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Space Sustainability: From Debris Management to Long-Term Sustainable and Financial Growth in Outer Space Activities

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Chapter I: State of The Art of Space Economy Sector

"We do not inherit the World from our ancestors,
we borrow it from our children".
- Native American Saying

1 The Starting of a New Era: Space Economy

To start the analysis, the following chapter will focus on the implications of modern issues and the related possible solutions, linked to the emerging "Space Economy" field in the economic sector.

History has always shown a huge interest in outer space matters, peaking with the "Space Race". This refers to the period of intense competition and rivalry between the United States and the Soviet Union during the Cold War era, particularly from the late 1950s to the late 1960s. It revolved around the exploration and conquest of outer space, particularly the achievement of significant milestones such as launching artificial satellites, sending humans into space, and eventually landing astronauts on the Moon.

These dynamics used to result mostly from public investments and political choices of the countries involved in the race, but nowadays the setting is completely changing.

Due to the privatization of space activities, a big revolution is happening: the worldwide turnover in the space economy sector has more than doubled from 216.6 to 469.3 billion US$, between 2009 and 2021[1], creating what we call the "Space Economy".

The OECD (Organization for Economic Co-operation and Development) defines the latter as: "*The full range of activities that create value to human beings through exploring, researching, understanding, managing, and utilizing space. It includes all actors engaged in developing, providing and using space-related products and services: research and development, space infrastructure, space-derived applications, as well as the resulting scientific knowledge*"[2].

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[1] Statista Data showing the global turnover in the space economy sector https://www.statista.com/statistics/946341/space-economy-global-turnover/

[2] Definition of Space Economy https://www.oecd.org/en/topics/policy-issues/space-economy.html#:~:text=The%20space%20economy%20encompasses%20all,management%2C%20and%20utilisation%20of%20space.

Space Economy, therefore, includes also all the Earth-related activities that might benefit from this sector, such as the development of new technologies in meteorology, transportation, and telecommunications.

According to ESA, the Space Industry "could be the next trillion-dollar industry by 2040"[3].

Another source confirming the trend is the Space Foundation Organisation, stating that the global Space Economy increased of 7.4% in the year 2022-2023, reaching a total of 570 billion US$, of which commercial revenues cover almost 78% of it[4].

With this kind of shift, going from the public sector to the private one, some of the problems traditionally related specifically only to the private sector are arising as well, but this time they are to be tackled in such an unprecedented environment like outer space.

The most successful outer space private companies, up to nowadays, are *SpaceX*, founded by Elon Musk in 2002; *Blue Origin*, founded by Jeff Bezos in 2000; *Virgin Galactic*, founded by Sir Richard Branson in 2004; *Rocket Lab*, founded by Peter Beck in 2006. Only in 2022, SpaceX has increased its revenue by 44%, starting with 2 and reaching 4 billion US$, and increasing again from 8 billion in 2023 to 13 US$ billion in 2024[5]. While Blue Origin's total revenue peaked at 42 million US$ in 2023[6].

Having said this, the main concern regarding this sector is related to its long-term successful growth, due to sustainable issues arising from the lack of immediate management, effort and action against space debris formation.

1.1 Space Sustainability in the Space Economy Sector

1.1.1 Selected Literature

Due to the increasing variety of papers on Space Sustainability, in the following paragraphs, I will be considering a selected group of academic papers that represent all the aspects to be considered while analysing the state of the art of the topic.

[3] ESA while talking about space industry future https://space-economy.esa.int/article/33/what-is-the-space-economy#:~:text=The%20Space%20Economy%20is%20defined,and%20utilising%20space.%5B1%5D

[4] Reference to the emerging trends https://www.spacefoundation.org/2024/07/18/the-space-report-2024-q2/

[5] Data showing SpaceX increased revenue in 2022 https://sacra.com/c/spacex/ , https://payloadspace.com/predicting-spacexs-2024-revenue/#:~:text=Payload%20projects%20that%20SpaceX's%20revenue,M%20customers%20to%203.8M.

[6] Source for Blue Origin total revenue in 2023 https://www.zippia.com/blue-origin-careers-1417898/revenue/#:~:text=Blue%20Origin's%20revenue%20is%20%2442.8%20million.&text=Blue%20Origin%20has%203%2C500%20employees,was%20%2442.8M%20in%202023.

Topic	Title	Main Insights
Market-based instruments	Market-based instruments to incentivize more sustainable practices in outer space	This document argues that market-based instruments could lower space debris levels (using economic tools to increase sustainable practices).
Future scenarios in the debris environment	Assessment of orbital capacity thresholds through long-term simulations of the debris environment	This document assesses the possible scenarios in which the space economy sector will fall in, by comparing no-future-launches (the most sustainable scenario) to the current state.
Paradox	The Space Sustainability Paradox	The document states that the increased levels of spacecraft production and orbital launches are increasing the debris creation, but at the same time the new discoveries are supporting the Sustainable Development Goals (SDGs).
Rating	The Space Sustainability Rating (SSR) System	A sustainability rating system based on six dimensions: type of mission, DIT, COLA, Data Sharing, design and operation standards, and external services.
Mining in outer space	Mining beyond earth for sustainable development: Will humanity benefit from resource extraction in outer space?	This document states that mining in outer space might provide both a positive impact for lowering the pressure on Earth's resources provision and a negative one in the management of property rights in outer space.
Management of debris risk	Space environment management: Framing the objective and setting priorities for controlling orbital debris risk	The document argues that Space Situational Awareness (SSA) and Active Debris Removal (ADR) services must coexist to provide the floor for a sustainable future of the sector.

Regulative Approach	The cost of (Un)regulation: Shrinking Earth's orbits and the need for sustainable space governance	This paper argues the fact that sustainability in the space sector will not come only from technological resolutions, but also from regulative provisions.

Table 1: Academic Papers on Space Sustainability in the Space Economy Sector

These papers are taking into account economic, technical and regulative perspectives on the matter. To introduce the topic of sustainability in space, I will be covering these points of view.

Firstly, I will be focusing on what sustainability in space means, defining it according to the present situation of the sector and literature (paragraph 1.1.2).

Secondly, I will be talking about the main issue of the next century for the space economy sector: space debris (1.1.3).

Therefore, in paragraph 1.1.4, I will discuss the possible available instruments to tackle the debris issue. To add to this, in paragraph 1.1.5, I will give an insight into how regulatory approaches might contribute to lowering the high level of space junk surrounding the planet. In the following paragraph, in 1.1.6, private companies providing remedies for the above-mentioned issue will be analysed.

In the 1.1.7 paragraph, I will be giving a historical background up until nowadays on the regulation of outer space, mentioning also the management of the resources and the property rights that might represent an issue, providing a further look into the present and future situation of space sustainable practices.

In paragraph 1.1.8 I will be analysing the Space Paradox, which will consider the trade-offs between space exploration for human development and the drawbacks that arise from these practices in terms of sustainability on Earth.

To follow, in paragraph 1.1.9 the focus will be on the 18th SDG, “Life in Space” or “Space for All”.

To conclude the first chapter, in paragraph 1.1.9 I will be providing a measure to possibly understand the level of potential danger of collision in outer space with the objects already present in it, after the analysis of the present literature. The measure works according to the number of trackable objects and the average time of permanence of said objects in a certain area.

1.1.2 Space Sustainability Definition

Our overall Planet's Ecosystem must consider Space Sustainability as the main topic for the next century. The reasons are explained in further detail in chapter 1.1.3, but broadly speaking they concern Space Debris, and it is closely related to Space Safety as well.

Outer Space Safety can be either seen from a national point of view or an international one. The first one considers the well-being of the human capital that is involved in space activities, which could be facing at a higher rate a series of harmful events while on board (e.g. collisions that entail life-threatening issues) and possible threats to public safety of the country while performing both launches and re-entry.

The international perspective instead studies the issue of Space Safety through the lenses of what possible threats would arise in terms of environmental protection (atmospheric pollution and ground pollution due to launches, nuclear contamination…).

At a national level, the issues might fall under the scope of application of already existing laws, on the other hand, from a global point of view the regulatory framework for outer space is nowadays lacking an international treaty that emphasizes the "global legal pluralism" that space itself is forcing the market to account for.

Sustainability, not only in terms of strictly environmental-related issues but also in terms of the long-term possibility of carrying out activities in outer space, is therefore compulsory.

The first attempt to highlight this important concept was made by the UN Committee on the Peaceful Use of Outer Space (UN COPUOS), in 2018. The committee provided for the first time a definition of "Space Sustainability": "*The ability to maintain the conduct of space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes, to meet the needs of the present generations while preserving the outer space environment for future generations*"[7].

This definition entails a series of actions that might be considered, following two distinct paths. A normative approach, such as the establishment of a Space Sustainability Rating

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[7] Definition of Space Sustainability
https://www.unoosa.org/res/oosadoc/data/documents/2018/aac_1052018crp/aac_1052018crp_20_0_html/AC105_2018_CRP20E.pdf

(SSR) system or an international mitigation program of space debris concentration removal. The systems might also entail a cap on the maximum level of space pollution for each of the member states participating in the space environment. These ex-ante approaches might be supported by a more scientific perspective, such as measures able to capture the actual level of possible danger arising from space debris concentration of a specific zone in Earth's Orbit. Numerous studies conducted by ESA on the incidence of harmful events, related both to debris creation and fragmentation, have shown that from 1957 until today a total of 630 explosion-like events created a total of 33 thousand orbital debris of 10cm and larger and a total of 130 million of space debris between 1mm and 1cm.

The issue not only concerns non-human made present objects (i.e. fragments of rocks), but also relates to the potential collisions between in-orbit entities' spacecrafts, as happened in 2019 between ESA and SpaceX. A collision avoidance manoeuvre was executed by ESA due to the presence of a large constellation of SpaceX: "The Agency's Aeolus Earth observation satellite fired its thrusters, moving it off a potential collision course with a SpaceX satellite in the Starlink constellation. Constellations are fleets of hundreds up to thousands of spacecrafts working together in orbit. [...] As the number of satellites in space dramatically increases, close approaches between two operated spacecraft will occur more frequently. Compared with such 'conjunctions' with space debris – non-functional objects including dead satellites and fragments from past collisions – these require coordination efforts, to avoid conflicting actions"[8].

This was one of the examples that best represents what future scenarios would look like if the Space Environment is not taken care correctly.

1.1.3 Earth's Orbit Debris Problem

According to the present literature, the scientific world has been showing increasing concern about the rise of numerous objects in Earth's Orbit. Space traffic is one of the main causes. It especially due to an augment of active satellites present in Earth's orbit, according to Statista's data: from 2020 with 2270, to 2022 with 6905 active satellites[9]. According to

[8] Here the article on the event registered in September 2019 https://www.esa.int/ESA_Multimedia/Images/2019/09/Predicted_near_miss_between_Aeolus_and_Starlink_44

[9] Statista data on active satellites from 1957-2022 https://www.statista.com/statistics/897719/number-of-active-satellites-by-year/

UNOOSA, there must be approximately 8261 satellites in the Earth's Orbit (in 2022), but only 4852 satellites are active[10].

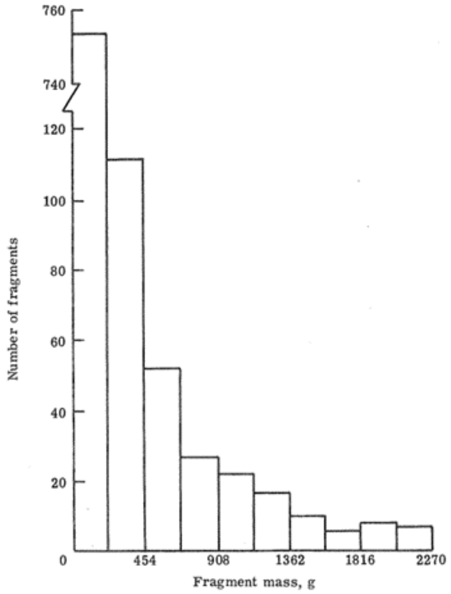
The U.S. military[11] has shown data, provided by its orbital tracking network, of roughly 23 thousand objects that have a diameter of 10cm or larger. For the objects measuring from 1-10cm, the estimation amounts to 500 thousand. Even though this last data might sound not that alarming due to their small dimension, we should consider the fact that these trackable objects are moving at an average speed of 10km/s[12], resulting to be a lethal threat to any other object, especially if carrying human lives.

To understand the types of impact of a collision between space debris and a spacecraft object, NASA performed numerous experiments. The data of explosions were taken from the *Langley Research Centre*[13] and the ones regarding explosions were taken from the registered accidents during history.

These tests were aimed at the estimate of how many fragments would be created when an explosion or a "hypervelocity impact" occurs[14].

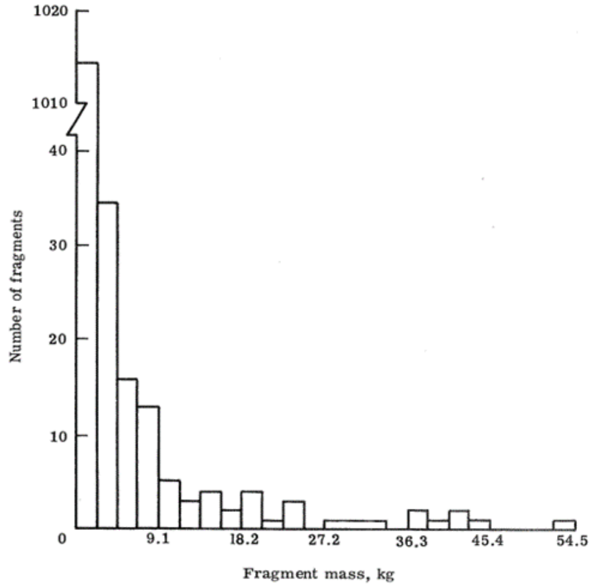
Two tests were made: one was shooting a 1,6g steel object of 0,56cm diameter into the spacecraft's wall, at 3km/s; the second test was shooting a 0,37g aluminium object of 0,56cm diameter, at 4,5km/s. the mass distribution of fragments resulting from these two tests was the following:

[10] Active vs Non-Active Satellites https://www.geospatialworld.net/prime/business-and-industry-trends/how-many-satellites-orbiting-earth/#:~:text=According%20to%20UNOOSA%20records%2C%20there,record%20of%20the%20operational%20satellites.
[11] U.S. available data https://swfound.org/media/206407/swf_space_sustainability_booklet_2018_web.pdf
[12] Average speed of space objects https://www.mckinsey.com/featured-insights/mckinsey-explainers/what-is-space-junk#:~:text=Space%20junk%20can%20be%20dangerous,speed%20would%20be%20even%20higher.
[13] LRC https://www.nasa.gov/langley/about-langley-research-center/
[14] Mass distribution graph and other details on the following document https://ntrs.nasa.gov/api/citations/19760007896/downloads/19760007896.pdf



(a) Fragments with mass less than 2270 grams.

Figure 6.- Mass distribution of fragments from tank explosion from Atlas missile.



(b) Fragments with mass less than 54.5 kg.

Figure 6.- Concluded.

