structures. Above all, access to GSC (Guiana Space Centre) was also blocked by protesters because of its strategic nature. Located around the Kourou launching base, the space industry is indeed the largest contributor to the GDP of the overseas department, as well as its largest employer with nearly 9,000 direct and indirect jobs [INSEE]. However, the space industry is also the main recipient of investments in the French territory. For the leaders of the social movement, the GSC is the symbol of the gap between state efforts towards advanced technologies and high value-added employment, and the lack of infrastructure in the rest of the department. Paradoxically, space actors are quite involved in the territory development, for example with the “Mission Guyane”. The GSC invests more than 50 million euros each year in modernization works, of which 40 to 50% are injected in the Guyanese economy. But these amounts are too low to meet the needs of the booming population, that present a 35‰ births per year rate, against 2‰ in France [INSEE], and a massive immigration from neighbouring countries. Therefore the 2017 Guianese movement appears to be the consequence of unequal economic and social development, the fruit of a failed policy and insufficient efforts on the part of the unavoidable space sector. In other words, until now, it has missed the ambition of sustainable development.

The concept of sustainable development indeed answers enormous challenges. It is a theoretical and practical approach for economic and social actors, based on three pillars also called Goals: economic development, social inclusion i.e. well-being of people, and environmental sustainability. It is, according to the World Commission on Environment and Development (Brundtland Commission), the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. This represents a change from current models, a change that must itself be made in a sustainable manner and involve all stakeholders, in their context.

In the case of the social movement in Kourou, economic development has not been accompanied by an adapted social policy. Due to the negligence of one of the dimensions of sustainable development by several stakeholders, the consequences were disastrous: significant costs incurred, about 500,000 € per day for the GSC according to Arianespace, and a social fracture on edge. On the one hand, it is the perfect illustration of the fact that without addressing the root causes of social inequalities, it is impossible to achieve other Goals of sustainable development, since they are all interconnected. By itself the economic growth of around 3% in French Guiana, mainly due to the space sector, does not ensure social justice and inclusion for all, while they are essential for cohesive societies. On the other hand, this is just one of the many examples that the space industry does not apply a consistent sustainable approach, even though space players are multiplying. While space activity will grow even faster, it seems crucial for all actors, new and old, to adopt a truly sustainable approach and taking into account all the stakeholders to avoid a new situation as in Kourou.

Furthermore, to be better understand why space sustainability is going to be critical in the coming years, it would be interesting to look into how sustainability approaches have been assimilated in the automotive industry over time. First invented and developed in the late 1800's, the automotive industry has been through a lot of transitions. In the early 21st century, the industry had already achieved a level of maturity and high structure. However, it had to face the increasing pressure of globalization, government regulations and technological advances. With the growing importance of business efficiency, stakeholder pressure and the need for legislative compliance, the automotive sector had to start manufacturing cleaner vehicles. To enhance those evolutions, governments have been implementing measures to reduce energy consumption, emissions and increase transportation safety (Rodrigues Vaz et al., 2017). For example, in some European countries, the European Union End-of-Life Vehicle Directive (ELV) has been introduced in order to increase the recovery of end-of-life vehicles and reduce waste. Therefore, the automotive industry has been adapting to new expectations and is now structured on the challenges of sustainability. At the same time, the sector has been requiring effective initiatives, solutions and measurement tools for sustainability assessment. The main environmental initiatives and tools used for the automotive industry are: the minimization of greenhouse gas emissions, Life Cycle Assessment (LCA), cleaner production, reverse logistics and eco-innovation. LCA is for instance based on the statement that the expansion of car-based transport over the last half-century lead to ecological and social impacts, such as noise, accidents, air pollution and resource depletion (Jasiński, 2016), and that those effects need to be mitigated by new approaches. So far, though, there has been no clear consensus among automotive experts and other stakeholders on which sustainability framework should be used as a standard. Moreover, most of the business frameworks only include an environmental dimension leaving out the social and economic ones, although crucial when assessing sustainability. For example, Volvo's Environmental Priority Strategies (EPS) system extends the scope of its assessment to the entire life cycle of the vehicle, but mainly focuses on the environmental impacts of the firm's operations. Scholars also point out that, in order to improve the reliability of sustainability assessment frameworks in the automotive industry, further development is necessary, in particular through empirical testing (Jasiński, 2016). They finally argue that a change in the business models is required to integrate sustainable matters at the core of the activity (Rodrigues Vaz et al., 2017).

It can then be concluded that after several decades of operation, the automotive sector first integrated sustainable approaches in response to recurring pressures from various stakeholders. Since the application of sustainability to the automotive industry is recent, it is still under development. In that respect, further action has to be taken and the existing ones need to be maintain. Moreover, the way sustainability concerns arrived in this particular industry could be used to better apprehend the importance and the development of sustainability in other industries, such as space. By putting in perspective both industries sustainability, areas of improvement appear. For instance the three forces: business efficiency, stakeholder pressure and the need for legislative compliance, that compelled the automotive sector to integrate sustainability approaches, are still low or non-existent in the space sector, thus giving rise to events such as Kourou social movement.

With both those examples in mind, the objective of the paper is to highlight the fact that space sustainability would be crucial for space industry stakeholders to face the future, but also a challenging subject for scholars. For this purpose, we will first present the few research works or initiatives that have been made concerning space sustainability; then, through an overview of relevant sustainable tools and the main research papers defining or discussing them, we will demonstrate why sustainability is of major importance for the space industry and its actors; finally, we will discuss the steps to lead and maintain a sustainable shift in the industry, in companies and in business models.

1 A FAST-GROWING INDUSTRY WITH ISOLATED INITIATIVES FOR REGULATION AND SUSTAINABILITY

1.1 MACRO-ENVIRONMENT

In order to better comprehend the context and the challenges around space sector sustainability, that we will later detail, we conducted a PESTEL analysis. For this purpose, we used four kinds of information sources: sectoral studies, specialized newspapers, governmental organizations' websites, and finally Mr Daniel Hernandez, lecturer at Toulouse Business School, provided us insights with his expertise. Performing this analysis allowed us to identify external factors which now affect the space industry, either positively or negatively, and to determine whether they will keep on doing so in coming years. The table below, summarizing our work, should be read as follows:

- Space sector external factors are either favourable (F) or unfavourable (U);
- The weight in right column indicates how much favourable (positive) or unfavourable (negative) a factor is;
- Trend interpretations for factors: ↗ improving, → stable, ↘ deteriorating.

Space sector external factors	***Weight Trend***
Political	
(F) Public policies are favourable to space activities: dedicated national space agencies' budgets are declining in proportion of GDPs but still rise in value, moreover governments are more and more likely to use commercial solutions to meet their needs.	++ →
(F) Dynamic "space poles" are located in various regions of the world, creating emulation effects: Copernicus and Galileo/EGNOS for the EU; Kepler, GPS, and so forth in the US; emerging Japanese, Indian and Chinese poles as well as noteworthy ambitions in e.g. Singapore, Korea.	+ ↗
(U) When the sovereignty of state actors is undermined, it causes instability for space activities. For example Brexit may end the cooperation between UK and the EU, implying some relocations in Germany and France and slowing down the European space industry.	- ↘