Image 1 and 2: Distribution of Fragments by NASA

Both mass distributions show how most fragments created by the collisions were included in a range of dimensions from 0 to 2270g, showing how much of a collision can create such small and untraceable objects, that due to their high speed are still very dangerous.

Therefore, the current state of Outer Space Environment would inevitably pose a threat to Space Safety and ultimately to Earth's Safety as well: any collision can potentially start the "*Kessler Syndrome*"[15]. The latter was proposed by a NASA scientist, Donald J. Kessler, who stated that any collision in LEO (Lower Earth's Orbit), due to the high population of space debris, could create a cascade for which the fragments created collide with other objects, and so on.

According to the academic paper of Romain Buchs et al.[16], the Kessler Syndrome has already started its process, and we might as well have passed a tipping point. This thesis is argued in the *Assessment of Environmental Capacity Thresholds through Long-Term Stimulations*[17] paper. Considering three variables: Launch traffic, Explosion rate, Disposal rate, and two

[15] Definition of Kessler Effect https://en.wikipedia.org/wiki/Kessler_syndrome
[16] Market-based instruments to incentivize sustainable practices https://www.sciencedirect.com/science/article/pii/S1877343522000999
[17] Academic paper Letizia F. et al. https://www.sciencedirect.com/science/article/pii/S0273117722004793, database from https://discosweb.esoc.esa.int/

scenarios Extrapolation (business as usual) and No More Launches (stopping any launching activity), the conclusions are depicted as follows:

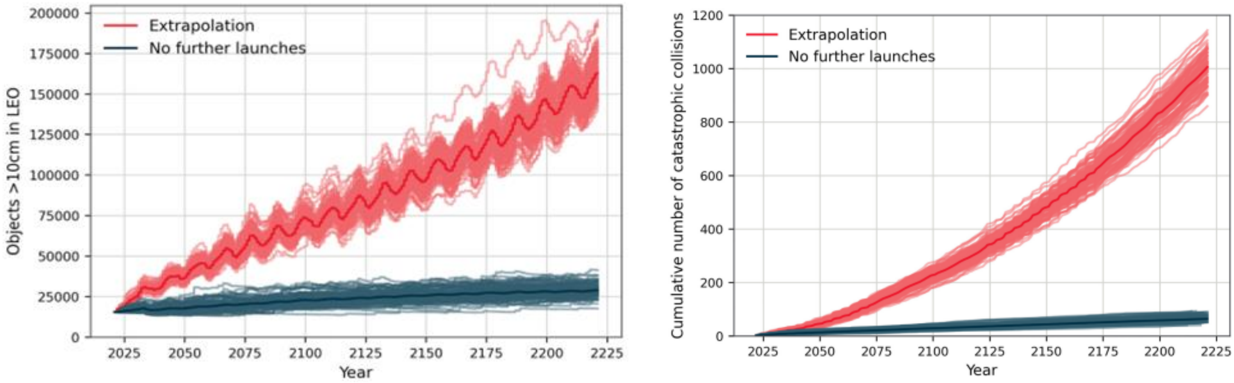


Image 3 and 4: Scenarios for Upcoming Years regarding the Increase of Objects and Collisions

1.1.4 Available Instruments to Tackle Debris Crisis

Currently, to tackle space debris issues, there are three main groups of approaches.

The first one is related to the active removal of space junk (ADR), the second one relates to technical approaches, and lastly, the market-based instruments. Both last two categories could fall within legal frameworks as well (i.e. European Space Law).

For the safe removal of space debris, the two broad categories of available mechanisms are: "atmospheric drag" or "direct retrieval".

The first one is initiated by the presence of the higher layers of the atmosphere which then captures the objects and takes them towards the Earth, but it can take either days or millions of years. The second one, instead, is based on active removal (ADR). The mission *ClearSpace-1*[18] will be the first space mission by ESA to actively remove debris, and its launch is planned for 2026. This project has been developed with a Swiss Startup *ClearSpace.*

ClearSpace mission focuses on the protection of human-led space activities through the restoration of the outer space environment from space debris. Even though space debris would autonomously re-enter the atmosphere after a century, the LEO region (Lower Earth's Orbit), around 700km of altitude, is extremely packed, endangering any activity or mission carried out in that area. *ClearSpace* recent collaboration, other than the one with ESA, was

[18] ClearSpace-1 mission ESA - ESA commissions world's first space debris removal

with the UK Space Agency, signing a contract for achieving the second phase of the project of 2 million £.

As the latest press release of *ClearSpace* says: "*The UK Space Agency is enabling UK companies to obtain the first-mover advantage in the emerging in-orbit services (IOS) market, which is forecast to reach $14.3 B in cumulative revenue by 2031"*[19]

If we consider the potential revenue forecast, by starting the first mission for active debris removal, ESA is following the right path. The target of the *ClearSpace-1* will be *Vespa* (Vega Secondary Payload Adapter), a space object with dimensions similar to a small satellite, now in a region between 800 and 600km of altitude, for a total of 112kg[20], of which we will be able to see the outcome from 2026 on.

Aside from ADR, some technical approaches can help to face the future debris crisis.

The SSA, Space Situational Awareness, the Space Traffic Coordination or Management (STC or STM), and the Space Environment Management (SEM).

The first practice, the SSA, focuses on the identification and on tracking of space objects, trying to avoid threats to human-led activities. It is part of the *EU Space Programme*[21], which is one of the first international frameworks, working at the European level that is trying to provide a harmonized approach to the space sectors' challenges. It has many components, such as Copernicus, EGNOS, Galileo, GOVSATCOM, IRIS^2, and SSA. The first component is an Earth Observation programme, the EGNOS component provides a reliable network for signals, the Galileo system can give precise information of the positions and timing to its users, the GVSATCOM provides safe communication tools, and IRIS^2 another service provider for interconnectivity goals.

SSA, instead, is defined as follows: "*A holistic approach, including comprehensive knowledge and understanding, of the main space hazards, encompassing collisions between space objects, fragmentation and re-entry of space objects into the atmosphere, space weather events, and near-Earth objects*"[22].

It aims to track and identify space debris, to understand the possible risk of any natural space objects that could reach the Earth's atmosphere and reach the surface, and lastly to minimize the risk of dangerous impacts by solar activities by controlling the general space weather.

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[19] ClearSpace press release ClearSpace secures a major UK contract to help clean up space - ClearSpace
[20] Archive on Vespa-removal mission ESA - ClearSpace-1 - Archive
[21] EU Space Programme https://www.euspa.europa.eu/european-space/eu-space-programme
[22] Definition of SSA https://defence-industry-space.ec.europa.eu/eu-space-policy/space-situational-awareness_en

SSA is also essential because of the constant monitoring of new radars or telescopes in the environment, distribution of new possible enhanced propagation models, and creation of screening tools for collision risks or maintenance of space objects. Other than this, a crucial contribution to the debris issues the SSA system finds a way to measure direct lethal non-trackable objects, which is one of the most dangerous categories of space junk, due to its unpredictability.

To continue, STM is a means to ensure safety and sustainability in space traffic. This method will be used in the next years as a consultation mechanism. Using STM as a basis, some requirements will be created for the European member states: binding obligations and soft law (e.g. guidelines) will be elaborated on the STM approach and it will create a higher level of cooperation among nations[23].

New regulations, directives or technical standards might be expected to enter into force in the next years, at the European level, creating the opportunity for the Union to be the future leader in the space sector, from a regulatory point of view, and all the benefits coming from the "first mover" label.

As for the latest press releases in the literature, the Internal Market Commissioner Thierry Breton has expressed his concern, and the one of Europe, for the creation of common frameworks and rules to create a Single European Market for space[24]. The future proposal for *European Space Law*[25] was expected to be seen in March 2024 but was postponed for release to the end of 2024, and it will focus on three main domains: safety, resilience and sustainability.

Due to the ongoing space debris crisis, Breton said that there must be a specific policy for launches, this is not limited to the launching activity only, but also to the entire LCA of a launch (namely the design of the spacecraft, the fuel used…). The future framework will of course be based on the sustainability of these practices, bringing new chances for opening innovative market fields, such as providers of hyper-specific technologies, modernisation of the old sites through new designs, alternative methods for the disposal of old materials used in the past, and many more breakthroughs.

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[23] STM analysis https://defence-industry-space.ec.europa.eu/eu-space-policy/space-traffic-management_en
[24] Press release of Thierry Breton and the European Space Law https://www.euractiv.com/section/global-europe/news/eu-looks-towards-future-space-law-launcher-alliance-and-threat-awareness-strategy/
[25] European Space Law https://www.europarl.europa.eu/legislative-train/carriage/eu-space-law/report?sid=8301

The last approach, the SEM, relies on the actions of players in the outer space environment. It aims to prevent new debris creation, providing the ground for a sustainable future in space. The actions might be of a different nature, but both encompass debris mitigation and remediation.

In the first category, we consider: responsible design and operations (prevent debris release, prevent explosions and collisions, management of re-entry in the atmosphere); establishing and defining guidelines; monitor and ensuring compliance. In the second group instead, we find: prevention from creating new debris, active debris removal, just-in-time collision avoidance.

The three approaches, SSA, STM and SEM constitute the Space Safety Framework: the basis of the system is rooted in the SSA information for "orbit predictions and conjunction notices", the SEM performs both prevention and removal activities based on the said information, and STM serves for creating effective collision avoidance strategies.

As reported in the academic paper of T. Maclay et al.[26] the biggest risk arises whenever the objects considered are between 1cm-10cm in size, because the prevention (SSA) and management (STM) approaches in the Space Safety system cannot track them, representing the greatest risk especially in the LEO regions.

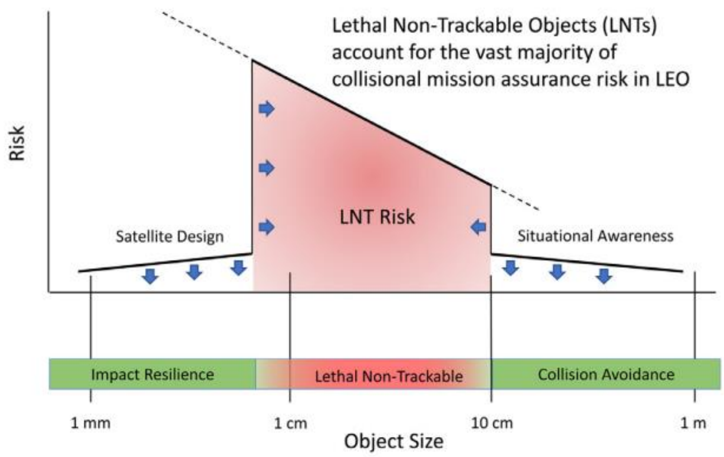


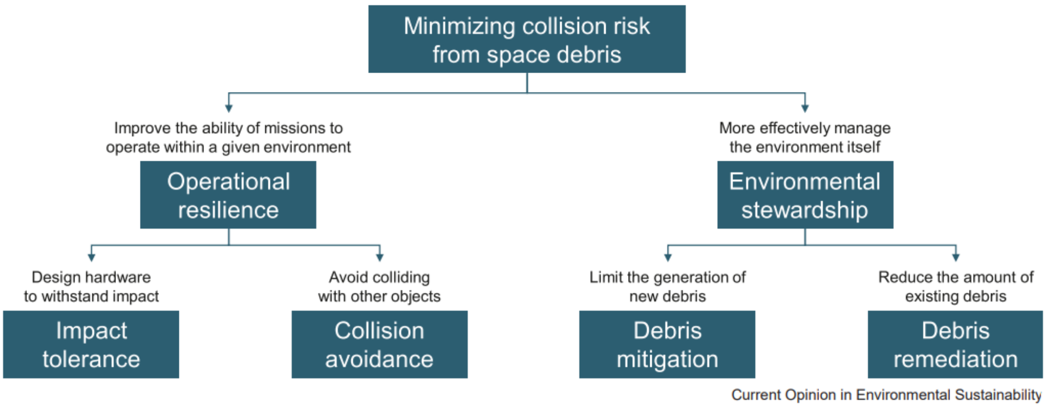
Image 5: Risk in LEO

As it is clear from the graph, the Situational Awareness method can inform the space players of imminent collisions with objects ranging from 10cm to 1m, avoiding potentially deadly

[26] Risk per object size https://www.sciencedirect.com/science/article/pii/S2468896720301415

impacts. Instead, for objects ranging from 1mm to 1cm the design of the spacecraft might be the best tool to face the threat of an impact. The resilience of the materials and of the structure could be standardized through guidelines, for example, a proposal for standardisation within the framework of *European Space Law*.

So, the conclusion of the paper is that both SSA and STM are not sufficient alone: SEM must be implemented as the main and possibly first solution to this kind of risk.



Graph 1: Minimizing Collision Risk

Aside from the technical approaches, the last group of available instruments to face the debris issue relates to market-based instruments. Those could be implemented within the European context as integrative tools to reach a harmonised and effective level of sustainable practices in space, at least in Europe. The following mechanisms are the ones recorded in the available literature.

Fees such as taxes or charges for a fixed amount of pollution must be considered as the most effective ones. I would be suggesting a distinction between the two environments: a tax for the level of CO2 emissions within the atmosphere during launch, and a level of pollution of the LEO or in general space environment for the debris creation level. The distinction might be difficult to assess in the second environment because it would entail a given harmful pollution level as a reference. A solution could be using the SD_i measure: an amount of maximum tolerable danger is fixed and according to it a tax is calculated.

As the scientific community is proposing from 2020, an annual "orbital-usage fee" for each satellite orbiting should be put in place. The annual fee would be about 235 thousand US$

per satellite[27]. The tax would target orbiting objects, which are much more dangerous for the rest of the population in the same area, therefore different from a "launch fee". A tax for before-launching activities has a different weight, and it's lower due to the relatively lower risk. This tax would be collected by the country where the spacecraft is registered. The additional burden of atmospheric and space pollution that is endangering the community will be indeed on the shoulders of the pollutant and might have different weights according to the additional risk added to the environment.

There are contrasting opinions on the possibility of future taxation systems. Especially if we consider on of the emerging force in space exploration: India. Nirmala Sithataman, the leader of the Bharatiya Janata Party, at the 50th meeting of the GST (Good and Services Tax) Council said: "Satellite launch services that are being provided by private organisations shall not be levied GST"[28]. This market-based instrument might in some cases increase the disparities, if the differences according to the North and South of the world are not considered. Therefore, a taxation system is still a very controversial topic in this field.

On the other hand, another type of instrument might avoid this effect: a subsidy. The support would be for entities satisfying some requirements or minimum standards and might be provided at a national level, namely in terms of sustainable design of the spacecraft or alternative fuels used, and so on. But this has only seen his proposal stage.

[27] Annual per satellite tax https://news.sky.com/story/orbit-tax-proposed-to-tackle-growing-problem-of-space-junk-11994748#:~:text=Instead%20they%20propose%20an%20international,by%202040%2C%20claim%20the%20researchers.

[28] Report on the GST Council https://www.businesstoday.in/latest/in-focus/story/gst-exemption-to-private-satellite-launch-service-firms-a-huge-financial-incentive-to-boost-growth-industry-389459-2023-07-12?onetap=true

1.1.5 Regulatory Approach to Tackle Debris Crisis

As history has shown, the space sector was always considered to be of public domain, since the main players used to be governments. But, due to the increasing privatisation of the sector, the need for harmonised practices is increasingly important. Legislative frameworks or international standards that are officially worldwide accepted might be the solution.

In these terms, a *Space Sustainability Rating* (SSR) was studied and proposed by the World Economic Forum's Global Fortune Council on Space Technologies. It is a rating system for which six types of data categories are collected for each new mission: type of mission; detectability, identification, and trackability (DIT); collision avoidance capacities (COLA); data sharing; design and operations standards; and external services[29]. According to what Emmanuelle David, the Vice-President, and Treasurer of the organization, said, the system is a way to create a sustainable environment within the space sector context, by establishing a disclosure regime for each new space mission in the sector.

It is a system that can provide a real representation of the level of sustainability in terms of design idealization, the activities performed by the undertaking, and the end of life of the mission[30].

The overall score will reflect the different stages of a mission and its sustainability. The labels have been divided into four groups: bronze, reflecting 40%-55% of sustainability; silver, reflecting 55%-70% of sustainability; gold, 70%-80%; and finally, platinum, with 80%-100% of sustainability level.

Bonus scores might be assessed if the undertaking is performing certain activities that do not belong to the rating system activities to be rated, but this does not affect the given overall label, but they are shown as additional "stars" to the label (one star is 25%-50% of additional activities in line with sustainability, and so on).

The indexes considered while making the computation are the following: module index, DIT, COLA, Data Sharing, ADOS, and External Services (for bonuses). According to the index considered a weight is given, after having performed a verification assessment of the module evaluation.

To the first index, the module index, is given the highest weight. It considers the ability of the entity to use sustainably the portion of space area in which it will perform the activities related to the mission, in the worst-case scenario it will be creating "harmful physical

[29] ESA perspective on SSR system ESA - Making space more sustainable, one rating at a time

[30] Rating system of SSR https://spacesustainabilityrating.org/the-rating/

interference” with the present population of the area. This index is studied and computed according to the characteristics of the mission, the ability to avoid collisions, and the method of disposal after the mission has ended.

The second index DIT, instead, reflects the capacity of the entity to track the small objects that are part of the mission and will be used for its activities, which might result difficult to track through a general surveillance system, but that could create a potential danger for the other population present in the same area.

The third index, COLA, considers the strategies used by the undertaking to avoid other objects in a highly populated environment, performing preventive actions to avoid additional creation of space debris.

The fourth index assesses the ability and the technologies of the examined entity to provide mission data, and the quality of the latter, to the various communities present in the area. It is needed to understand the level of contribution to “spaceflight safety” that they are providing by simply informing other actors of their activities or positions. Some undertakings might not want to share information due to the level of sensitivity of the data, resulting in a higher level of risk for others.

The second, the third, and fourth indexes are given a medium weight of importance.

The fifth index, the ADOS, is providing the assessment of the ability of the entity to avoid space debris creation. Creating a standardized procedure to successfully reach this goal might be the solution, as proposed by the SSR system. This index has a low weighting in the system.

The whole system is based on the fact that the data sources are reliable, and the level of verifiability is assessed by technical authorities. Therefore, the quality of the data provided, and the level of verification provided have an impact on the overall SSR system.

Therefore, a weight to the verification is attached. This could be the main driver for transparency and thus encourage the undertaking to take real actions against unsustainability in space.

This process is performed through the compilation of questionnaires by the entity, and to each verified response of the undertaking a weight is given.

The first category represents the first statement of the entity, usually assumed to be reliable without further verification needed. The factor associated is 0.5.

The second category is verified, and technical documentation is provided to support the quality of the data. To provide an example, the SSR system is asking to provide the covariance of their orbit determination, for the questions regarding the collision avoidance module. These data might be verified by third parties involved in the mission, such as launch providers. To this category, a factor of 0.6 is given.

The third group considers the provision of documentation that was submitted to either governments or non-profit organizations that will make the data available to the public. This step is only certifying at a formal level of transparency. The factor given is of 0.8.

The last category is probably the most important one: with a factor of 1.0, the aim is to provide a verified assessment of the technical credibility information provided by third parties, whether they be governments, regulators, or technical qualified entities.

All of these mechanisms of verification might increase in the future due to both the development of the sector itself and the stricter requests in terms of transparency.

It would contribute to reducing additional space debris and create equal opportunities for new entries in the field. Governments shall help the private enterprises to follow these sustainable practices, in terms of transparency and disclosure, by establishing a certain threshold of sustainability level.

At the national level, these dynamics would mostly concern the private sector, influencing the annual sustainable reports, resulting in positive reinforcement of sustainable practices, while not affecting economic outputs.

To continue the analysis of the normative-oriented solutions, mitigation programs should be mentioned, such as ESA's most important ones: *Clean Space Initiative* and *Zero Debris Approach*.

The first one started back in 2009, and its main goal is to study and decrease the type of environmental impacts for space missions, throughout their whole life cycle, while trying to find the optimal level of production of debris to consent sustainable activities to continue. Additionally, the aim stated is to create a well-functioning system for which the removal of space debris lies within the application of the model itself, by following three main methods: eco-design, management of end-of-life, and in-orbit servicing.

The first one is adopting an ex-ante perspective, meaning that the design of the mission itself should consider sustainable practices such as compliance with environmental regulations or the establishment of the life cycle assessment.

The second method also considers sustainable practices in terms of prevention, it tries to set standards for deorbit activities, for discharging of energies, and any sort of action that might introduce new debris to the space environment.

The third method, lastly, considers an ex-post perspective, which entails the active removal of already-present space objects and space junk from a certain area[31].

The second initiative, instead, is a very ambitious program that sees as its main goal to reduce to zero space debris by 2030[32]. The project is considering a large variety of actors and tries to combine technical targets with principles that would create an efficient Zero-Debris Roadmap, towards the goal of 2030.

Both initiatives show a strong need for international cooperation because the root of the problem of space sustainability is affecting the entirety of the participants in the sector, differently from other traditional sectors. This might mean both a higher risk for the level of complexity of international cooperation, but also a boost for finding optimal solutions to the common problem.

[31] Clean Space Initiative Program Clean Space (esa.int)

[32] Zero Debris Approach ESA - The Zero Debris Charter

1.1.6 Private Companies Contributing to the Solution

In this Space Debris Crisis, some private companies have found a new field of the market for which they perform the so-called Active Debris Removal (ADR). The most famous ones are the following: with an estimation of an annual revenue of 126 million in US$ per year, *Astroscale* (based in Japan); with 173 million US$ per year, *Surrey Satellite Technology Ltd* (UK); *Northrop Grumman* (US) with 39 billion US$; *Kall Morris Incorporated* (US), following more of a start-up setting, with fundings of 5 million US$.

Here follows the analysis of the above-mentioned companies, to understand the developments of the private sector in the field of space sustainability active-removal activities.

Astroscale company was founded in 2013, it was one of the most pioneering companies to ever consider space sustainability as a fundamental goal in the private space sector. Their vision is strongly rooted in the definition of space sustainability provided by the UN COPUOS, so considering the future generations within the framework of actions performed today in space. Their mission is based on the creation of innovative technologies that could lead to a new sustainable use of space.

The company provides four main services: end-of-life (EOL), active debris removal (ADR), life extension (LEX), and Space Situational Awareness[33].

The vision on sustainability is linked to satellite optimisation design to balance costs and reliability, pre-launch support for compliance with regulations, operational set-ups aiming to prevent non-trackable debris, and lastly protect Earth's orbit from accumulation of space objects and possibly restoration of initial natural conditions.

The tools through which they would want to obtain said goal are technological ones. The technologies proposed by the company could be able to reach high expectations. The said technology is called *ELSA-M* (EOL Service by Astroscale-Multiple), and it is the world's first service debris removal for clients that have produced space junk while on their missions. The spacecraft can grant the tracking of space objects, docking of the object, and release to reduce the re-entry time in the atmosphere[34].

The *ELSA-M* technology novelty might be considered the leader in the space sector, since it aims for the long-term sustainability of space, by being able to remove safely space debris, for multiple clients.

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[33] Services provided by Astroscale https://astroscale.com/services/end-of-life-eol/
[34] Spacecraft ELSA-M by Astroscale https://astroscale.com/elsa-m/

The ADR activity grants two types of services: *ADRAS-J* and *COSMIC*[35].

The first type is working through the same programming of *ELSA-M*, and the second one, while still using the same methods, is considering some additional improvements.

ADRAS-J is a space debris removal mission to demonstrate the possible capturing methods of space debris. Instead, *COSMIC* is a project that tries to be the first mover of a potential commercial framework for in-orbit services (IOS).

The third service considered, the life-extension service[36], is based on the fact that the substitution of already-established private or public spacecraft in space is far more expensive than the costs of reparation. The issue with restoration of damaged bodies is very difficult to achieve, due to the high-level technology requested by the environment where the reparation will take place. Namely, the amount of money needed to launch a satellite into a geostationary orbit is 10 to 20 thousand US$ per kilogram[37]. In the case of Astroscale, the company is relying on the ongoing studies of the new subsidiary Astroscale U.S. which will be focusing on the creation of the Life Extension In-Orbit (LEXI) Mission[38]. The service provides refuelling, repair, relocating satellites that are close to their end-of-life phase.

Lastly, the fourth service takes the name of Space Situational Awareness (SSA), which aims to study the activities in orbit. An important subset of the SSA is Space Surveillance and Tracking (SST), which focuses on the tracking of both active and inactive objects. The technology used is based on radars or telescopes[39].

To continue the analysis, the *Surrey Satellite Technology Ldt* was founded in 1985 in the United Kingdom, and its main goal was initially to build small satellites, but later also endorsed the space debris removal practice to which our interest goes.

In 2018, the "*Remove Debris Satellite Platform*" demonstration took place, and it was financed by the European Commission, according to the European Union Seventh Framework Programme[40]. The satellite's mission was to demonstrate four types of active removal activities: on board net to capture debris, identification system to track space debris,

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[35] ADR service and technologies used by Astroscale https://astroscale.com/services/active-debris-removal-adr/
[36] LEX service by Astroscale https://astroscale.com/services/life-extension-lex/
[37] Cost of lauching a satellite https://satcomtalk.com/the-cost-of-satellite-communication-an-in-depth-analysis/
[38] Astroscale U.S. https://astroscale-us.com/
[39] Astroscale SSA system https://astroscale.com/services/space-situational-awareness-ssa/
[40] Debris Removal program by Surrey Satellite Technology Ldt https://www.sstl.co.uk/space-portfolio/launched-missions/2010-2019/removedebris-launched-2018

catching the object through a stick with a panel at the end and lastly redirecting the object's trajectory towards the atmosphere[41].

The level of international cooperation for this mission was very high, the consortium consisted in UK, France, Germany, Netherlands, and South Africa components. It is clear that within the space sector, this kind of cooperative programs will be acquiring more importance, making this company a possible leader in the sector.

The third company analysed is the *Northrop Grumman* multinational aerospace and defence technology company. It was founded in 1994, firstly providing aerospace services and secondly expanding its mission towards outer space. The company's perspective on sustainable practices in space is not only based on active removals but also on extending the functional life of a satellite.

Additionally, as the Vice President of Operations and Business Development for Space Logistics LLC Joe Anderson said: "Eighty percent of the mass of a satellite is just to support a launch. Imagine what would happen if we could assemble satellites in orbit? Rather than throw away satellites, we can make them reusable."

The direction towards which the company is aiming could be the most interesting one yet. Space debris creation comes mostly from the initial stages of a launch, as explained above, which brings an explanation to the current situation of the Lower Earth's Orbit region (LEO). The plan is still just an idea, but as Anderson has reportedly explained, robots could be creating satellites with 3D printers, requiring less material to be launched, while increasing space sustainability[42].

Following the trends, not only the privatization of outer space has risen from the exploration activities, but also, from those ancillary businesses that are relevant to the exploration itself. Therefore, from an economic point of view, the market could be exploited with blue ocean strategies.

Although this might sound promising, there are some entry barriers to be considered, the most important one is the cost coming from specialization of knowledge in technologies needed in such extreme environments. According to the official data given by Bloomberg, to remove just 1kg of space debris, 900 thousand US$ would be needed. As written in the article, the cost of removal would be the least expensive option to consider while trying to

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[41] RemoveDEBRIS project https://www.surrey.ac.uk/news/harpoon-successfully-captures-space-debris

[42] Ideas for sustainable future of space sector https://www.smithsonianmag.com/innovation/robots-may-soon-fix-fuel-satellites-in-space-180979659/

mitigate the effects of space debris concentration. To report the mentioned example, in March 2023 a corps of space junk was aiming toward the International Space Station, endangering the astronauts' lives. The risk was already being tracked down; thus, an emergency manoeuvre was being put in place to deviate the trajectory of the object. These operations costs around 1 million US$, due to the expensiveness of the propellant.[43]

As these accidents keep happening, the initiatives directed at mitigating the high concentration of space debris will become mandatory, not only from an ethical point of view but especially from an economic point of view: the cost of inaction is higher than the cost of actively remove the space junk and to track possible objects to avoid possible collisions.

The current state of the art is therefore providing a huge opportunity for creating a link between analysis of the environment, mitigation, and regulation to tackle the future "debris crisis".

1.1.7 Sustainability: between Mining and the Regulation of Outer Space

Space Sustainability is not only relative to human activities but also relates to the environment itself, as an ecosystem with its own rules. Therefore, human operations, if not regulated, might be impacting the overall environment.

According to the paper by J.A. Dallas et al[44], mining in outer space might be the next step in terms of human-led activities performed in space. The reasons behind space extractions are that particular minerals and also water is available in the ecosystem.

Water might be useful both for sustaining life on-site, but also could be used as a "rocket propellant". To add to this, different minerals are found that are scares on Earth: The Platinum Group Materials (PGM), usually found in the asteroids as well.

These resources might be subject to various political and international frictions, due to a not fully developed level of regulation regarding outer space activities. The main document upon which the outer space legislative background is based is the *Outer Space Treaty*, by the United Nations, in force from 1967[45]. This legislative framework is based on the principles of equal opportunities for exploration carried out by all states, entailing the principle of non-

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[43] Data on space debris removal https://www.bloomberg.com/opinion/articles/2023-03-23/our-space-junk-problem-just-got-a-cheap-solution

[44] Academic paper on resources of Outer Space and the relevant sustainable practices and implications of it Mining beyond earth for sustainable development: Will humanity benefit from resource extraction in outer space? - ScienceDirect

[45] Principles on Governing the Activities of States in the Exploration and Usage of Outer Space The Outer Space Treaty (unoosa.org)

appropriation, and the principle of peaceful usage. This comprehends also mutual help, as the following article says. Art. 5 states that: "*States Parties to the Treaty shall regard astronauts as envoys of mankind in outer space and shall render to them all possible assistance in the event of accident, distress, or emergency landing on the territory of another State Party or the high seas*."