Economic		
	(F) Prosperous economic context: steady global economic growth [World Bank], and the space sector has also been growing over the past years, even though not continuously [Space Foundation Reports].	+ →
	(F) New players, i.e. New Space private actors, are bringing more competitiveness to the space industry but also more efficiency, at least in the short-term. Thus the lower costs for going into space.	+++ ↗
	(F) Economic fields of application are maturing, e.g. agriculture and meteorology.	++ →
	(F) Massive investments from other sectors, especially from the digital sector and the GAFA i.e. biggest digital companies: Google, Amazon, Facebook, Apple.	++ ↗
Social		
	(F) More and more "individual" consumers of the space sector products and services, such as for tourism (e.g. Virgin Galactics and Blue Origin services) or transport. In these cases, it should be noted that the potential market is questionable as the target group is only the upper social class and rich consumers.	+ ↗
	(U) Citizens/end consumers have limited interest and knowledge in space because it is too vague, although this should evolve with the growing usefulness of space and its increasing accessibility.	-- ↗
Technological		
	(F) Increasing maturity: industrial space actors are moving from custom-designed products to mass-production with cheaper, more advanced components, making satellites cheaper to build and to launch.	+++ ↗
	(F) Large investments in R&D, for instance the amount of space patents quadrupled in 15 years.	++ ↗
	(U) Cyber risks: there are concerns about the security of confidential data and data related to the privacy of users, albeit the digital sector now provides better solutions for traceability and data protection.	- →
Environmental		
	(F) Many advances in the space industry as well as new applications are already meeting the environmental challenges, regarding for example urbanization, management of natural resources, global pollution.	++ ↗
	(U) Orbital space debris: growing issue that needs to be addressed to prevent the scenario imagined by Kessler from occurring, that is the congestion of space due to too many debris orbiting, which will appear in case of reckless space use.	--- ↘

Legal	
(U) International entities that can shape space laws like COPUOS (UN committee to regulate space) still are to be developed, with the adequate authority. Because when they exist, regulations are not always applied by major space countries.	- ↗
(U) Space legal frameworks are obsolete and not strictly regulating space activities, like the Outer Space Treaty of 1967; recent national space laws (e.g. USA 2015, Luxembourg 2017) need to be homogenized or may collide with each other. Now the commercial sector too must participate in the creation of laws that induce sustainability, considering its raising investments in the industry.	--- ↘

1.2 SPACE SUSTAINABILITY RESEARCH INVENTORY

Until recently, space sustainability had been considered low priority because of the low production volume which was associated with low environmental impact. However, the situation has changed with the increasing number of microsatellites, mega constellations and launches and sustainability became an inevitable concern. At the same time, the European Commission had begun to work on the harmonization of procedures for LCA across European industries and developed a guideline framework (the Product Environmental Framework) compliant with the ISO 14040 and 14044. Moreover, intergovernmental organizations of the space industry like the Committee on the Peaceful Uses of Outer Space (COPUOS) of the United Nations that governs the exploration and use of space for the benefit of all humanity, or the European Space Agency (ESA) dedicated to the exploration of space, have been recently attempting to develop sustainability of space activities. Strongly encouraged by the European Commission to adapt the Product Environmental Framework to the space industry, the ESA started to work on the environmental impacts of space activities in 2008. Although numerous newspaper and a few academic articles have been studying the accumulation of space debris phenomenon, the potential consequences and solutions (e.g. Hitchens, 2007), no scientific paper has been exploring space sustainability as a whole. Therefore, this first part will focus on the researches and guidelines elaborated by intergovernmental organizations or other space industry actors.

On March 10, 2017, ESA posted on its blog an article noting that it was “really encouraging to see that the Committee on the Peaceful Uses of Outer Space recognises [...] that the long-term sustainability of outer space activities is of interest and importance not only for current and aspiring participants, but also for the international community as a whole.” Indeed, in its last report (February 2017), COPUOS presented a first set of guidelines for the long-term sustainability of outer space activities. The committee also defined the sustainability of space activities as “the conduct of space activities in a manner that balances the objectives of access to the exploration and use of outer space by all States and governmental and non-governmental entities only for peaceful purposes with the need to preserve the outer space environment in such a manner that takes into account the needs of current and future generations.”. The fact that space sustainability has been defined for the first time by the most important intergovernmental organization brought hope to all the big and small organizations that were acting in favour of sustainable space activities, such as ESA. The long-term sustainability of outer space activities is a subject on which ESA has been actively working for years through the program Clean Space, "an eco-friendly approach to space activities. On the ground, that means adopting greener industrial materials, processes and technologies. In space, it means preserving Earth's orbital environment as a safe zone, free of debris", and that is now a shared goal for the Member States of the United Nations. Through Clean Space, ESA has been implementing a lot of environmental oriented actions through programs like the Clean Space Eco-Design to "evaluate the environmental impacts, identify the main sources of pollution, and propose technical solutions to reduce their impacts", using the Environmental Life Cycle Assessment (E-LCA) tool (Figure 1).

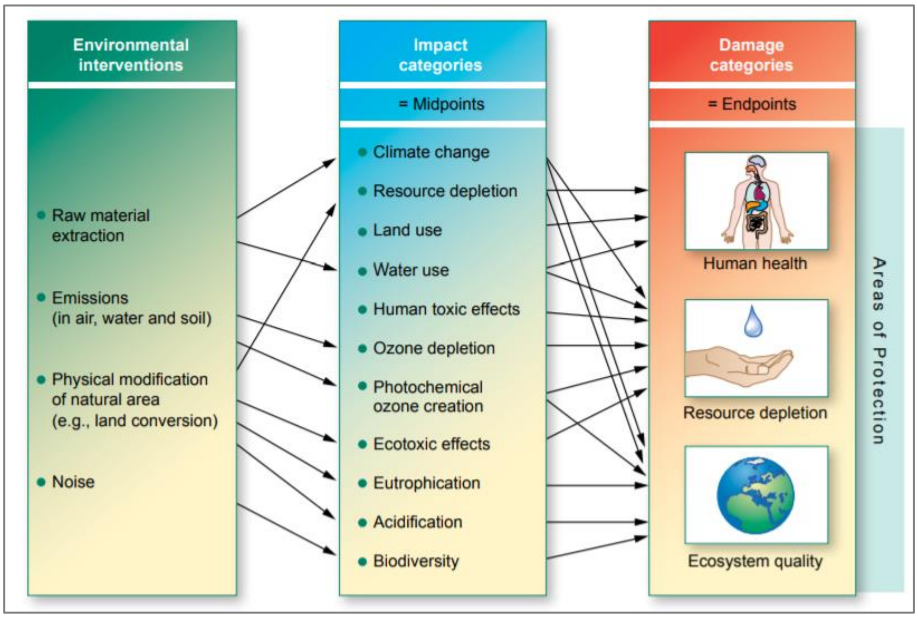

Figure 1 - Scheme of the environmental LCA framework (after UNEP, 2011)

However, the specificities of the space sector make it quite hard to conduct environmental assessments [ESA, 2016]. For instance, the specialised materials and processes used for the production of space systems are not included in inventory databases (e.g. ecoinvent.org). The long development cycles and R&D are responsible of a non-negligible portion of the environmental impacts, due to the high-tech and low-volume nature of many space products. In addition, as R&D data collection is performed across a long-time frame, in multiple contexts and geographical areas, the data collected can be highly uncertain and difficult to collect. Furthermore, testing is another specificity of the space sector that can make LCA harder. Due to low production rates and high reliability requirements, tests performed for space applications have a considerable impact on the environment. Lastly, when calculating the environmental impacts of transport, it is crucial to assess the impacts based on volume and not mass. Indeed, the necessary packaging for certain space systems, although not heavy, is voluminous and occupies a large part of the transport vessel's capacity. Other specificities of the space sector, such as the absence of a completely free market as a result of state funded projects along with limited players, can make the environmental impact assessment complex.