The damages that are done by space objects are a liability for the states that have started the missions, as Art. 8 states: "*A State Party to the Treaty on whose registry an object launched into outer space is carried shall retain jurisdiction and control over such object, and any personnel thereof, while in outer space or on a celestial body*."[46] This last point is particularly relevant because it entails space debris accumulation and unsustainable practices performed by the states.

In 1968, the *Rescue Agreement* entered into force[47], and its aim was to expand the concepts stated in the art. 5 and 8 of the Outer Space Treaty, by providing legal agreements on the help of astronauts in distress and in the recovery of any space object.

A further step was taken in 1972, with the *Liability Convention*[48], based on the principle of liability for damages caused by space objects to elaborate the art. 7 of the Treaty: "*Each State Party to the Treaty that launches or procures the launching of an object into outer space, including the moon and other celestial bodies, and each State Party from whose territory or facility an object is launched, is internationally liable for damage to another State Party to the Treaty or its natural or juridical persons by such object or its parts on the Earth, in air or outer space, including the moon and other celestial bodies.*"

The convention aim was to establish a liability regime, for which a launching state should be compensating the possible damages occurred. This legislative framework is very relevant to the analysis, due to the fact that the liability of damages is directly linked to the state, and therefore should be proposing an ex-ante solution to the space debris issue: each damage incurred in the history of space exploration has a direct liable undertaking. This might be leading to a question, how is this not stopping any state from creating space pollution? Why are these legal acts not helping the situation with the implementation of strictly sustainable practices in outer space?

[46] Articles 5 and 8 are found in the following website Outer Space Treaty (unoosa.org)
[47] Rescue Agreement by United Nations Rescue Agreement (unoosa.org)
[48] Liability for Damages Liability Convention (unoosa.org)

To continue the analysis of the legislative background, in 1976 the *Convention on Registration of Objects Launched in Outer Space* [49] was established, expanding the scope of the three other legal documents above mentioned. This comprehends a system for which the satellites, probes, landers, spacecraft and other objects used for missions are registered within the Secretary-General, to which it was given the responsibility[50].

Lastly, the *Moon Agreement* was established in 1984, giving further expansion to the principle of peaceful use of the celestial bodies, and that the environment should not be damaged[51].

During the history of space regulation, five main declarations and legal principles were redacted.

Firstly, the *Declaration of Legal Principles*[52], in which space exploration was declared to be pursued by respecting the equal opportunities of each state and following the international laws, comprehending also the principle of non-appropriation.

Secondly, the *Broadcasting Principles*[53] that the activities in the television broadcasting field should follow the sovereign rights of the state providing the service.

Thirdly, according to the *Remote Sensing of Earth Principles*[54] all the services provided that involve electromagnetic waves emissions should be given within the interests of all countries.

The *Nuclear Power Principle*[55] was established to regulate the activities using nuclear power sources in outer space, and those activities are following the international law, in accordance with the Charter of the United Nations.

Lastly, the *Benefits of Declaration Principles*[56] stated that the states with major space capabilities in terms of activities and knowledge are to help, especially developing countries and contribute to the international cooperation principles.

All of the principles above depict a framework for which cooperation is not an option, but it's almost mandatory. This entails a high level of interconnectivity between space activities and states as well. This concept is crucial because space sustainability is a global issue to be

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[49] Convention on Registration Registration Convention (unoosa.org)
[50] Registration Submission Update United Nations Register of Objects Launched into Outer Space (unoosa.org)
[51] Moon Agreement Moon Agreement (unoosa.org)
[52] Declaration of Legal Principles Legal Principles (unoosa.org)
[53] Broadcasting Principles DBS Principles (unoosa.org)
[54] Remote Sensing Principle Remote Sensing Principles (unoosa.org)
[55] Nuclear Power Principle NPS Principles (unoosa.org)
[56] Benefits of the Declaration Space Benefits Declaration (unoosa.org)

tackled in an environment that by definition is hostile, therefore the ensemble of development in knowledge and technologies provided by each state must be used in finding international solutions to the space debris accumulation issue.

Sustainable development is strongly rooted in the idea that preserving an environment is the only way through which long-term development can happen. According to the above-mentioned legal frameworks and principles, this should be granted. But due to recent developments, it might not be so sure.

In 2015 the US Spurring Private Aerospace Competitiveness and Entrepreneurship (SPACE) Act was established, and it grants that: US companies shall "*engage in the commercial exploration and exploitation of space resources* […] *the United States does not* (by this law) *assert sovereignty, or sovereign or exclusive rights or jurisdiction over, or the ownership of, any celestial body*.[57]" This kind of law seems not to ensure international cooperation and equal treatment between the states that will have access to the space resources. This might cause attritions due to the possibility of appropriation of resources through extraction.

In 2017, Luxemburg passed a new law regarding the same concepts, the e *Law on the Exploration and Uses of Space Resources.* This act gives the right to private companies to use space resources.

In these terms, both these law provisions can violate the Outer Space Treaty, but might bypass the Outer Space Treaty because they do not entail ownership of space objects when in the outer space environment, but they refer to extraction[58].

The implications of this future branch of public law are difficult to handle: according to the present legislation, excluding the SPACE Act of US, there is no notion of ownership in outer space and therefore the laws to which we are used to in our planet do not hold.

Not only outsourcing the mineral/water resources could provoke some legal attritions, but also some impacts to the level of unsustainable practices on Earth.

Considering the high costs of space travel, such as huge amounts of expensive fuel, the market would be only interested in the resources of high value, such as the Platinum Group Materials, as explained at the beginning of the chapter. Therefore, in the following paragraphs I will be analysing the implications of mining in outer space, for the said materials.

[57] SPACE Act PUBL090.PS (congress.gov)

[58] Luxemburg Law on Space Mining Luxembourg's New Law Gives A Boost To Space-Mining (wccftech.com)

The practices used of outsourcing PGM in outer space, such as asteroid mining, or moving industries into space, might represent a big opportunity in terms of carbon dioxide reductions. Currently, on Earth, the average CO_2 emissions per ton of platinum is 40 thousand tons, which is huge.

To assess the real impact of mining in outer space, an LCA analysis must be made.

LCA is used to assess the environmental implications of certain products or services, throughout all the stages of the creation, provision of the service or product and disposal. The stages consider: resource usage, energy usage to create the final output and the relative wastes associated (either air, soil, water pollution).

By this assessment, “spillover effects” are avoided because the phases are perfectly recognized, mapped and evaluated. According to Hein et al.[59], the conclusion made after having analysed LCA for 1kg space-mined platinum (Pt) was that the emissions were considerably less.

On the other hand, if we consider a space launch whether it serves as a mining mission, the emissions are extremely high. For example, the SpaceX company with the launch of Falcon 9B spacecraft has introduced in the atmosphere almost 337 thousand Kg of CO_2. The average amount of CO_2 emitted per Kg of Kerosene is 3 Kg, and Falcon 9B burned 29 thousand of Kerosene gallons[60].

Therefore, if we consider LCA system, only by considering the level of emission at the start of the activity (such as the amount of energy used to reach the site, or the fossil fuel needed), it should not be considered sustainable at all.

Not to mention that even if mining in space might result in scarcity of the resources themselves, once the market starts developing, only just increases the unsustainable trends already majorly present nowadays.

This kind of market, rooted in outer space mining would certainly exclude the lower-income nations, creating the so-called “Space Gap”[61]. These dynamics would be considered as not sustainable in the long run, because it would of course lead not only to hostile environments among nations, but also to long-term inequity between the North and the South of the world.

[59] LCA mining assessment Abstract CEAS2015 ESA Standardised LCA Methodology Space (aerospace-europe.eu)

[60] Level of emissions One SpaceX Rocket Launch Produces the Equivalent of 395 Transatlantic Flights worth of CO2 Emissions | Champion Traveler

[61] Space Gap Definition https://scholarworks.bgsu.edu/cgi/viewcontent.cgi?article=1064&context=irj

Nevertheless, the increasing demand for specific minerals will not be satisfied by Earth's resources only in the long run, especially if we keep the "business as usual" scenario trajectory in consideration. The mentioned trajectory is provided by the IPCC, technically speaking it takes the name of RCP 8.5 (representative concentration pathway), which expresses the future scenario according to a certain level of cumulative emissions. Thus, mining activities in outer space will become soon an option for the market, even though this would not be starting the right path towards sustainability at all, whether that be sustainable for the environment, for the rivalry among nations and for space debris issues.

1.1.8 The Space Paradox: between Contributing to Earth's Sustainability and Increasing Space Debris

The space paradox concept lies in the idea that efforts to enhance sustainability on Earth within the space sector may inadvertently decrease sustainability in space itself.

This paradox arises because increased space activity, intended to mitigate unsustainable practices on Earth according to the 2030 Agenda goals, inevitably leads to a rise in space debris and ultimately to Earth's unsustainability once again. The increased number of actors, also due to the privatization of the sector itself, is contributing to the debris issue and is posing a threat to the long-term accessibility of low Earth orbit (LEO) regions, because of the *Kessler Syndrome* effects, which we already talked of.

Sustainability on Earth is enhanced by space use due to the immense network of satellites and internet service providers around the globe: climate change monitoring; extreme events predictions with early warning systems; optimizing farming practices by monitoring soil moisture, crop health, and weather conditions; tracking groundwater levels and the health of freshwater system as NASA's GRACE (Gravity Recovery and Climate Experiment); monitoring species migration, habitat loss; tracking air pollution, such as smog, particulate matter; providing data on solar radiation, wind patterns, and ocean currents, to optimize the placement of renewable energy infrastructure and so on.

Unfortunately, the exploration and use of space require huge amounts of energy, and requires specific minerals, contributing to the depletion of the resources on Earth. Once again posing a threat to the on-Earth environment. If this kind of practice is going to be pursued in space, to lower Earth's resources' excessive misuse, then the outer space environment itself will be in danger as well. As a consequence, the main problem that could arise in the latter scenario is related to the "Tragedy of the Commons"[62] concept. This means that, if all the participants within the space sector are going to use it for personal and egoistic scopes the outer space resources, without taking responsibility and without any assessment of property rights, they will ultimately deplete this environment as well.

All of these trade-offs clearly highlight the paradox for which sustainable goals on Earth clash with sustainable practices on and for space.

To clarify what type of issues are part of the paradox itself, the academic paper by Andrew Ross Wilson et al.[63], provides a classification of three main pillars: sustainability *from* space, sustainability *in* space, and sustainability *for* space.

The first one refers to the fact that space is used to achieve sustainable goals *on* Earth.

This can be pursued by the implementation of different activities, such as *Earth Observation* (EO), which is defined as "the gathering of information about Earth's physical, chemical and biological systems, monitoring and assessing the status of changes in the natural man-made environment"[64]. This is very useful if climate change and environmental changes are to be analysed and kept under control, it ensures a fast response for action to be taken and a realistic perspective on the matter.

Another type of means is the *Global Navigation Satellite System* (GNSS), which aims to provide telecommunications and can be used for any human-led activity on Earth.

Satellite Communication (SatCom) is similar to the latter but additionally serves the scope to connect even isolated communities.

Space Science serves instead for the observation of natural phenomena that occur in the space environment, helping understand the various effects that can impact the Earth itself.

Space Exploration aims the increase knowledge of our solar system firstly, but of space in general, contributing to the development of new technologies and human discoveries.

Technology Transfer is a mechanism for which the transfer of knowledge on technologies used by some entities is transferred to another one.

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[62] Definition of the concept by Harvard Business School https://online.hbs.edu/blog/post/tragedy-of-the-commons-impact-on-sustainability-issues#:~:text=The%20tragedy%20of%20the%20commons%20refers%20to%20a%20situation%20in,British%20writer%20William%20Forster%20Lloyd.

[63] Space Paradox and its three pillars https://www.sciencedirect.com/science/article/pii/S0959652623030275?fr=RR-1&ref=cra_js_challenge

[64] Definition of EO https://sustainableearthreviews.biomedcentral.com/articles/10.1186/s42055-021-00045-6

The second pillar, instead, deals with the sustainability *in* the environment of outer space, comprehending space resources being used thoughtfully and all those practices that help with space debris removal and in-orbit servicing.
Lastly, the third pillar focuses on the impact that the space sector has on Earth, for example through the analysis of the entire LCA (Life Cycle Analysis) of a mission: raw material extraction, manufacturing, launch, disposal and socio-economic impacts.
Both sustainability from space and in space sustainability activities contribute to the pursuit of the 17 SDGs, while still taking part in the debris creation or resource depletion processes in the outer space environment.
Namely, if we consider a space mission for the installation of a satellite belonging to the EO category of activities, in principle the type of satellite will require certain types of materials and minerals, which will contribute to the already-intensive activities of extraction on Earth. According to NASA, the materials necessary to be used in a space-craft creation, are the following: "high strength alloys of aluminium, titanium, and stainless steel […]. The 5000-series aluminium alloys containing more than 3% magnesium shall not be used in applications where the temperature exceeds 66 °C (150 °F), because grain boundary precipitation above this temperature can create stress-corrosion sensitivity or exfoliation. […]"[65], which entails also an additional and non-neglectable waste of the extracted material. Other necessary elements are related to fuel and, stepping outside of our example considering the satellite, other materials also relate to oxygen reserves for human-led space crafts.
After having reached the final product, the object will be launched and may contribute to the creation of debris while on its mission, whether that be of collision with big space junk or smaller one. Lastly, if no longer needed, the satellite will be following a disposal phase for which a standardized approach is not available yet in the international frameworks landscape, therefore it might also be left in outer space without actively removing it, representing an additional body in the debris population.
Even though the whole mission will serve for the enhancement of analyses of Earth's situation and finally for climate change-related actions, it will lastly be impacting Earth a lot as well.
This would be the true meaning of the so-called space paradox.

[65] Materials needed for a spacecraft to be built
https://ntrs.nasa.gov/api/citations/20160013391/downloads/20160013391.pdf

1.1.9 SDGs for Outer Space: 18th goal, "Life in Space"

Sustainable Development Goals are mandatory for humanity to have a future, not only on this Planet but on this Solar System as well. Up until these years, these goals have always counted up to 17, and they aimed towards reducing poverty, and hunger, increasing health assistance, providing education etc.

In 2020, on May 11th, a UN75 Dialogue took place, and it focused on the possibility of adding an 18th goal to the list, called "Space for All" or "Life in Space".

According to Michelle L.D. Hanlon, Co-Founder for All Moonkind and Permanent Observer at the United Nations Committee on Peaceful Uses of Outer Space, "The 17 SDGs cannot be achieved without proper space harvesting […] we have satellites that can stop human trafficking! imagine what could we do if Space can be used at its full potential, but in a proper way that consents future to be sustainable"[66].