Today though, these difficulties seem to have been overtaken. Indeed, ESA published its first “Space system Life Cycle Assessment guidelines” at the beginning of 2017, which provides the space industry with a framework to perform “comprehensive quantitative assessments and consistent environmental declarations for complete space system as well as individual hardware equipment, components, material and processes” and methodological rules on how to correctly perform space-specific Life Cycle Assessments. This framework takes into consideration the specificities of space activities. We were able to have access to the LCA guidelines by contacting Jessica Delaval, Clean Space Coordinator at ESA. The “Space system Life Cycle Assessment guidelines” goes through the four main elements of a LCA: Goal and Scope, Life Cycle Inventory Analysis, Life Cycle Impact Assessment and Results Interpretation. It introduces LCA general methodology, the results that can be expected and how to interpret them. The document also presents the difficulties of applying LCA to the space sector. Afterwards, it exposes the guidelines that need to be taken into account when conducting a space LCA. Finally, the “Space system Life Cycle Assessment guidelines” addresses how to communicate LCA’s results. The environmental impact of a space system is presented as the sum of the impacts of the space segments, the launch segment and the ground segment. Thus, for each segment, space missions can be broken down in six phases (Figure 2). Therefore, the space LCA methodology relies on a functional and phase breakdown, resulting in more clarity. Thanks to Clean Space and the “Space system Life Cycle Assessment guidelines”, ESA has been able to conduct life cycle assessments on several space activities. Additionally, the space agency plans to work on many future projects such as “GreenSat”, which is the design of an entire space mission reducing its environmental impacts.

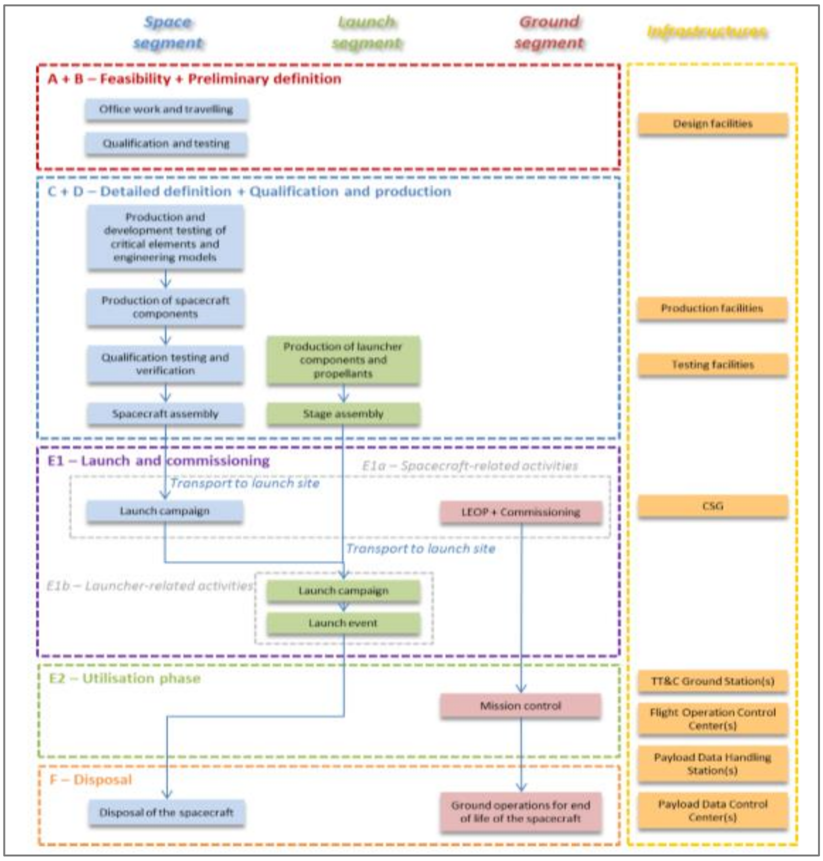

Figure 2 - Space mission system boundaries (after ESA, 2016)

1.3 ISSUES EMERGING FROM THE RESEARCH INVENTORY

Therefore, after several adjustments, ESA was able to use the LCA tool for space activities, which is a step forward in space sustainability. Moreover, the space industry has begun to get involved in this area too. Actors like Airbus Defence & Space, CNES (Centre National d'Études Spatiales) and Arianespace are now performing environmental impact studies. Finally, the recent publication of space sustainability guidelines by COPUOS goes along with all those advances and support them.

However, even though space industry organizations and actors acknowledge the triple dimension of sustainability assessment, as mentioned it at the beginning of ESA's CSR Report (2016), "Reporting about corporate responsibility and sustainability enables ESA to consider its environmental, social and economic impacts, and pushes for transparency and awareness regarding the risks and opportunities ESA faces.", the focus has mainly been only done on environmental concerns as mentioned further in the report "In a CSR approach, studying, measuring and monitoring in order to remediate our environmental impacts [...] occurring due to our core business activity is of high level importance.". Thus, the sustainability assessments and decisions that have been made hitherto by the space industry actors are based on environmental impacts, leaving out crucial the social and economic impacts (Chofreh et al., 2017). Moreover, most of the actions taken by space actors are based on a general perspective i.e. macro-level and barely mention the lower level of sustainability i.e. micro-level of the industry corresponding to manufacturing (H. Garbie, 2014). The LCA framework proposed by ESA, though, is a distinct case as the level of detail is expensive and could be easily applied to space operations. We will see in the following parts what is the value added and the necessity for the space industry to consider a comprehensive and utilitarian extent of sustainability.

2 APPLYING THE WHOLE SUSTAINABILITY CONCEPT TO SPACE IS CRUCIAL

2.1 BRIEF LIFE CYCLE THINKING AND MANAGEMENT RESEARCH INVENTORY

As mentioned by COPUOS guideline 27 (2017), "In their conduct of space activities for the peaceful exploration and use of outer space [...], States and international intergovernmental organizations should take into account, with reference to the outcome document of the United Nations Conference on Sustainable Development, the social, economic and environmental dimensions of sustainable development on Earth", meaning that the three dimensions of sustainable development should be part of the assessment of space activities sustainability. This perspective is in line with quite a few scholars' research work in recent years, such as Chofreh et al., (2017) about how to conduct general and comprehensive sustainability assessments. Many of them emphasized the necessity for industries to introduce Life Cycle approaches in their operations to achieve long-term sustainability (e.g. Kuzincow et al., 2015).

Life Cycle Thinking corresponds to the awareness that throughout the value chain of a product, social, economic and environmental resources are exploited, leading to positive and negative impacts (Kuzincow et al., 2015). Life Cycle Management (LCM) (Figure 3 and Figure 4), makes Life Cycle Thinking operational by helping enterprises to minimize the environmental and social impacts of their product during its entire life cycle [Life Cycle Initiative]. LCM gathers the following main tools: Environmental Life Cycle Assessment (E-LCA) and Social Life Cycle Assessment (S-LCA) which provide two complementary perspectives of the products' life cycle impacts; Life Cycle Costing (LCC) which gives information on costs throughout the products' life cycle. LCM also includes general sustainability tools such as eco-design, green procurement, energy labelling, environmental product declarations, carbon footprint analyses and environmental performance.

Life Cycle Thinking is a modern concept. It was first defined by the United Nations Environment Programme (UNEP) and the Society of Environmental Technology and Chemistry (SETAC), which were brought together in the "Life Cycle Initiative" and introduced Life Cycle Thinking in the discussions leading up to the World Summit on Sustainable Development (2002). However, Life Cycle Assessment, one of the Life Cycle Management main tools, was invented in the 1970s but only considered by the UN for the first time in 2002 (de Leeuw, 2005). Therefore, Life Cycle approaches have been developed by public organizations and scholars for almost two decades. As a result, an increasing number of leading companies and organizations from various industries are integrating Life Cycle approaches in their decision tools. It allows them to create more efficient production processes and increase stakeholder satisfaction (Blanco et al., 2015). However, even though Life Cycle Thinking has been actively supporting the transition to a green economy [Life Cycle Initiative], the approach need to be perfected to better adapt to practical and manufacturing contexts (H. Garbie, 2014). Several actors, indeed, consider the frameworks too general and difficult to apply. S-LCA, in particular, recently has been in the spotlight of many research papers and articles, as experts attempted to make the tool more applicable to the industry [UNEP, 2009], (Prasara-A et al., 2018).

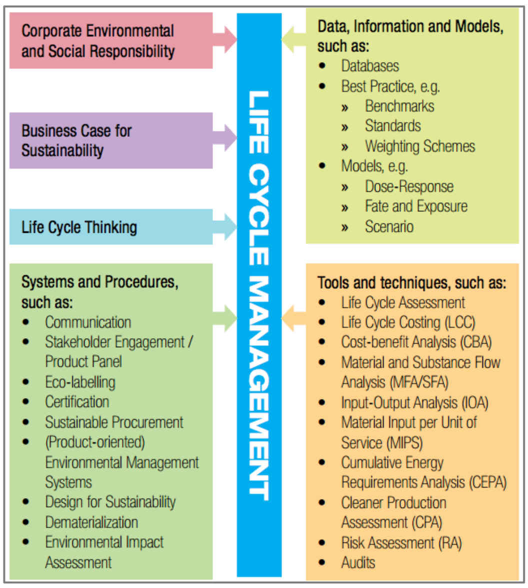

Figure 3 - Elements of Life Cycle Management (after Life Cycle Initiative)

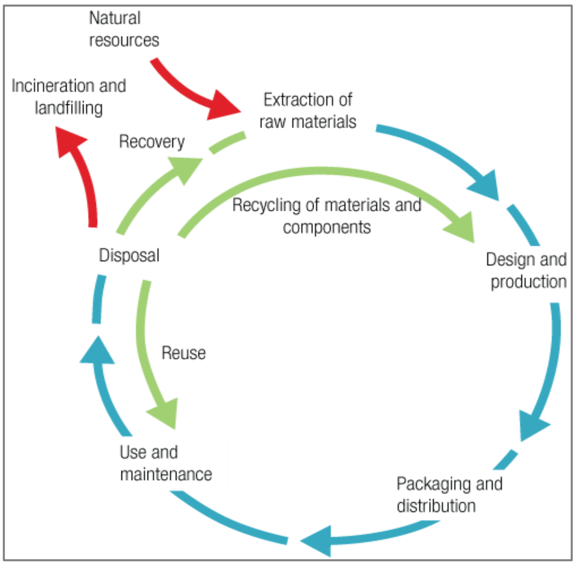

Figure 4 - A typical product lifecycle diagram (after Life Cycle Initiative)

2.2 Sustainability and Life Cycle approaches are worthwhile for all space industry stakeholders

Although no existing research studying the usefulness of the Life Cycle approach in general for the space sector can be found, since the scope of Life Cycle Thinking includes the three pillars of sustainability and the entire life-cycle of a product (Kuzincow and Ganczewski, 2015), one can argue that it is a necessary tool for the space industry. Thus, with the help of researches conducted about the utility of Life Cycle approaches in general and in manufacturing contexts, space economy features and data, it can be demonstrated what stated above.

On one hand, Life Cycle Thinking gives citizens, companies, and governments the information required when making decisions on how to consume, produce, or elaborate on policies and management strategies (de Leeuw, 2005). On the other hand, the space economy has been defined as “all public and private actors involved in developing and providing space-enabled products and services. It comprises a long value-added chaining, starting with research and development actors and manufacturers of space hardware and ending with the providers of space-enabled products and services to final users” [OECD, 2007]. Therefore, the space economy involves more and more actors and is increasingly complex. Because Life Cycle Thinking is a comprehensive approach, it avoids shifting problems between life cycle phases or geographic regions, what used to happen when conducting impacts assessments. It also avoids shifts from one type of a problem to another [Life Cycle Initiative, 2009]. Thus, the systematic use of Life Cycle Thinking would allow space industry actors to better integrate the numerous stakeholders in their decision making as they are an integral part of the methodology. Indeed, interactions with stakeholders provide a priority basis for companies or organizations and help integrate environmental, social, and economic thinking (Kuzincow and Ganczewski, 2015). Furthermore, thanks to Life Cycle Management, Life Cycle Thinking and product sustainability concepts can be made operational for businesses. It allows them to reduce their footprints along with minimizing their environmental and socio-economic liability. At the same time, companies can maximize their economic value and social value. A product can gain value as it goes through the product chain. At every step of it, value is added to the product resulting in a significant value creation at the end of the process [Life Cycle Initiative, 2009]. As the space industry is costly, due to several factors such as high quality raw materials, long operating time and high qualified workers [ESA, 2016], optimizing the value creation with the use of sustainability tools, in particular Life Cycle Management, would be a winning bet.

As stated above, leading companies from various industries are incorporating Life Cycle Thinking in their activities (Kuzincow and Ganczewski, 2015). Relevant companies include 3M, UTC and Veolia, as part of their operations focus on space activities (Figure 5). Those companies use Life Cycle Management to achieve different goals. 3M and UTC for instance aim at preventing pollution and maintaining their right to operate in response to pressures from non-governmental organizations, consumer groups, or from the applicable laws. 3M and Veolia share the objective of saving money and increasing efficiency by reducing energy and raw material use. Veolia also uses Life Cycle Management to support strategic choices in technology and to create a competitive advantage [Life Cycle Initiative, 2009]. Therefore, nowadays, the leading companies are not only using advanced technological methods but are also addressing major sustainability challenges to grow, leading to new and more profitable business models (Blanco and Sheffi, 2015). To support this shift in the space industry in particular, governments and consumers would benefit from integrating Life Cycle Thinking in their approaches. International and governmental initiatives integrating LCT are necessary to help space-related businesses respond to the new challenges mentioned above. Furthermore, governmental organizations can use Life Cycle Thinking to make relevant decisions and to set appropriate priorities, by selecting relevant indicators of environmental, social and economic performance. On the consumer side, Life Cycle approaches offer better information on the product chain like extraction means, resources used, recycling and disposal programs to help consumers make sustainable purchasing choices [Life Cycle Initiative, 2009]. This would allow the distant end customers to be more implicated and mindful when buying a product or enjoying a service derived directly or indirectly from the space industry.

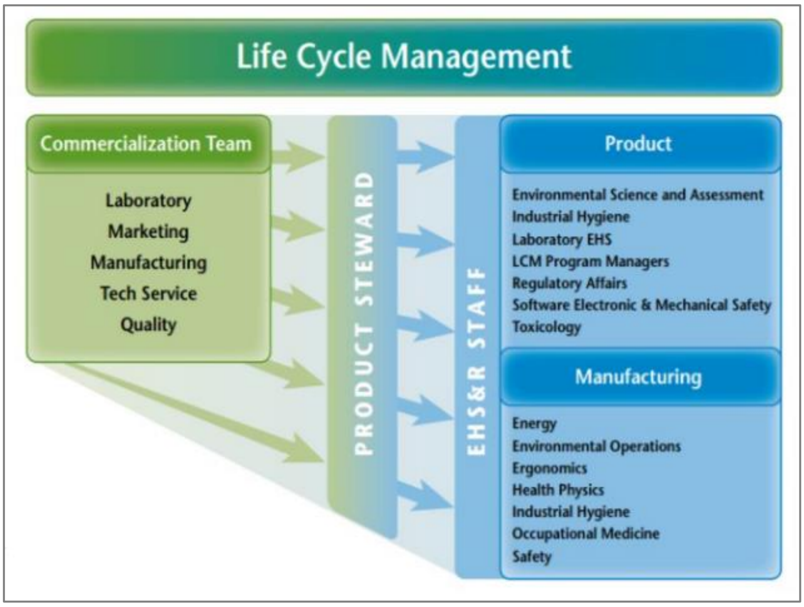

Figure 5 - Life Cycle Management implementation at 3M (after Life Cycle Initiative, 2009)

2.3 SUSTAINABILITY AND LIFE CYCLE APPROACHES ARE CRITICAL FOR THE SPACE INDUSTRY STAKEHOLDERS

The implementation of Life Cycle approaches by every space industry actor, from manufacturing companies to consumers, would allow the sector to optimize its adaptation to ongoing changes and is therefore essential. The development of the space industry is relatively new in comparison to other industries (cf. Introduction) and has been accelerating the last decade. The high cost of ground, launch, and space segments had been preventing further development of the space economy. However, these past years, a new trend has emerged: low-cost space operations. This trend could revolutionize the industry and would require more than ever the space actors to integrate Life Cycle and sustainability approaches. As one of the current most visible space actors, SpaceX and its reusable launchers shows evidence of cost awareness and to some extent environmental interest. The concept of reusable rockets first appeared in popular science fiction more than a century ago, and until recently it was still considered too complex by actual manufacturers. Compared to traditional launchers that are destroyed after being used, such technology increases the possible amount of launches in time and reduces the waste of materials, thus making launches much cheaper. When Elon Musk founded SpaceX in 2002 with the idea of reusable launchers in mind, he was convinced that it would reduce the cost of access to space by “as much as a factor of a hundred” [SpaceX]. In December 2015, after years of various trials, Musk did manage to overcome technical and financial obstacles to achieve launcher reusability. And for today’s and tomorrow’s missions, costs are indeed plummeting.