As mentioned by Tomas Hrozensky, the Resident Research Fellow at the European Space Policy Institute & Chairman of Slovak Space Policy Association, the ESA's point of view is that: "Complying with the space debris mitigation programmes is not sufficient", and he adds that "The implementation of other tools like end-of-life schemes, standardization, information sharing on the tracking of the space objects, space situational awareness system will do the work"

Agnieszka Lukaszczyk, Senior Director for European Affairs at Planet, argues that it's essential to contribute to the sustainability of the space environment because: "People's lives depend on satellite efficiency on everyday life, banking systems are synchronized on the atomic clocks on the satellites […] imagine turning them off for a week, it will bring us back of 20 or 30 years, so it's crucial to keep their environment safe enough to keep functioning".

Creating a stronger legal framework for the space sector could be implemented also through SDGs. It could create the right environment in terms of international agreements on the matter, providing healthier management of the resources in space. It is crucial for the future of space, whether that be from a private or public perspective, to look up to the 17 goals. For example: we would not be able to explore space without the 17th goal: collaboration, especially in an environment for which the Space Treaty has expressively stated that it can be used only in peaceful ways and not exploited for personal scopes.

[66] UN75 Dialogue https://youtu.be/MNRSlTSDuZ4?si=UDZILKjztPaArN5T

In 2018, UNOOSA by collaborating with the European GNSS Agency, conducted a study that confirmed "almost 40% of the targets of the 17 SDGs are directly taking advantage of the use of geo-location and Earth's observation satellites".
UNOOSA, therefore, took the "Space4SDGs" initiative that highlights the strict relationship between the goals and the space inputs that could be used to reach them. The initiative is linked to the *Space Solution Compendium*[67], which is a web portal that can provide information on what kind of space activity is contributing to the achievement of an SDG goal. For example, the ESA Space Debris Training course implements the 15th goal, the GNSS scheme. The monitoring of the Earth's environmental variables situation (e.g. air quality) is helping achieve goals 3 (health), 9 (industry innovation), 11 (sustainable cities and communities) and 13 (climate action).
Having said this, the fact that UN sustainable goals have been drafted and proposed to preserve the Space Environment shows a clear message on what will be the priorities for the next century, especially if privatisation and human discoveries in space will be increasing.

[67] Space Solution Compendium https://ssc.demoviewer.live/

1.2 The SD_i Measure

In the existing literature, the Debris issue has been important in the context of collision avoidance, meaning that spacecraft and satellites, needed to be protected against space objects that might have represented a threat to their existence, and for astronauts, especially during the so-called "spacewalks".

To better understand the present literature for the debris issue, I have categorised three types of findings, with its most important author or academic study group.

Firstly, I will show what kinds of collisions there might be, secondly, I will consider how to track their orbits and thirdly I will talk about the potential effects.

Starting with the types of collisions, according to the Australian Space Academy studies[68], two collision scenarios have been distinguished: a *non-catastrophic* one and a *catastrophic* one. To understand to which category an impact is put, the following formula holds:

$$\Gamma = \frac{Mt}{Mi}$$

In the non-catastrophic event, the "impactor", (the object categorised as space debris) with mass Mi, is destroyed, while the "target" (the e.g. spacecraft), with mass Mt, is not.

$$Mi < \frac{Mt}{\Gamma}$$

While, in the second case, both the impactor and the target are destroyed.

$$Mi \geq \frac{Mt}{\Gamma}$$

In the second case, the debris creation is obviously much higher, which entails a bigger risk of collision for any other future "space user" because the mass ejected (Me) is the sum of the two destroyed bodies.

$$Me = Mi + Mt$$

[68] Studies on Catastrphic and Non-Catastrophic events by the Australian Space Academy https://www.spaceacademy.net.au/watch/debris/collision.htm

Considering especially the last scenario, it is mandatory to be able to study the orbit of these fragments.

One of the models mostly used by the scientific community is the *Gabbard Diagram*[69], which is useful as it can confirm if an explosion has occurred, estimate the energies involved, and risk to other satellites can be estimated.

This is an example of a Gabbard Diagram for a 1000kg target in a catastrophic collision[70], and the depicted lines show the trajectories of the fragments.

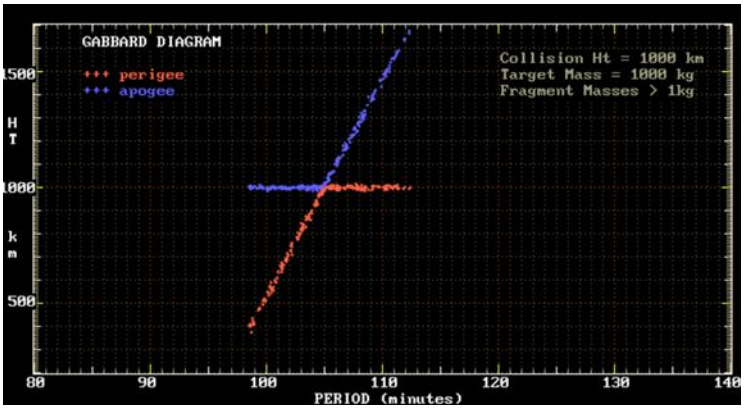

Image 6: Gabbard Diagram

Lastly, I will be talking about the potential effects. Donald J. Kessler one of the most influential scientists in the field contributed to the study of debris issues with the nowadays called "*Kessler Syndrome*" theory: "a scenario where space debris collisions cause a domino-effect resulting in an overwhelming number of debris"[71].

The study conducted by him was to understand the collision rate between Jupiter's Moons, and conceptually speaking the following formula hold:

$$\text{flux} = \text{spatial density} * \text{velocity}$$

and

$$\text{number of collisions} = \text{flux} * \text{area} * \text{time}$$

[69] Gabbard Diagram Theory Explained https://kth.diva-portal.org/smash/get/diva2:1807713/FULLTEXT01.pdf

[70] Debris Tracking Orbits https://www.spaceacademy.net.au/watch/debris/collision.htm

[71] Kessler Syndrome definition https://aerospace.org/article/space-debris-101#:~:text=The%20objects%20are%20moving%20so,boost%20in%20a%20different%20direction.

All of these above-mentioned inputs have considered the type of collisions, the orbit-tracking of the space debris and the possible effects of the latter.
My contribution to the literature, according to what I have studied in the previous paragraphs of the chapters and to the theories already present, would like to be focused on the possibility of predicting the level of danger of a specific area according to the number of trackable objects and to their average time of permanence in the said area.
Therefore, I here propose the following measure. Firstly, there has to be considered two main variables: the number of objects, and the average time of their permanence in the considered zone.
The underlying assumptions are that the objects are trackable, and the regions are known.
If we take into account that the danger arising from collisions strongly and positively depends on the above-mentioned variables, we could create a function representing Space Danger (SD) (1) in a certain region of the Earth's Orbit as the average probability of finding the said objects in a certain area:

$$(1)\, SD_i = \sum_{1}^{n_i}(tmp)$$

Where the Space Danger of the region i is the summation of the average time of permanence tmp (2) of the objects in the area, from 1 to the total number of objects n_i.

$$(2)\, tmp = \frac{days\ of\ crossing}{365}$$

Where stationary satellites have an average time of permanence equal to 1 ($\frac{365}{365}$).
An initial qualitative assessment in terms of the nature of the object might be considered as well due to different impact magnitudes between fragments, smaller pieces of an initial object that are now moving uncontrollably space debris, and non-functional man-made objects. Some additional remarks should be highlighted: smaller space debris corps, from 1mm to 1cm are usually not tracked because of their small dimension, but they travel at a speed of 28160 km/h.
The formula might suggest an additional supportive system, database-like, in which new programmed launches are written down, in terms of the desired time of the launch and

average permanence in a specific area, so that the user of the formula might also consider the Expected Space Danger (3) in a specific future timeframe.

$$(3)\, E(SD_i) = E(\sum_{1}^{n_i}(tmp))$$

An estimate for the probability of collision in the Lower Earth's Orbit has already been provided by ESA's MASTER, following a software-based approach. This software considers the overall time of permanence in the zone, the future scenario (e.g. business as usual), and the thresholds for the size of the objects (e.g. from 100m to 1mm), and provides the result for a 3D plan between the spatial density distribution, altitude, and declination.[72]

Another fundamental contribution to the literature is given by the academic paper of Darrel Martin-Lawson et al. (2024)[73]. It provides a model that considers a series of variables: trackable objects, collision debris, and satellites launched that are studied according to the scenario upon which they are bounded (e.g. if business as usual, then the growth rate of total objects in space will be following the economic growth of the space sector). This model suggests that a critical point will be reached in terms of collisions by 2031 for the baseline scenario.

In terms of expectations of collision accidents' peaks, the time gap that this scenario is providing us with is about 6/7 years in total. Considering that the space sector is increasing at an extremely high-rate pace the above-mentioned expectations force the sector to take immediate action. Whether that be normative or scientific actions, these efforts should be mostly based on prevention, since simple removal is not enough.

1.2.1 SD_i Measure and Regulative Approaches

To give further proof of how useful the "space danger measurement" would be, I will link it with the regulative context I analysed in the previous chapters.

The "SD_i" if considered in the regulative perspective, might be useful since it can indicate how much of both a preventive or ex-post-management action is needed for a certain area of the Earth' orbit, whether that be in terms of rating system or policy-related initiatives.

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[72] MASTER software tool provided by ESA
https://www.esa.int/ESA_Multimedia/Images/2013/04/ESA_s_MASTER_software_tool

[73] Academic paper by Martin-Lawson, Stefania Paladini, Krishnendu Saha, Erez Yerushalmi, *The cost of (un)regulation: shrinking Earth's Orbits and the need for sustainable space governance*
https://www.sciencedirect.com/science/article/pii/S0301479723021709

The higher the SD_i the higher the need of taking action from an initiative-led perspective. Whenever there is a higher rating for collision avoidance capacities (COLA), we might expect to see a lower SD_i. This is because the lower the COLA, the higher the SD_i level will be: a lower ability to avoid impacts means a higher probability to create additional space debris, increasing the overall population of a certain area (4).
Let SD_{i,m_1} be the measure of Space Danger for the mission m_1 considered in the SSR system, with the assessed index $COLA_1$:

$$(4)\, SD_{i,m_1} = \frac{k}{COLA_1}$$

Where k is a constant. In the analysis, for the sake of the assumptions for the model, the index representing the DIT must be taken into account as well, because by definition SD_i only works with trackable objects. So, the higher the level of trackability of the various objects used in the mission, the better the SD_i measure works.
To be fair, if we consider that the assumptions state that there must be trackability, there must be 100% DIT transparency level, so the COLA relationship might function only if a maximum level of COLA is granted.
Therefore, rating systems like SSR are essential for the better understanding of the space sustainability and for assessing risks but also opportunities arising from the situation.
A further step into the analysis of SSR could be made. The SD_i measure might be applicable in terms of how much the level of the danger changes once the said mission takes place. If we quantify the SD_i at time t_0 for a mission m_1 and it shows a lower figure compared to SD_i at time t_1 after the said mission has reached its end, then it means that the sustainability rating of the mission should be low.

$$SD_{i,m_1}(t_0) < SD_{i,m_1}(t_1)$$

When this is valid, the SSR becomes a way to tackle the reasons why the mission is unsustainable: it uncovers the relative unsustainable practices for which SD_{i,m_1} was not satisfying the right level of ex-ante or ex-post characteristics in order not to increase the space debris population.

If we consider the situation in which $SD_{i,m_1}(t_1)$ is increased exponentially, it means that the probability of having recorded a collision, or even more than one, during the execution of the mission, is high. This is due to an increase of $SD_{i,m_1}(t_1)$ of such dimensions, at least the amount of space objects was increased by the same proportion, since the average time of permanence of the sum of the objects will increase as much as the number of objects recorded.

To give further proof of the reliability of the formula, I will now be talking about some results in the present scientific literature.

As reported and analysed in the academic paper *Interactions of the space debris environment with mega constellations* by Jonas Radtke et al.[74], the life cycle of a single set of satellites, namely *OneWeb*, has been divided into four phases to understand the probabilities of collisions between the set of satellites and space debris, at different levels of altitudes. The phases are the following: spiral-up phase, operational mission, active and passive disposal.

If a set of 720 satellites is placed at 1200km from Earth's surface, the probability of collision estimated is at 35%. The biggest danger arises when crossing the regions at 800km and 1000km, during spiral-up and active disposal phases, due to the high level of space objects. Which would mean, in other terms, that SD_i would likely to be higher in these two regions.

If a set of 1000 satellites is placed at 800km, and one with 640 is placed at 1400km, the probabilities of collisions follow the same reasoning as before. According to the measure, the SD_i should be higher because of the higher number of objects considered, and higher because the two regions considered are in the first case highly populated and in the second case at a higher altitude, implying a higher average time of permanence on the region. And, in fact, the results are showing higher probabilities of collision: almost 70% of probabilities of collision for the first constellation considered and 45% for the one at 1400km.

Another proof in favour of the SD_i measure reliability comes from the post-mission disposal activities data (the post-mission moment does not belong to the four phases). If we consider the first example of the constellation at 1200km, after 10 years of operation the probability of incurring into a collision is 22%, while after 20 years it increases to 42%.

A method to avoid this kind of collisions would be to perform emergency manoeuvres, which might reflect into higher costs of both training requirements for on-board crew, and in terms of additional-used fuel.

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[74] Academic paper on the analysis of OneWeb life cycle to understand its implications with space debris https://www.sciencedirect.com/science/article/abs/pii/S009457651630515X

To be able to avoid these kinds of costs, the paper proposes to reach a level of 1600km, where the population of objects is lower and therefore less dangerous or, economically speaking, costly.

The trade-off, in this case, lies in the fact that a higher level of altitude means a higher need for fuel storages. To add to this, in my opinion this is not a sustainable solution, it only postpones the issue.

In conclusion, the final remarks shown in the paper are proving that the longer the permanence and the number of objects present, the higher the collision probabilities, exactly as depicted in the formula SD_i.

This is proving how much of an innovative measurement SD_i is.

1.2.2 SD_i Measure and the available instruments

Once again, to prove the possible usefulness of the SD_i measure, I will be linking the measure in the Space Environment Management context (5), mentioned in chapter 1.1.3.

The contribution that SD_i could give in the SOA framework is related to the fact that Space Danger is a proxy for the level of Space Debris in an area, so the following formula holds:

$$(5) SD_i = \frac{k}{SEM_i}$$

Meaning that the higher the level of SEM in a certain area i, the lower the Space Danger in the same area.

The actions of active removal of space debris and restoration of the environment would be the most impactful ones, from an ex-post point of view.

The assumptions of the SD_i measure imply that the SSA must provide the analysis with a high-level quality of information to satisfy the model correctly. The main limitation of the model is that, as seen in the graph, the most dangerous objects are usually non-trackable, meaning that the highest danger levels would be left outside the analysis.

On the other hand, this could represent a huge opportunity for creating new services for tracing these 1cm-10cm objects. New technologies are once again our greatest ally for a sustainable future.

1.3 Conclusions on the State of The Art

Considering the enormous level of space debris population that is now present in the LEO, the actions are not only mandatory but must be taken immediately, in order not to reach the tipping point form where the unsustainability in space will stop humanity from exploring and advancing its economic growth.

Both private sector, mainly through the ADR methods, and public sector, through technical approaches and proposals for legal frameworks, are pointing in the same direction: without a safe environment in which the players can thrive, the future in space is not guaranteed.