However in this case, rocket reusability may prove counterproductive regarding sustainability in its full definition, as it is not part of a comprehensive Life Cycle approach. Economically, benefits seem unquestionable. From the environmental point of view though, impacts are more contrasting. Even if reusable launchers imply lower waste of materials, only the rocket is reusable, not its fuel. With less time-consuming preparations and less expensive flights, launches will occur more frequently, hence an increase in the global fuel consumption harming all the atmosphere layers. Space actors may not be mature enough to prevent such undesired effects, for example by making the rocket fuel efficient first, or to fix them afterwards. Especially since these actors are becoming more and more numerous and diversified. Indeed SpaceX is an example of how a startup can come to compete with governmental entities, it created a breach into which its competitors are quickly stepping. So the offer for the launchers segment is rising just as the demand, thanks to dropping costs and prices. This may lead to another negative environmental impact: space debris will continue to accumulate at an even faster pace. Monitoring them will become much more difficult than it is today and as described in the Kessler syndrome, the eventual consequence will be a difficult if not impossible access to space for future launchers (Hitchens, 2007). Also from social point of view, the reusability of launchers and lower launch prices will facilitate the militarization of space, a high stake for countries and non-state actors. Up to the present moment, military missions in space were too expensive compared to the terrestrial alternatives. Now some wild players may turn space new opportunities into a show of force, and worse can cause chaos.

Therefore, it is clear that the low-cost access to space should go along with Life Cycle and sustainable development strategies. First, because space sustainability has been neglected for years, several effects are too significant not to be considered, for instance the accumulation of space junk. Many solutions, such as e.deorbit as a part of the Clean Space program [ESA, 2016], have been developed but none has been implemented so far. The lack of funding from governmental organizations has been a major a drag on solution implementation (Hitchens, 2007). But, as De Leeuw (2005) exposes it in when speaking about Life Cycle Thinking and sustainability tools, “The world cannot afford to wait another ten years to see what works and what does not work. Marketers and entrepreneurs, students and young people are all needed to bring about holistic solutions for a world in danger”. It is then critical for space businesses and organizations to run sustainable operations as of now, with the help of governments. Moreover, without a close coordination of all space stakeholders, every isolated initiative for space sustainability will be counter-productive. The example of the recyclable launchers demonstrates that several actors willing to implement more sustainable operations have to conform with the rest of the space stakeholders in order to get the desired effect and disrupt the industry in a good way (Harrison et al., 2017), [Quartz]. It means that upstream segments i.e. ground, launch and space operations, and downstream segments i.e. telecommunication, navigation, observation, of the space industry need to be coordinated when integrating sustainability strategies, not to shift the burden on another activity or production stage. It is thereby critical for the space industry to integrate Life Cycle Thinking along with other sustainable tools at all the stages of the production and for the three segments of the industry. Indeed, Life Cycle Thinking and Management allow stakeholders to be conscious of the others and to communicate. It would also prevent the space industry from burden shifting between different segments, product life cycle stages or actors (Kuzincow and Ganczewski, 2015) and optimize sustainable actions.

We will explore the different solutions and methods that can be contemplated through the available researches on how to implement Life Cycle and sustainability approaches in an industry and a company, as no research can be found on how to apply those approaches to the space sector in particular.

3 HOW TO APPLY SUSTAINABILITY CONCEPTS AND LEVERAGE THE SUSTAINABLE SHIFT

3.1 INTEGRATE A LIFE CYCLE APPROACH IN THE SPACE INDUSTRY AND COMPANIES

The mere application of Life Cycle approaches to the space industry should not be a significant obstacle in achieving space sustainability. Indeed, the combination of space sector data provided by public or private organizations (e.g. The Space Economy at a Glance 2007 by OECD) (Figure 6) with Life Cycle and sustainability tools, and the help of existing space-adapted frameworks (e.g. Clean Space by ESA), would allow space stakeholders to broadly implement Life Cycle Thinking and sustainability in the industry. Further adoption by businesses of Life Cycle approaches and data sharing could remedy to the lack of information that remains a prominent issue when assessing space operations’ impacts [ESA, 2016] (Figure 7).

Category of impact	In the space sector	In other sectors
New jobs	Workforce in the space sector	Employment locally, regionally serving the space sector workforce (*e.g.* local shops, industries).Employment in companies, organisations, using space-related products or services to create new products or services (*e.g.* imagery in geospatial equipment, satellite signals in navigation equipment).
New revenues	Revenues from new services	Revenues coming from new services, based on space-based elements (telecommunications, navigation, geospatial services).
Efficiency	Increased competitiveness of some space firms (see Norway example)	Productivity gains achieved by improving space assets users' production and distribution. Cost savings.
Cost avoidance	—	Reduced damage to properties and lives.
Social inclusion	—	Satellite communications infrastructure projects contribute to addressing the problem of social exclusion by improving accessibility.

Figure 6 - Types of impact of space investments (after OECD, 2007)

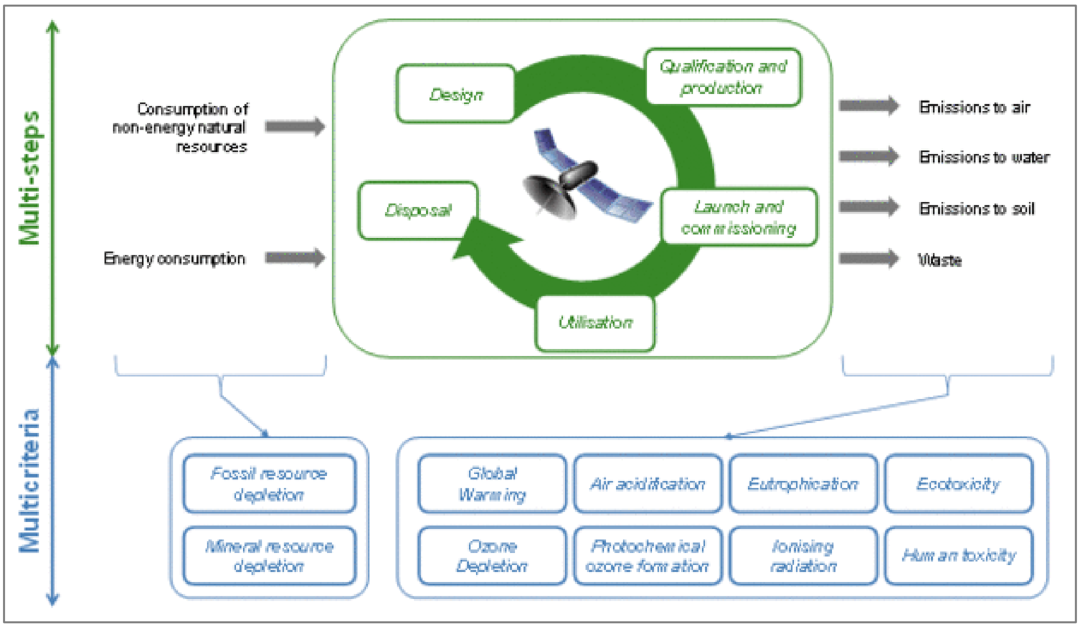

Figure 7 - Clean Space and Life Cycle Assessment (after ESA, 2016)