The main difficulty that lies within the debris problem is the so called "tragedy of the commons"[75]. This mechanism is based on the use of common resources by individuals that will contribute to the degradation of the resources themselves.

As the main components for pollution are either the launch stage, the debris-creation through collisions and the disposal after a mission, legal provisions could be taken trough guidelines or even hard laws.

Through the main legal provisions regarding space, history has thought us the cooperation among different players whether they be companies or governments is necessary to face the global issue. First steps were taken by international entities such ESA, with programs like *Clean Space Initiative* and *Zero Debris Approach.* Always within the European Context the next proposals in relation to space sustainability are towards a harmonised European Space Law.

Aside regulation methods, debris to be tackled must be identified, or at least the area it's in. In order to understand the level of danger that at the moment is present in a certain area of space, the SD_i measure could be used.

It is directly proportional to the number of objects present in the area and it provides a figure representing the sum of the average times of the objects' travel of the said area. Therefore, it is inversely proportional to measures like COLA, which shows the ability to avoid collisions, and it is inversely proportional to the Space Environment Management (SEM) measure as well, which represents the number of actions to restore the environment.

Paolo Nespoli, an Italian ex-astronaut, engineer and military, has envisioned the future path towards space sustainability from four points of view: terrestrial sustainability, use of

[75] Sustainability in Space
https://www.sciencedirect.com/science/article/pii/S0959652623030275#:~:text=The%20tragedy%20of%20the%20commons,gain%20(Hardin%2C%201968).

satellites to increase equal opportunities between nations, the debris issue, and the application of sustainable principles that we apply nowadays to planet Earth even to other celestial bodies.

The first goal on the terrestrial sustainability is based on the collection of enormous quantity of data, and according to the analysis provided in this chapter, this might be reached through the technical approach of SSA, basis upon which the whole mechanisms of space safety rely on.

The second goal, instead, might be implemented through the new space legal frameworks, as to follow the principles of the *Outer Space Treaty* to provide equal opportunities to everyone.

The third goal was largely studied in this chapter and the solutions proposed are to use a strategy that puts together the ADR practices with the technical approaches such as STM and SEM.

Instead, the fourth and last topic, must be faced through ex-ante regulation, being more similar to the second solution proposed.

In conclusion, the available instruments, companies and practices contributing to space sustainability in the scene are going towards the right path, but need a huge boost as soon as possible, in order not to reach the unsustainability tipping point.

Chapter II: Establishing Sustainability Criteria for Outer Space Activities

Negotiation in the classic
diplomatic sense assumes
parties are more anxious to
agree than to disagree.
- Dean Acheson

2 Standardisations, ratings, and indexes for Sustainability in Outer Space

2.1 Selected literature

The following table depicts the selected papers of reference for analysing the three main methods to measure sustainability in space.

Topic	Title	Journal and Year	Main Insights
Standard	Space systems – Space debris mitigation requirements (ISO 24113:2023)	European Cooperation for Space Standardization, 2023	This document identifies the clauses and requirements (including notes and clarifications) modified or added concerning the standard ISO 24113, Space systems — Space debris mitigation requirements, fourth edition 2023-05 (referred to as ISO 24113:2023) for application in ECSS.
Standard	IADC Space Debris Mitigation Guidelines	NASA, 2022	The Inter-Agency Space Debris Coordination Committee (IADC) is an international forum of space agencies, and authorized governmental or inter-governmental entities

			for the coordination of activities related to the issues of human-made and natural debris in space.
Rating	The Space Sustainability Rating (SSR) System	International Astronautical Congress (IAC), 2023	Provides a sustainability rating system based on six dimensions: type of mission, DIT, COLA, Data Sharing, design and operation standards, and external services.
Index	SSI (Space Security Index)	University of Adelaide, 2019	The Space Security Index project aims to improve trust and transparency related to space activities and increase the level of good governance of outer space.
Index	CNES Space Sustainability Index	ScienceDirect, 2023	CNES is creating an index to monitor and regulate the space environment, considering the increasing number of satellite launches.

Table 2: Selected Standards, Rating and Indexes on Space Sustainability

This chapter will be divided into three main sections, each dedicated to exploring different aspects of measuring sustainability in space to enhance long-term sustainability in the outer space environment.

The first section, 2.2, will focus on creating standards for space sustainability, by establishing guidelines and best practices to ensure responsible use of space resources. The second section, as seen in the table above, will take into account rating systems for space sustainability. So, section 2.3 will examine various methods for evaluating and comparing the sustainability efforts of different space missions and organizations. Finally, the third section, 2.4, will discuss the development and application of indexes, which aggregate multiple sustainability metrics into comprehensive indicators to provide a clearer picture of overall sustainability performance in space activities.

2.2 Standardisation for Outer Space Activities

Space debris issues are increased by the lack of standardized protocols for space data exchange. The absence of universal standards for debris mitigation among the huge number of organisations and nations involved in space activities worsens the whole debris issue. To add to this, without a cohesive framework for sharing data on satellite positions, and potential collision alerts, the risk of accidents and further debris generation escalates. This lack of cooperation not only jeopardizes individual missions but also threatens the long-term viability of space operations.

Broadly speaking, standardizing sustainability on Earth has been a challenge due to the differing points of view of various countries, which have led to deep fragmentation on the topic. When considering space, the efforts to achieve a common understanding of sustainability might be even more complex.

In the previous chapter, it was observed that the perspectives on space activities are no longer only governmental. The privatization of the space sector has introduced a high number of new market players, each bringing their own approach. This dynamic has complicated the overall setting by fragmenting even more the space sustainability solutions. As a result, common practices in terms of standardization and frameworks have not been considered as a solution to implement an efficient action plan for achieving a shared intentions for achieving sustainability in space.

Therefore, a unified framework is needed to categorize the various activities in space as sustainable or not. Such a framework would help harmonize the diverse approaches of different stakeholders and provide a clear, consistent method for assessing sustainability practices.

The most effective method to reach this goal is to provide a common legislative and regulatory framework. Standardizing sustainable practices in space could be one of the most efficient tools for achieving international cooperation. By establishing clear guidelines and benchmarks, a standardized approach would help ensure that all space actors, whether governmental or private, adhere to practices that minimize environmental impact and promote long-term sustainability.

Additionally, standards would directly contribute to the sustainability goals set for both Earth and Space, as seen in Chapter 1.1.9. It would facilitate better resource management, reduce the generation of space debris, and enhance the overall safety and sustainability of space operations (mainly talking about space missions). This would encourage innovation and technological advancement by providing a clear set of expectations for sustainability, which could drive the development of new, more efficient technologies.

While the diversity of perspectives and practices poses significant challenges, this approach can provide the necessary structure to guide sustainable practices and might be crucial for several reasons.

Firstly, they help mitigate the growing problem of space debris seen in chapter 1.1.3. As the number of satellites and missions increases, so does the risk of collisions, which can create more debris and further endanger operational spacecraft. A standardized approach to debris mitigation, including guidelines for end-of-life disposal and collision avoidance, can significantly reduce the likelihood of these events and help maintain a safer orbital environment.

In addition, standards promote international cooperation and consistency. The space sector is highly globalized, with numerous countries and private companies. Without common standards, these entities may follow different protocols, creating conflicts. Internationally agreed-upon standards ensure that all space actors adhere to the same guidelines, increasing the level of collaboration. This not only enhances operational efficiency, but also builds trust among spacefaring nations and companies, paving the way for more collaborative projects and joint efforts in tackling global challenges.

Standards might drive innovation and technological advancement as well. By setting clear sustainability criteria, standards create a benchmark for companies and researchers to meet or exceed. This encourages the development of new technologies and processes that are not only more efficient but also more sustainable. As a result, standards can create advancements in areas such as satellite design, propulsion systems, and materials science, ultimately contributing to a more sustainable and resilient space industry. In essence, standards on space sustainability are vital for ensuring the long-term viability of space activities, protecting the orbital environment, and fostering a cooperative and innovative global space community.

As stated in the academic paper "Space Policy" by M. Palmroth et al.[76]: "*With the increase of non-legally binding guidelines and standards, there has been a significant interest by States to enact national space laws. In addition to creating a legally binding framework for conducting space activities under national jurisdiction, national space laws also take on a bridging role between international and domestic laws, as well as between legal obligations and "soft law"*."

Therefore, the need for standardisation is more urgent than ever.

As seen in the previous chapter, space sustainability can be defined in general as the ability to continue space activities in a manner that preserves the space environment for future generations. Ensuring space sustainability requires addressing both the immediate threat posed by space debris and the systemic issues related to data sharing. By establishing robust standards for space data exchange, the global space community can increase situational awareness, improve collision avoidance, and foster a collaborative approach to managing the space environment.

The current trajectory, marked by increasing congestion and fragmented data practices, shows the urgent need for international cooperation and policy development. Only through coordinated efforts we can mitigate the dangers of space debris and ensure that space remains a safe and accessible domain for all. Thus, addressing the dual challenges of space debris and data exchange standards is not just a technical need but also the first step towards securing a sustainable future in space.

To provide some examples of standardisation for Space Sustainability, and to have a reference for the following paragraphs of the chapter, I chose the most used and internationally accepted standards among the present ones, nowadays[77].

According to *ISO* official release of the 17th of June 2021[78], the standards created by the *ISO/TC 20* (the committee in charge for the space-related topics) have been used "in thousands of human and robotic missions by space agencies around the world, including NASA and the European Space Agency", in the official release of the 27th of August 2021, they state that "World leaders at the G7 earlier this year called on all countries to work together to clean it up, and encouraged collaboration with ISO to help build a better future".

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[76]Space policies state of the art https://www.sciencedirect.com/science/article/pii/S0265964621000205

[77] The Development and Implementation of International UN Guidelines for The Long-Term Sustainability of Outer Space Activities https://www.unoosa.org/documents/pdf/PromotingSpaceSustainability/Publication_Final_English_June2021.pdf

[78] Release https://www.iso.org/news/ref2686.html

As reported by the *CCSDS* report published on the 18th of March of 2019, the *CCSDS* standards "have been used on over 900 space missions"[79].

For what concerns instead the *IADC* guidelines, since the 2007 official release, the state members that adhere to the guidelines are the following Italian Space Agency (ASI), British National Space Centre (BNSC), Centre National d' Études Spatiales (CNES), China National Space Administration (CNSA), Deutsches Zentrum fuer Luft-und Raumfahrt e.V. (DLR), European Space Agency (ESA), Indian Space Research Organisation (ISRO), Japan, National Aeronautics and Space Administration (NASA), the National Space Agency of Ukraine (NSAU) and Russian Aviation and Space Agency (Rosaviakosmos).

To start off, I will be talking mainly about *ISO standards*, *CCSDS Space Standards*, and *IADC guidelines*, which have developed technical standards for space data exchange, design, test, operations, management, materials, and debris mitigation, having as a point of reference the document *ISO and CCSDS Space Standards* by the UNOOSA[80].

Starting with ISO has been defined as an "official observer" to UN COPUOS and the "world leader in the development of space-related standards".

In its standardisation process, the organization has addressed space-related issues by establishing a committee for those topics only: *ISO Technical Committee 20*[81] (ISO/TC 20 Aircraft and space vehicles). In its turn, a subcommittee that considers specifically space data and information transfer systems was created: *ISO/TC 20/SC 13*[82]. The latter is operating together with CCSDS, about which I will be talking about in some time.

The most important standards are *ISO 24113*, Space Systems – Space debris mitigation requirements, and *ISO 26900*, Space Data and Information Transfer Systems – Orbit data messages.

The first standard is assessing the scope as follows: "*This document defines the primary space debris mitigation requirements applicable to all elements of unmanned systems launched into, or passing through, near-Earth space, including launch vehicle orbital stages, operating spacecraft and any objects released as part of normal operations*."[83]

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[79] CCSDS report https://ntrs.nasa.gov/api/citations/20190025718/downloads/20190025718.pdf

[80]Space standards by UNOOSA https://spacesustainability.unoosa.org/sites/spacesustainability.unoosa.org/files/files/documents/2021/Dec/iso_ccsds_case_study_submission_submitted.pdf

[81] ISO Technical Committee 20 https://www.iso.org/committee/46484.html

[82] ISO/TC 20/SC 13 Https://www.iso.org/committee/46612.html

[83] Scope of the standard https://www.iso.org/obp/ui/en/#iso:std:iso:24113:ed-4:v1:en

Broadly speaking, the abstract of the standard states that: “This document defines the primary space debris mitigation requirements applicable to all elements of unmanned systems launched into, or passing through, near-Earth space, including launch vehicle orbital stages, operating spacecraft and any objects released as part of normal operations.” To add to this, the abstract states that: “The requirements contained in this document are intended to reduce the growth of space debris by ensuring that spacecraft and launch vehicle orbital stages are designed, operated, and disposed of in a manner that prevents them from generating debris throughout their orbit lifetime. The requirements are also intended to reduce the casualty risk on the ground associated with atmospheric re-entry of space objects.”

The *ISO 24113* terms and definitions, related to space debris are reported as follows:

Terms and Definitions	**Content**
3.1 approving agent	entity from whom approval is sought for the implementation of space debris (3.23) mitigation requirements concerning the procurement of a spacecraft (3.25), its launch, its operations in outer space, or its safe re-entry (3.22), a combination of those activities
3.2 break-up	event that completely or partially destroys an object and generates space debris (3.23)
3.3 controlled re-entry	type of re-entry (3.22) where the time of re-entry is sufficiently controlled so that the impact of any surviving debris on the surface of the Earth is confined to a designated area
3.19 passivate	passivation is an effective measure for significantly reducing the chance of an accidental explosion that can generate space debris (3.23).
3.21 protected region	region in outer space that is protected with regard to the generation of space debris (3.23) to ensure its safe and sustainable use in the future

3.22 re-entry	permanent return of a space object (3.24) into the Earth's atmosphere - several alternative definitions are available for the delineation of a boundary between the Earth's atmosphere and outer space
3.23 space debris	objects of human origin in Earth orbit (3.7) or re-entering the atmosphere, including fragments and elements thereof, that no longer serve a useful purpose - spacecraft (3.25) in reserve or standby modes awaiting possible reactivation are considered to serve a useful purpose.
3.24 space object	object of human origin which has reached outer space

Table 3: ISO 24113 content

For the second standard, the *ISO 26900*, Space data and information transfer systems – Orbit data messages, I will only be reporting the abstract since it has not been made free to the public yet.

The beginning of the abstract states as follows: "This document specifies four standard message formats for use in transferring spacecraft orbit information between space agencies and commercial or governmental spacecraft operators: The Orbit Parameter Message (OPM), the Orbit Mean-Elements Message (OMM), the Orbit Ephemeris Message (OEM), and the Orbit Comprehensive Message (OCM)."

The information exchanged during the can be grouped as follows:

Standard	**Content**
	(a) pre-flight planning for tracking or navigation support
	(b) scheduling tracking support;
	(c) carrying out tracking operations (sometimes called metric predicts);
ISO 26900, Space data and information transfer systems –	(d) performing orbit comparisons;

Orbit data messages – ABSTRACT	
	(e) carrying out navigation operations such as orbit propagation and orbit reconstruction;
	(f) assessing mutual physical and electromagnetic interference among satellites orbiting the same celestial body (primarily Earth, Moon, and Mars at present);
	(g) performing orbit conjunction (collision avoidance) studies; and
	(h) developing and executing collaborative maneuvers to mitigate interference or enhance mutual operations.”

Table 4: ISO 26900 Content

Moving on to the *Consultative Committee for Space Data Systems* (CCSDS), the following areas are considered for the ISO TC20/SC13:

Standard	**Content**
	(1) Space Internetworking Services
	(2) Mission Operations and Information Management Services
Consultative Committee for Space Data Systems (CCSDS), areas for ISO *TC20/SC13*	(3) Spacecraft Onboard Interface Services
	(4) System Engineering
	(5) Cross Support Services
	(6) Space Link Services.

Table 5: CCSDS Content

In the area of space systems and operations, there were published 180 space standards with an additional 45 in development, relevant to the long-term sustainability of space activities. ISO TC20/SC14 is divided into working groups (WGs) that cover these topics: Design, engineering, and production; Interfaces, integration, and test; Operations and ground support; Space environment (natural and artificial); Space system programme management and quality; Materials and processes; Orbital debris.

The last topic is covered by Working Group 7 (WG7), which is trying to codify the IADC guidelines[84] into international standards for contractual incorporation and potential national regulatory adoption.

Finally, I will be talking about the *IADC* Space Debris Mitigation Guidelines.

The scope of the guidelines is stated in the official document as follows: "*The IADC Space Debris Mitigation Guidelines describe existing practices that have been identified and evaluated for limiting the generation of space debris in the environment. The Guidelines cover the overall environmental impact of the missions with a focus on the following: Limitation of debris released during normal operations; Minimisation of the potential for on-orbit break-ups; post-mission disposal; Prevention of on-orbit collisions.*"

Standard	**Terms and Definitions**	**Content**
	3.1 space debris	space debris are all man-made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional.
	4 general guidance	during an organisation's planning for and operation of a spacecraft and/or orbital stage, it should take systematic actions to reduce adverse effects on the orbital environment by introducing space debris mitigation measures into the spacecraft or orbital stage's lifecycle, from the mission requirement analysis and definition phases.
IADC Space Debris	5.1 limit debris released during normal operations	in all operational orbit regimes, spacecraft and orbital stages should be designed not to release debris during normal operations.

[84] IADC guidelines https://orbitaldebris.jsc.nasa.gov/library/iadc-space-debris-guidelines-revision-2.pdf

Mitigation Guidelines		Where this is not feasible any release of debris should be minimised in number, area and orbital lifetime.
	5.2 minimise the potential for on-orbit break-ups	5.2.1 minimise the potential for post mission break-ups resulting from stored energy; 5.2.2 Minimise the potential for break-ups during operational phases; 5.2.3 avoidance of intentional destruction and other harmful activities
	5.3 post mission disposal	5.3.1 Geosynchronous Region; 5.3.2 Objects Passing Through the LEO Region
	5.4 prevention of on-orbit collisions	In developing the design and mission profile of a spacecraft or orbital stage, a program or project should estimate and limit the probability of accidental collision with known objects during the spacecraft or orbital stage's orbital lifetime [...]

Table 6: IADC Content

In the "general guidance (4)" section the following actions are considered:

General Guidance Detailed
(1) A management plan addressing space debris mitigation activity
(2) A plan for the assessment and mitigation of risks related to space debris, including applicable standards
(3) The measures minimising the hazard related to malfunctions that have a potential for generating space debris
(4) A plan for disposal of the spacecraft and/or orbital stages at end of mission

(5) Justification of choice and selection when several possibilities exist
(6) Compliance matrix addressing the recommendations of these Guidelines

Table 7: Detailed Guidance of IADC

Summing up, all the mentioned standards are considered the main tool for the creation of commonly accepted definitions and terms, creating a consensus on space practices.

The first standard, *ISO 24113*, concentrates on space debris mitigation requirements, aiming to reduce the growth of space debris to ensure safe and sustainable use of space. The second one, *ISO 26900*, considers standardizing orbit data message formats to improve the exchange of spacecraft orbit information, which is essential for maintaining safe and coordinated space operations. Both objectives converge in the reduction of space debris, with complementary roles in enhancing space safety and sustainability. *ISO 24113* provides the framework for mitigating space debris through comprehensive requirements for space system operations, while *ISO 2690*0 enhances the effectiveness of these operations through standardized data exchange, supporting various essential functions like collision avoidance and coordinated manoeuvring.

When talking about the *CCDS* standards developed together with the ISO *TC20/SC13*, the contents are mainly related to the connection services, information and support systems developed and managed in outer space, since it was created together with standard *ISO 26900*, providing a technical perspective on the matter.

Lastly, if we consider the *IADC Space Debris Mitigation Guidelines,* the approach is more from a regulative perspective, resembling one of the first standards *ISO 24113,* clearly since the scope of the application of these standards will be for the whole globe.

As stated in the introductory paragraph of the document: "*The development of consensus space standards that codify best practices and expected norms of behaviour is one of, if not the, most critical approaches to achieving long-term sustainability of space activities."*[85]

In conclusion, standardisation might be the very first efficient step to follow to reach a common action framework to mitigate debris issues.

[85] IADC guidelines https://orbitaldebris.jsc.nasa.gov/library/iadc-space-debris-guidelines-revision-2.pdf

2.2.1 Enforcement and Monitoring practices

For what concerns the *IADC guidelines*, and *ISO 24113* were mentioned in the Space Debris Compendium COPUOS released on the 6th of April of 2021 as the international standards to consider when implementing regulation on outer space activities[86].

The compendium's analysis reveals that out of 40 countries considered, 16 have established legal frameworks to enforce these standards. This means that 40% of the assessed nations have implemented binding regulations to ensure at least an alignment of some sort with the *IADC guidelines* and *ISO 24113*. Considering that almost half of the world is to some extent in line with the standards, the results are encouraging. These regulations are critical for maintaining a sustainable space environment by preventing and managing space debris.

As follows the list of the application methods for granting that both international guidelines (e.g. *IADC*) and the related standards are being followed:

Country	Application	Compliance and monitoring
Australia	The Act and Rules are binding Australian legislation. The Act outlines certain obligations on the Commonwealth.	*Part 6—Civil penalties, PAR 80* A civil penalty provision of this Act is enforceable under Part 4 of the Regulatory Powers Act. A relevant court may order a person contravening a civil penalty provision to pay to the Commonwealth a pecuniary penalty. *Space (Launches and Returns) Act, 2018*.[87]
Austria	The scope of application of the Austrian Outer Space Act is regulated in its § 1: “(1) This Federal Law is applicable to space activities carried out 1. on Austrian territory, 2. on board	*Sanctions, PAR 14* Everyone who infringes provisions of the present Federal Law or the respective ordinances commits an administrative offence and will be

[86] UNOOSA compendium https://www.unoosa.org/documents/pdf/spacelaw/sd/Space_Debris_Compendium_COPUOS_8_Apr_2021.pdf

[87] Federal Register of Legislation https://www.legislation.gov.au/C2004A00391/latest/text

	of vessels or airplanes, registered in Austria or 3. by a natural person with Austrian citizenship or legal persons seated in Austria. (2) Entitlements under private law are covered by this Federal Law only if Austrian law is applicable according to the rules of private international law. ”	fined up to € 100 000, unless the action represents a criminal offence falling within the competence of the courts. Everyone who carries out a space activity without the authorisation provided for in § 3 and § 7 will be fined minimum € 20 000. *Austrian Outer Space Act, 2011*[88]
Azerbaijan	Presidential orders on "Azercosmos" OJSCo are applicable to all satellite related activities of the Republic of Azerbaijan within and outside the country.	*Chapter 1, general provisions, Article 4* Principles of space activity 4.1. Space activity is carried out based on the following principles: […] 4.1.5. safety of space activity and space industry, reduction of impact from space debris to the environment. *Chapter 2, final provisions, Article 23* Persons who are guilty of violating the requirements of this Law are liable in the cases provided by law. *Law of the Republics of Azerbaijan on Space Activities*[89]
Belgium	The Law applies to any activity which is carried on by an Operator from the Belgian territorial jurisdiction. The Operator is now defined (in the revised text) as he who exercises the ultimate authority over the activity (that is, the	*Chapter VII, final provisions, Article 19* §1. Any person carrying out the activities referred to in article 2 without authorisation shall be liable to a period of imprisonment of

[88] Austrian federal law https://www.unoosa.org/documents/pdf/spacelaw/national/austria/austrian-outer-space-actE.pdf
[89] Law of the Republics of Azerbaijan on Space Activities https://api.azercosmos.az/files/space_activity_law.pdf

	maneuvering of the space object). In the case of nonmaneuverable space objects, the Operator is identified by the Law as he who orders the launch of the object according to specific parameters. The Law doesn't make any distinction in its application whether the Operator is of Belgian nationality or foreign nationality.	between eight days and one year and a fine of between 25 and 25,000 euros, or to one of these sanctions. *Law of 17 September 2005 on the Activities of Launching, Flight Operation or Guidance of Space Objects*[90]
Canada	The Act and its regulations are mandatory in Canada, and also apply to the following persons with respect to their activities outside Canada: (A) Canadian citizens; (B) permanent residents; (C) corporations that are incorporated or continued under the laws of Canada or a province; (D) members of any prescribed class of persons having a substantial connection to Canada related to remote sensing space systems.	*Contravention of subsection 7.3* A corporation that is convicted of an offence under this Part punishable on summary conviction is liable to a fine not exceeding twenty-five thousand dollars. *Aeronautics Act 1985*[91]
Denmark	The Danish Outer Space Act and Executive Order apply to space activities carried out within the Danish State. Furthermore, the Act and Executive Order apply to space activities carried out outside the Danish State on Danish craft or facilities or by Danish operators.	*Part 6, liability and insurance, 11(1)* The operator is obliged to compensate for any damage caused by a space object to persons or property on Earth as well as damage to aircraft in flight. *Outer Space Act, 2016*[92]

[90]Law of 17 September 2005 on the Activities of Launching, Flight Operation or Guidance of Space Objects https://www.belspo.be/belspo/space/doc/beLaw/Loi_en.pdf
[91] Aeronautics Act https://laws-lois.justice.gc.ca/eng/acts/a-2/page-7.html#h-8320
[92] Outer Space Act https://ufm.dk/en/legislation/prevailing-laws-and-regulations/outer-space/outer-space-act.pdf

Finland	Space activities on the territory of Finland or carried on aboard a vessel or aircraft registered in Finland or by a Finnish citizen or a legal person incorporated in Finland fall under the scope of the Act. The Act applies both to governmental and non-governmental space activities. However, the provisions on authorization, insurance and supervision are not applied to space activities by the national Defence Forces.	*Section 5* the operator seeks to prevent the generation of space debris and adverse environmental impacts on the earth, in the atmosphere and in outer space in accordance with section 10. *Section 10* In accordance with generally accepted international guidelines, the operator shall seek to ensure that the space activities do not generate space debris. *Section 21, penal provisions* carries on space activities without an authorisation referred to in section 5 or an approval referred to in section 11. *Act on Space Activities, 2018*[93]
France	The scope of the FSOA covers: – Launch and return operations carried out from the French territory – Launch and return operations carried out by a French operator from a foreign country – Procurement of a launch by a French entity – Control of space objects in outer space by a French operator as a law, it is mandatory for concerned space operators.	*Article 5 SOA* The authorizations granted pursuant to the present act may include "prescriptions" set forth for the safety of persons and property, protection of public health and the environment, in particular to limit risks related to space debris. *Administrative penalties* Possibility to withdraw or to suspend the authorizations in case of violation of the obligations

[93] Act on Space Activities https://finlex.fi/en/laki/kaannokset/2018/en20180063.pdf

		established by the space legislation or of international treaties, […] *French Space Operation Act, 2008*[94]
Germany	The Product Assurance and Safety Requirements for DLR Space Projects are mandatory throughout all phases of all space missions of the DLR Space Administration.	[no penalties associated with breach of sustainable practices in space activities, but they adhere to international treaties] *Outer Space Treaty and the Liability Convention*, which outline general responsibilities and liabilities related to space activities, including the creation of space debris.
Italy	ASI applies the European Code of Conduct for Space Debris Mitigation, which it has signed on 14 February 2005, through its standard contract provisions, by making the European Code of Conduct an ASI standard contracts applicable mandatory document.	*Applicability PAR 2.2* […] The application of the Code of Conduct for Space Debris Mitigation is voluntary and should be applied by the European Space Agency, by national space agencies within Europe. […] The Code of Conduct contains provisions that may be given binding effect by means of legal instruments between contracting parties. *European Code of Conduct for Space Debris Mitigation, 2004*[95]
Japan	JAXA applies the standard to all its space projects. JAXA requires the	[not legally binding, but adhere to Japan's Basic Space Law, which

[94] The SOA https://www.unoosa.org/pdf/pres/lsc2009/pres-04.pdf
[95] European Code of Conduct for Space Debris Mitigation https://www.unoosa.org/documents/pdf/spacelaw/sd/2004-B5-10.pdf

	compliance with the standard to the contractors who design its spacecraft and launch vehicles and recommend other users who apply to launch their spacecraft with the launch vehicles that JAXA has responsibility for their launch and flight safety. To show the compliance, contractors are requested to develop a "Space Debris Mitigation Management Plan" to be authorized by JAXA.	regulates, and outlines responsibilities related to safe use of space] *Article 20(1)* The national government is to take necessary measures to promote outer space development and use that considers harmony with the environment. (2)The national government is to endeavour to secure international cooperation in order to conserve the outer space environment. *Basic Space Act, 2008*[96]
Nigeria	The National Space Research and Development Agency Act 2010, is applicable to all space activities within Nigeria by both citizens and non-citizens.	*Part I, other controls, Article 9* (1) Space activities shall not cause environmental damage to the Earth or outer space or parts of it, directly or indirectly. *Article 10* (1) Any space activity shall be carried out in such a manner as to avoid the generation of space debris. [obtaining the license implies assessing an Environmental Impact Assessment certificate] *Article 43, penalties* (1) An offence is committed under the regulations where a person: […] (b) for obtaining the license makes

[96] BSA https://www.japaneselawtranslation.go.jp/en/laws/view/4194/en

		a statement which is false; (g) fails to comply with any such part of the Regulations as may be prescribed. *Regulations on Licensing and Supervision of Space Activities, 2021*[97]
Russian Federation	National procedures of the Russian Federation (federal legislation and documents of strategic planning of space activities) are legally binding and provide legal regulation of industrial enterprises of the rocket and space industry and research organizations involved in space activities. GOST R 52925-2018 "Space Technology Items. General Requirements for Space Vehicles for Near-Earth Space Debris Mitigation" is not legally binding, but its requirements apply to newly created and modernized spacecraft scientific, socio-economic (including exploring deep space), commercial and special (defense) purpose in accordance with the technical specifications. The standard requirements apply at all stages of the space equipment life-cycle specification development, design, construction, production, operation and disposal.	[not legally binding measures related specifically to space debris, but law issued by Roscosmos is designed to comply with international guidelines on debris mitigation].