However, a bigger challenge for the space industry will be that, as suggested by several academic studies, businesses cannot be sustainable independently from the system of which they are part. The space industry as a whole need to integrate a "System-Level Sustainability", according to Stubbs and Cocklin (2008), in order to achieve economic, social and environment goals. Therefore, to manage the considerably growing space industry, every space stakeholder, that is to say customers, governments, intergovernmental organizations, non-governmental organizations (NGOs), and businesses, should take action. For instance, organizations such as ESA or COPUOS can influence governments to adopt regulations that support space sustainability with the help of lobbying (Starik et al., 1995). In this context, businesses will have external motivation and pressure to run sustainable operations, since the main drivers of sustainability for companies are customers' expectations and regulations (H. Garbie, 2014).

Beside system and stakeholders' pressure, environmental and economic concerns such as space junk accumulation or increasing operating costs can also push space business to integrate a "Firm-Level Sustainability" (Stubbs and Cocklin, 2008) and life cycle thinking into their decision making. To that end, contractors can use several types of environmental and economic concepts and tools connected with the life cycle. Yet, many studies have proposed a framework to implement sustainability within a business but most of them only focused on one out of the three dimensions of sustainable development (Chofreh et al., 2017). Therefore, Life Cycle Management seems to be an adapted framework, as demonstrated in the previous part. The decision of executing LCM, has to be made by the top management but is often suggested by the company's department of environment or sustainability. Interactions with stakeholders, inside and outside the company, also ensure inspiration for the integration of environmental, social and economic thinking (Svensson et al., 2016). The top management has to make sure that a life cycle approach is in line with the strategy, for it to be first applied in different functions such as manufacturing, marketing, research and development or environmental health and safety and then be spread to the entire company (Kuzincow and Ganczewski, 2015) thanks to sustainability "champions" who educate employees and support change (Stubbs and Cocklin, 2008).

Once sustainability and Life Cycle approaches have been integrated, maintain a sustainable growth is the next objective space businesses should aim at. Numerous researches and articles have been led on how to grow sustainably in various contexts, such as diverse manufacturing industries or countries (e.g. Mohit et al., 2017 or Real et al., 2015). In order to apply a sustainable growth model to space industry manufacturers, a general framework would be the most suitable. The Eco-Growth framework proposed by the MIT scholars Blanco and Sheffi (2017) is one of them. In order to achieve sustainable growth, businesses have to make efforts that can be characterized by two dimensions: the extent of congruence with the company's basic goals and the supply chain scope involved. They are four types of strategies that go along those dimensions: Eco-Efficiency, Eco-Alignment, Eco-Innovation and lastly Eco-Growth (Figure 8). In the short-term, companies usually begin with achieving Eco-Efficiency, which corresponds to the strategies that aim at improving environmental and economic sustainability. To this end, Eco-Efficient businesses only focus on the company's operations by assessing and reducing environmental impacts of goods or services production. The Eco-Efficient strategy leads to waste and cost reductions. Then, in the long-term, through Eco-Alignment manufacturing businesses will extend their efforts to make operations sustainable to suppliers, customers and firm's stakeholders in general. In this context, the Eco-Aligned companies regulate the actions of their supply chain partners and communicate to their consumers the environmental and social performance of suppliers along with product information. After assessing the economic, social, environmental burdens and communicating the results to consumers, business aiming at Eco-Innovation will get involved in the research of solutions to improve sustainability, such as Eco-Designed products and processes. By doing so, manufacturing companies are creating a competitive advantage as they develop new valuable skills and intellectual property. Finally, the combination of environmental and social sustainability with economic performance corresponds to the Eco-Growth strategy. Businesses that want to achieve Eco-Growth have integrated the whole Life Cycle approach in their operations, that help them reducing their environmental and social impacts while achieving significant growth goals.

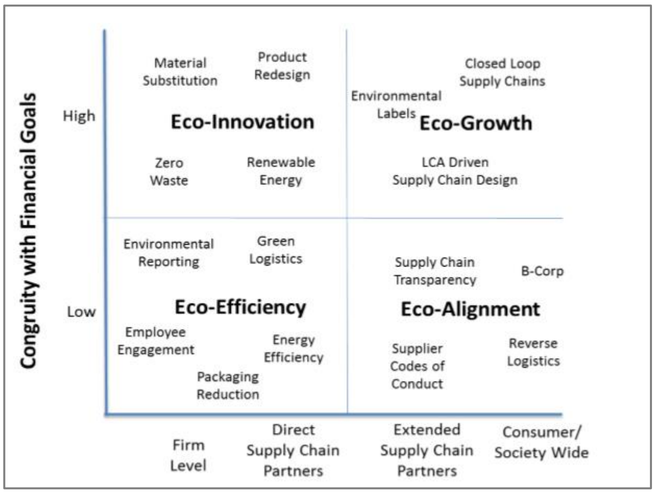

Figure 8 - Green Supply Chain Management Strategies (after Blanco and Sheffi, 2015)

The Eco-Growth concept is based on a Life Cycle approach since, according to the Life Cycle Initiative, (2009): "One key characteristic of Life Cycle Management is that this approach requires companies to move away from just looking at their own operations and to look at what is happening in their value chain (upstream and downstream operations that are outside the company's direct control)" [Life Cycle Initiative, 2009], therefore adapted to the space industry. Finally, in order to ensure an efficient and adapted progression towards sustainability and Eco-Growth, space businesses would need to track their progresses with performance measurement tools such as Quality Using Employee Suggestions and Teamwork (QUEST) to monitor waste reduction or SocioMetrics to measure the social performance (Stubbs and Cocklin, 2008). Nevertheless, to take full advantage of Life Cycle Management and Eco-Growth, further theoretical researches are necessary to specify their introduction in space industry businesses, and the related challenges.

3.2 THE OPPORTUNITY OF CHANGING BUSINESS MODELS FOR SPACE ACTORS

However in practice, one cannot ignore that integrating Life Cycle and sustainability approaches, such as Eco-Growth, may be complicated for manufacturing businesses, in particular for space businesses where no guideline is available. Since those approaches are demanding and require major evolutions in the way decisions are made and operations run, space industry businesses may be reluctant in changing their operational mode. A solution would be to redesign the structure of businesses for them to be more adapted to sustainability. Such an undertaking corresponds to the adoption of new business models. A business model is a conceptual tool that helps to understand how a firm does business and that includes different elements: value proposition; activities, resources, partners and distribution channels i.e. value creation and delivery; cost structure and revenue model i.e. value capture (Osterwalder and Pigneur, 2005). Because business models enable to analyse how a company converts resources and competences into economic value, they actively participate in providing social and environmental sustainability in an industrial system. For instance, the adoption of new business models is currently considered by scholars and experts of the automotive industry, in order to achieve better sustainability (cf. Introduction).

In this context, sustainable business models are business models that "incorporate a triple bottom line approach and consider a wide range of stakeholder interests, including environment and society [...]" (Bocken et al., 2014). They help businesses to integrate sustainability in their commercial goals and processes, and lead to the creation of a competitive advantage. For this purpose, one of the main challenges is to enable firms to capture economic value through the generation of social and environmental benefits. Many articles and researches have explored the theory of business models for delivering sustainability. Very few articles, though, have provided a framework to guide innovation activities. Thus, to overcome this deficiency, the scholars Bocken et al. (2014) provided a categorisation of business model innovations that deliver sustainability. The objective was to give firms an idea of how to approach the incorporation of sustainability in their business models. Eight sustainable business model archetypes are exposed: "Maximise material and energy efficiency; Create value from 'waste'; Substitute with renewables and natural processes; Deliver functionality rather than ownership; Adopt a stewardship role; Encourage sufficiency; Re-purpose the business for society/environment; and Develop scale-up solutions". The archetypes are classified in superior groupings, corresponding to the main type of business model innovations: Technological, Social, and Organisational. Since no research focusing on the space industry has been conducted so far, this categorisation could guide space businesses when designing sustainable business models.

The embedding of sustainability in space business models will require a shift in the purpose of business and in how operations are currently undertaken. Therefore, new and sustainable business models would particularly be adapted to space startups. Along with the growth of the entire industry, space startups development and investment have been soaring. Transactions involving space tech businesses, including startups, have increased more than 400% between 2012 and 2015 [cbinsights, 2017]. In 2016, $2.8 billion has been invested in space startups, $400 million more than in 2015 [cnbc, 2017]. Therefore, due to significant potential investments, the number of space startups has been steadily increasing. On one hand, this trend represents a threat for sustainability as the number of space operations will keep increasing and have possible negative impacts (cf. 2.3). However, on the other hand, it is mainly an opportunity for the space industry sustainability. Indeed, startups can effortlessly design and pursue sustainable business from the very beginning (Stubbs and Cocklin, 2008), as their structure is new and will not require changes to adapt. Some of these new players' business model already is sustainable. Gil Denis, who is a senior manager at Airbus Defence and Space working with startups, shared with us several examples, including startups which position themselves on an offer to clean orbital debris, thus responding to the clean space issue. Since space startups are more and more numerous, a mass adoption of sustainable approaches would contribute positively to space sustainability. The main challenge would then be to develop the space industry's "System-Level Sustainability", as mentioned earlier. It would pressure space startups in adopting sustainable business purposes, and to have positive economic, environmental and social impacts. In this way, the space industry will leverage the growth of startups to establish a new standard for business models.

CONCLUSION

These last years, the space sector has been knowing a renewed interest from various industries and investors. To take full advantage of this growing interest and run lasting operations, we have shown that space actors would benefit from adopting sustainability approaches. For this purpose, we proposed the application of life cycle approaches along with other sustainability tools. We argued that the outcomes of such actions would be the creation of additional value for all space stakeholders and the reduction of negative economic, environmental, social impacts.

Despite the efforts of intergovernmental organisations such as ESA or COPUOS to frame space sustainability, more research is needed to develop a comprehensive and concrete model. For instance, a framework detailing how to conduct a Social Life Cycle Assessment (S-LCA) taking into consideration the specificities of the space industry, e.g. the distance of end-consumers, could be combined with the Environmental Life Cycle Assessment (E-LCA) guidelines already performed by ESA and represent a complete sustainability tool for stakeholders. Additional research works could also focus on elaborating more tangible sustainability frameworks for the space industry, with very detailed indications on how to make use of them in specific contexts e.g. launchers manufacturing.

Finally, the main objective of this paper was to point out that it would be a challenging opportunity for scholars to address space sustainability and that this research work would represent a necessary support for stakeholders when implementing sustainability approaches. Our research work also provides all actors, especially businesses, with a basic understanding of relevant sustainable development tools applicable to space operations and identifies paths for action, such as a change in business models.

APPENDIX

BIBLIOGRAPHIC SOURCES

JASIŃSKIA Dominik, MEREDITH James, KIRWANA Kerry, *A comprehensive framework for automotive sustainability assessment* - Journal of Cleaner Production, 2016, Nov2016, Vol. 135, p1034-1044. 11p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/detail/detail?vid=8&sid=7ba32e72-a8ef-4425-bd9a-dbb052fe15b7%40sessionmgr4008&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=117518498&db=bth

RODRIGUES VAZ Caroline, SHOENINGER RAUEN Tania Regina, ROJAS LEZANA Álvaro Guillermo, *Sustainability and Innovation in the Automotive Sector: A Structured Content Analysis*, Department of Industrial and Systems Engineering, Federal University of Santa Catarina, 2017, available at: https://www.researchgate.net/publication/317097759_Sustainability_and_Innovation_in_the_Automotive_Sector_A_Structured_Content_Analysis

ŻAK Agnieszka, *Triple Bottom Line concept in theory and practice*, research paper, Wroclaw University of Economics, 2015, Issue 387, p251-264. 14p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/resultsadvanced?vid=5&sid=7ba32e72-a8ef-4425-bd9a-dbb052fe15b7%40sessionmgr4008&bquery=TI+((Triple+AND+Bottom+AND+Line+AND+concept+AND+%22in%22+AND+theory)+AND+practice)&bdata=JmRiPWJ0aCZ0eXBlPTEmc2l0ZT1laG9zdC1saXZlJnNjb3BlPXNpdGU%3d

KUZINCOW Joanna, GANCZEWSKI Grzegorz, *Life Cycle Management as a crucial aspect of corporate social responsibility*, research paper, Wroclaw University of Economics, 2015, Issue 387, p91-108. 18p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/detail/detail?vid=3&sid=7ba32e72-a8ef-4425-bd9a-dbb052fe15b7%40sessionmgr4008&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=108617122&db=bth

JITTIMA Prasara-A, GHEEWALA Shabbir H, *Applying Social Life Cycle Assessment in the Thai Sugar Industry: Challenges from the field* - Journal of Cleaner Production, 2018, Vol. 172, p335-346. 12p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/detail/detail?vid=10&sid=246008ab-d36b-4e94-9a04-c0f537e89a76%40sessionmgr4007&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=126871798&db=bth

SVENSSON Goran, HOGEVOLD Nils, PETZER Danie, PADIN Carmen, FERRO Carlos, KLOPPER HB, SOSA VARELA Juan Carlos, WAGNER Beverly, *Framing stakeholder considerations and business sustainability efforts: a construct, its dimensions and items*, Journal of Business & Industrial Marketing, 2016, Vol. 31 Issue 2, p287-300. 14p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/resultsadvanced?vid=6&sid=7ba32e72-a8ef-4425-bd9a-

dbb052fe15b7%40sessionmgr4008&bquery=TI+((Framing+AND+stakeholder+AND+considerations)+AND+(business+AND+sustainability+AND+efforts%3a+AND+a+AND+construct%2c+AND+its+AND+dimensions)+AND+items)&bdata=JmRiPWJ0aCZ0eXBlPTEmc2l0ZT1laG9zdC1saXZlJnNjb3BlPXNpdGU%3d

HITCHENS Theresa, *Debris, Traffic Management, and Weaponization: Opportunities for and Challenges to Cooperation in Space*, Brown Journal of World Affairs, 2007,Vol. 14 Issue 1, p173-186. 14p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/resultsadvanced?vid=4&sid=7ba32e72-a8ef-4425-bd9a-dbb052fe15b7%40sessionmgr4008&bquery=TI+((Debris%2c+AND+Traffic+AND+Management%2c)+AND+(Weaponization%3a+AND+Opportunities+AND+for)+AND+(Challenges+AND+%22to%22+AND+Cooperation+AND+%22in%22+AND+Space))&bdata=JmRiPWJ0aCZ0eXBlPTEmc2l0ZT1laG9zdC1saXZlJnNjb3BlPXNpdGU%3d

DE LEEUW Bas, *The World Behind the Product*, Journal of Industrial Ecology, 2005, Vol. 9 Issue 1/2, p7-10. 4p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/detail/detail?vid=3&sid=246008ab-d36b-4e94-9a04-c0f537e89a76%40sessionmgr4007&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=17228494&db=bth

STUBBS, COCKLIN, *An ecological modernist interpretation of sustainability: the case of Interface Inc.*, Business Strategy & the Environment, 2008, Vol. 17 Issue 8, p512-523. 12p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/detail/detail?vid=18&sid=246008ab-d36b-4e94-9a04-c0f537e89a76%40sessionmgr4007&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=35387142&db=bth

GARBIE Ibrahim H., *An analytical technique to model and assess sustainable development index in manufacturing enterprises* - International Journal of Production Research, 2014, Vol. 52 Issue 16, p4876-4915. 40p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/detail/detail?vid=5&sid=246008ab-d36b-4e94-9a04-c0f537e89a76%40sessionmgr4007&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=97066617&db=bth

CHOFREH, GONI, ARIANI, *Review of Frameworks for Sustainability Implementation,* Sustainable Development, 2017, Vol. 25 Issue 3, p180-188. 9p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/detail/detail?vid=12&sid=246008ab-d36b-4e94-9a04-c0f537e89a76%40sessionmgr4007&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=123566854&db=bth

MOHIT, HARSHAL, A. K, *Modeling the Critical Success Factors for Sustainable Growth of Mining Industry in India*, IUP Journal of Operations Management, 2017, Vol. 16 Issue 2, p7-20. 14p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/detail/detail?vid=14&sid=246008ab-d36b-4e94-9a04-

c0f537e89a76%40sessionmgr4007&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=123176610&db=bth

STARIK Mark, RANDS Gordon, *Weaving an Integrated Web: Multilevel and Multisystem Perspectives of Ecologically Sustainable Organizations*, Academy of Management Review, 1995, Vol. 20 Issue 4, p908-935. 28p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/detail/detail?vid=20&sid=246008ab-d36b-4e94-9a04-c0f537e89a76%40sessionmgr4007&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=9512280025&db=bth

BLANCO Edgar E., SHEFFI Yossi, *Eco-Growth: A Framework for Sustainable Growth*, research paper, Massachusetts Institute of Technology, Engineering Systems Division, 2015, available at: http://hdl.handle.net/1721.1/97643

BRADY Kevin, HENSON Patrice, A. FAVA James, *Sustainability, Eco-efficiency, Life-Cycle Management and Business Strategy*, Environmental Quality Management, 1999, Vol. 8 Issue 3, p33-41. 9p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/detail/detail?vid=7&sid=d447201f-9728-471f-9d80-9685b77ec520%40sessionmgr4008&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=1863758&db=bth

OSTERWALDER, PIGNEUR, *Clarifying Business Models: Origins, Present, and Future of The Concept*, Communications of the Association for Information Systems, 2005, Vol. 16, p1-25. 25p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/detail/detail?vid=16&sid=246008ab-d36b-4e94-9a04-c0f537e89a76%40sessionmgr4007&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=19323565&db=bth

BOCKEN, SHORT, RANA, EVANS, *A literature and practice review to develop sustainable business model archetypes, Journal of Cleaner Production*, 2014, Vol. 65, p42-56. 15p., available at: http://eds.a.ebscohost.com.hub.tbs-education.fr/ehost/detail/detail?vid=7&sid=246008ab-d36b-4e94-9a04-c0f537e89a76%40sessionmgr4007&bdata=JnNpdGU9ZWhvc3QtbGl2ZSZzY29wZT1zaXRl#AN=94307408&db=bth

OTHER SOURCES

INSTITUTE FOR DEVELOPMENT OF FREEDOM OF INFORMATION (IDFI), *Why are Sustainable Development Goals important?*, available at: https://idfi.ge/en/why_does_sdgs_matter

LA CROIX, *Le PDG d'Arianespace s'inquiète des retombées des blocages en Guyane*, available at: https://www.la-croix.com/Economie/France/Le-PDG-dArianespace-sinquiete-retombees-blocages-Guyane-2017-04-18-1200840430

BOURSIER, *Lancement d'un plan renforçant l'action du spatial en Guyane*, available at: https://www.boursier.com/actualites/reuters/lancement-d-un-plan-renforcant-l-action-du-spatial-en-guyane-212859.html

THE JAPAN TIMES, Protesters converge on space center as French Guiana's financial crisis worsens, available at: https://www.japantimes.co.jp/news/2017/04/05/world/social-issues-world/protesters-converge-space-center-french-guianas-financial-crisis-worsens/

LA CROIX, Guyane, comment en est-on arrivé là? available at: https://www.la-croix.com/France/Securite/Guyane-comment-en-eston-arrive-la-2017-03-27-1200835155

ESA*, Clean Space, The UN And The Sustainability Of Space Activities,* available at: http://blogs.esa.int/cleanspace/2017/03/10/clean-space-the-un-and-the-sustainability-of-space-activities/

ESA, *Eco Designing Space Technologies*, available at: http://blogs.esa.int/cleanspace/2016/07/28/ecodesigning-space-technologies/

ESA, *Life Cycle Assessment Training*, available at: http://www.esa.int/Our_Activities/Space_Engineering_Technology/Clean_Space/Life_Cycle_Assessment_training_at_ESA

ESA, *Clean Space In ESA's 2015-16 CSR Report*, available at: http://blogs.esa.int/cleanspace/2017/12/12/clean-space-in-esas-2015-16-csr-report/

COMMITTEE ON THE PEACEFUL USES OF OUTER SPACE (COPUOS), *Guidelines for the long-term sustainability of outer space activities*, United Nations General Assembly, Vienna, 30 January - 10 February 2017, available at: http://www.unoosa.org/res/oosadoc/data/documents/2017/aac_105c_1l/aac_105c_1l_354rev_1_0_html/V1609033.pdf

ESA LCA WORKING GROUP, *Space system Life Cycle Assessment (LCA) guidelines*, ESA internal, October 2016, available on request to cleanspace@esa.int.

XERFI France, L'industrie Aéronautique et Spatiale, November 2017, available at: www.xerfi.com

THE LIFE CYCLE INITIATIVE, *Life Cycle Approaches*, available at: https://www.lifecycleinitiative.org/starting-life-cycle-thinking/life-cycle-approaches/

HARRISON, HUNTER, JOHNSON, ROBERTS, *Implications of Ultra-Low-Cost Access To Space*, CSIS Aerospace Security Project, 2017, available at: https://www.csis.org/analysis/implications-ultra-low-cost-access-space

QUARTZ, *Reusable Rockets Could Disrupt The Space Industry, And Not Always In A Good Way*, available at: https://qz.com/944145/reusable-rockets-could-disrupt-the-space-industry-and-not-always-in-a-good-way/

JOLLY, RAZI, *The space economy at a glance: 2007*, OECD Publishing, available at: http://www.oecd-ilibrary.org/docserver/download/0307021e.pdf?expires=1517669630&id=id&accname=guest&checksum=8048A9912AC4D15A13833594894F67D5

CBINSIGHTS, *The Space Tech Market Map: 57 Startups Charting The Final Frontier*, available at: https://www.cbinsights.com/research/space-tech-startups-market-map/

CNBC, *Investors pour billions into commercial space startups as they approach exit velocity*, available at: https://www.cnbc.com/2017/08/09/investors-pour-billions-into-spacex-blue-origin-planet.html

NEWSWEEK, *Timeline: A Brief History Of SpaceX's Reusable Rocket Launches*, available at: http://www.newsweek.com/spacex-timeline-brief-history-reusable-rocket-launches-417944

BUSINESS INSIDER FRANCE, *Here's why landing a rocket on a ship just might save humanity*, available at: http://www.businessinsider.fr/us/how-spacex-rocket-landing-works-2016-4/#thats-why-elon-musks-spacex-and-bezos-rocket-company-blue-origin-are-trying-to-develop-reusable-rockets-3

THE SCRIBE, *The Pros and Cons of Reusable Rockets*, available at: https://scribewilcox.com/2250/op-ed/the-pros-and-cons-of-reusable-rockets/