[97] Regulations on Licensing and Supervision of Space Activities https://central.nasrda.gov.ng/wp-content/uploads/2023/11/Space-Regulation-official-gazette.pdf

Ukraine	The scope of application of the Law of Ukraine on Space Activity is regulated in its preamble: "This Law defines general legal principles of carrying out of space activity in Ukraine and, under jurisdiction of Ukraine, abroad. Provisions of this Law are distributed to all kinds of activity connected with research and use of outer space". The requirements of the standard URKT-11.03 are compulsory for all subjects of space activity. They extend to launch vehicles and spacecraft, including the ones that are developed for foreign organizations, if the contract does not specify other space debris limitation activity.	*Article 8, regulations governing space activity* The regulations governing space activity in Ukraine include operating standards for space facilities, and standards and regulatory texts governing procedures for the following: […] Environmental protection in the course of space activity. *Section VII, final provisions, Article 29* Offences under the legislation on space activity in Ukraine shall be punishable by disciplinary, civil-law or criminal penalties in conformity with Ukrainian legislation currently in force.
United Kingdom	OSA is a mandatory, statutory instrument applying to UK nationals (i.e. personal rather than territorial).	*Schedule 1, particular conditions that may be included in licenses, PAR 1* Conditions as to compliance with—[…] (g) space debris mitigation guidelines. *Penalties for offences under this Act, Article 55* A person who commits an offence under a provision of this Act, other than section 24(8), section 32(9), section 33(8), section 40(2) or (3), section 41(5), section 42(5), section 66(5) or Schedule 4, is liable […].

		Space Industry Act 2018[98]
United States of America	(1) National Space Policy the National Space Policy provides guidance to all U.S. Government Departments and Agencies. (2) U.S. Government Orbital Debris Mitigation Standard Practices These government orbital debris mitigation standard practices apply to all U.S. Government Departments and Agencies involved in space operations, including regulatory authorities. The implementation of these standard practices is executed through Department/Agency specific requirements or regulations, as applicable. The National Space Policy requires the head of the department or agency sponsoring a launch to approve exceptions to the Standard Practices and notify the Secretary of State.	*Preserving the Space Environment to Enhance the Long-term Sustainability of Space Activities.* (a) Preserve the Space Environment. To preserve the space environment for responsible, peaceful, and safe use, and with a focus on minimizing space debris the United States […]. *National Aeronautics and Space Program, 2017*[99] Proposed § 453.5(c) would specify the information that must be included in an ODAP to demonstrate compliance with § 453.5(a) and (b). Specifically, the ODAP must include (1) a demonstration through environmental qualification and acceptance testing that the system is designed to limit the release of orbital debris. [If not, civil penalty as for Swarm Technologies in December 2018[100]]

Table 8: Enforcement Framework

98 Space Industry Act https://www.legislation.gov.uk/ukpga/2018/5/pdfs/ukpga_20180005_en.pdf
99 National Aeronautics and Space Program https://uscode.house.gov/view.xhtml?path=/prelim@title51/subtitle2/chapter201&edition=prelim
100 Penalty https://docs.fcc.gov/public/attachments/FCC-18-184A1.pdf

2.2.2 Advantages of Standardisation: Reduced Legal Transition Risk and Positive Impacts on Earth's Climate Crisis Mitigation

To analyse the perks of standardizing the space practices, I will proceed by using two methods: Transition Risk analysis and an Impact (positive and negative), Risk and Opportunities analysis (IRO analysis).

I will consider now how Transition Risk is mitigated if standardisation is taken into account. If we consider *IADC Guidelines*, point 4 "general guidance" in detail: (1) A management plan addressing space debris mitigation activity; (2) A plan for the assessment and mitigation of risks related to space debris, including applicable standards […], the standard is guiding the necessary plans of action that might be implemented when complying with the guidelines.

This mechanism could decrease legal-related transition risks in terms of compliance with new regulatory requirements, which will certainly be part of future discussions on space sustainability, especially at the international level (e.g. ESRS standards on sectors for space activities[101]). By creating a uniform set of rules and guidelines, this mechanism can ensure that all parties involved in space activities are on the same page regarding compliance. This uniformity reduces the ambiguity and complexity associated with adhering to multiple, potentially conflicting national regulations. As a result, companies and nations can focus on innovation and development rather than being misled by legal uncertainties. Standardized regulations can also facilitate smoother international cooperation. As space activities often involve multiple countries, having a common legal framework can streamline collaboration and reduce the potential for disputes. This is particularly important in joint missions, international space stations, and projects that require shared use of space resources.

To add to this, compliance towards new standards not only is a big sign of up-to-date management choices but also a sign of transparency, which ultimately leads to an increased sense of trust from the stakeholders, resulting in reduced reputation-related transition risks.

When a company or organization actively follows the latest standards and regulations, it shows a commitment to staying current with industry best practices and technological advancements. This proactive stance indicates that the management is forward-thinking and open to changes in the regulatory and operational environment. Stakeholders, including

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[101] SEC 1 sector classification
https://www.efrag.org/sites/default/files/sites/webpublishing/SiteAssets/Working%20Paper%20Draft%20ESRS%20SEC1%20Sector%20Classification%20Standard[1].pdf

investors, customers, partners, and regulatory bodies, view this as a positive attribute, reflecting a well-managed and progressive organization.

Therefore, the application of standards to space activities, not only could be the most efficient way to mitigate the debris crisis and to consent to a sustainable use of outer space but also might offer a great opportunity to reduce transition risk for any actor in the space economy.

To continue, I will now focus on the IRO analysis.

The Positive Impacts related to climate crisis mitigation that space exploration and space use have brought to humanity are numerous.

Starting with the UNOOSA public release of 2015, *Space-based information, and the Sendai Framework for Disaster Risk Reduction*[102], the relevant information that emerges from the document relates to the use of the Hyogo Framework for Action (HFA), which refers to: "earth observation, space technologies remote sensing, and geographic information systems (GIS) as a way to contribute to hazard modelling and prediction, weather and climate modelling and forecasting, communication tools and the studies of the costs and benefits of risk assessment and early warning; and to support disaster risk reduction, particularly for training and for the sharing and dissemination of information among different categories of users." The document provides proof of how space technologies and GIS are instrumental in the economic analysis of disasters. They help assess the economic impacts and the benefits of mitigation strategies, enabling better allocation of resources to areas where they are most needed and can be most effective. This cost and benefit analysis is crucial for informed decision-making in disaster risk management. They also provide valuable data for training emergency responders and disaster management professionals, enhancing their preparedness and response capabilities. Additionally, these technologies enable the sharing of critical information among various users, including governments, NGOs, and the public, fostering a collaborative approach to disaster risk reduction.

To mention other publications by UNOOSA related to the importance of Space for Earth's people and environmental safety: in 2015, *The United Nations/Germany International Conference on Earth Observation — Global Solutions for the Challenges of Sustainable Development in Societies at Risk*[103] states that Earth observation reduces disaster risks;

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[102] Positive impacts of space activities for climate change https://www.unoosa.org/res/oosadoc/data/documents/2015/aac_1052015crp/aac_1052015crp_16_0_html/AC105_2015_CRP16E.pdf

[103] Global Solutions for the Challenges of Sustainable Development in Societies at Risk https://www.un-spider.org/sites/default/files/FlyerBonnConf15_KP.pdf

identify different alternatives to plan adaptation to climate change […]". This document also emphasized the fact that through disaster risk management, societies that might be in danger could be protected through Earth's monitoring from space. As a result, authorities can issue timely warnings and implement emergency response measures more effectively. It might result in increased resilience and preparedness of communities, reducing the overall impact of disasters on human lives, infrastructure, and economies. Moreover, the data collected from space can inform long-term planning and risk mitigation strategies, contributing to sustainable development and better resource management. This integration of space technology into disaster risk management frameworks exemplifies how advancements in space exploration can have profound benefits for societal well-being and safety on Earth.

To add to this, the *Inter-Agency Meeting on Outer Space Activities on the use of space technology within the United Nations system to address climate change issues*[104] by UNOOSA stated how relevant space activities have been to "improve knowledge on the influence of solar electromagnetic radiation on Earth's environment, including climate". This document highlights the fact that in terms of weather and climate modelling and forecasting, satellite data greatly improves the accuracy of weather forecasts, which helps communities better prepare for severe weather events like hurricanes, storms, and heavy rainfall. Also, if we think about the long-term data collected from space technologies, studying the patterns contributes to understanding climate change, which is essential for climate modelling and forecasting. Accurate climate models are fundamental for developing adaptation strategies to mitigate the impacts of climate change on vulnerable regions.

The latest document redacted by UNOOSA was written in 2016 and it dealt with Agricultural topics related to space: *Space for Agriculture Development and Food Security*[105]. In the paper, space-based technologies are considered to play a crucial role in monitoring crops, livestock, forestry, fisheries, and aquaculture, supporting decision-making in agriculture and food security. These technologies help address challenges such as adverse weather conditions, droughts, floods, desertification, and land degradation. They are utilized by United Nations organizations to ensure access to sufficient nutritious food for all and are instrumental in capacity-building efforts for developing countries, particularly in remote sensing, satellite navigation, and meteorology.

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[104] Inter-Agency Meeting on Outer Space Activities on the use of space technology within the United Nations system to address climate change issues https://www.unoosa.org/pdf/reports/ac105/AC105_991E.pdf

[105] Agriculture and food topics related to outer space https://www.unoosa.org/res/oosadoc/data/documents/2016/stspace/stspace69_0_html/st_space_69E.pdf

To finish with, I will now talk about the available Opportunities, from the financial side in the IRO analysis.

If we consider the Legal Transition Risk, the relative Opportunity arising from early compliance with the standards would be lower operating costs (e.g., higher compliance costs, increased insurance premiums); extended life of existing assets despite policy changes; decreased costs and/or reduced demand for products and services resulting from fines or judgements. For instance, organizations that comply early can avoid the higher compliance costs associated with last-minute implementations, such as expedited shipping of necessary materials, rush fees for services, or overtime pay for workers. Additionally, these organizations can spread out the costs of compliance over a longer period, making the financial burden more manageable.

To add to this, in the context of insurance, companies that demonstrate early compliance with new standards often benefit from lower insurance premiums. Insurers view these companies as lower-risk clients because they are less likely to incur claims related to non-compliance issues, such as environmental fines, accidents, or regulatory breaches.

In conclusion, Positive Impacts for space-climate-change tracking and disaster risk management, lower Legal Transition Risk for complying with mandates and regulations of existing products and services, and lower costs as an Opportunity deriving from compliance result in providing very good reasons for any company to apply outer-space standards.

2.2.3 Disadvantages: Technological Challenges, Obsolescence and New Costs

Standardizing outer space activities could be a threat to companies that are not up to date in terms of technological advances. The technology-related transition risks might be a positive driver when it comes to creating positive competition among the space actors and pushing towards new trends of more advanced and non-carbon-intensive technologies.

To provide a perspective on this matter, we will consider *ISO 24113, ISO 26900, CCSD standards,* and *IADC Guidelines.* They all provide terms and definitions for specific space activities, for which is required a certain level of technical expertise on behalf of the companies performing the said activities.

To mention some examples of each of the categories: *ISO 24113,* in point 3.19 mentions the "passivation" method, which consists of a metal-finishing process to prevent corrosion. By applying this practice, a chemical barrier to avoid rusting is created, the maintenance costs are lower, and the life of the object is therefore extended. This process is one of the most important ones to lower space debris arising from metal corrosion, but it is also costly and not all of the companies can perform it.

ISO 26900 in its abstract mentions, in point (f) “assessing mutual physical and electromagnetic interference among satellites orbiting the same celestial body (primarily Earth, Moon, and Mars at present)” which mainly entails very advanced techniques of electromagnetic measuring.

The primary difficulty lies in the complexity and precision needed to measure and analyse electromagnetic signals in the crowded and dynamic environment of space. Satellites operate nearby, and their orbits are constantly shifting due to gravitational forces, solar radiation pressure, and other events. This dynamic nature makes it challenging to predict and monitor potential interference accurately.

Additionally, the electromagnetic spectrum used by satellites is densely packed with signals from various sources, including other satellites, ground stations, and space debris. Differentiating between these signals and isolating the specific interference caused by satellites is a highly complex task that demands sophisticated signal processing algorithms and advanced measurement techniques.

These challenges, again, imply costly solutions and high level of knowledge.

Both *CCSD standards* and *IADC Guidelines* respectively mention once again space technological expertise in points 5.3.1 Geosynchronous Region; 5.3.2 Objects Passing Through the LEO Region, and in point (1) “space internetworking services”.

Key new technologies of the New Space sector include scalable, cost-efficient satellites, and reusable rocket technology. To mention some examples, here follows a list of the main innovative space technologies.

Micro Launchers are cost-effective technologies dedicated to launching small satellites and cube-satellites, catering to the increasing demand for miniaturized payloads. Another example is Small Satellites, which are expected to dominate future launches, small satellites (weighing less than 500 kg) are crucial to the dynamic space market. Space data-related technologies involve information collected through space-based observations and measurements. Other examples fall under the categories of Smart Materials and Advanced Communication Technology.

In summary, technological transition risk in the case of standardization might be increased, mainly due to the transition towards lower emission technologies. Another case could be the one for companies to invest in technologies that will no longer serve the scope once they want to comply with the standard.

I will now move on to the Impact and Risk & Opportunities analysis.

Starting off with the Impacts, the negative ones might be that due to the high level of technologies requested, the waste would increase.

Standardization for sustainable outer space practices can produce negative impacts by making older technologies obsolete. This obsolescence can lead to increased levels of space waste and debris, increasing once again an already significant problem.

Standardization often entails the adoption of new protocols, materials, and technologies that are more efficient or safer. The standardization process looks at the long-run viability of space, therefore old methods are no longer considered when following this purpose. This means that existing technologies, which do not meet the new standards, are rapidly phased out. Satellites, spacecraft, and other space assets that were built under previous guidelines may no longer be viable, leading to their decommissioning. These older technologies, if not properly managed, contribute to the growing accumulation of space debris. The issue of space waste is particularly concerning because once a satellite or piece of technology becomes obsolete, it often remains in orbit unless actively removed. This process is not straightforward. Deorbiting and safely managing the re-entry of old satellites and equipment require substantial resources and coordination.

To finish with the possible Risks arising from the standardisation process I will focus on how companies and countries with significant investments in existing space technologies may face financial losses if their assets are deemed non-compliant with new standards.

This can create problems in the acceptance of standardization efforts and slow down the adoption of necessary sustainable practices. The cost of upgrading or replacing technology to meet new standards can be prohibitive, particularly for smaller nations or private entities, potentially limiting their participation in the space industry. For companies, particularly those with large fleets of satellites or extensive space infrastructure, the cost of upgrading or replacing non-compliant technology can be prohibitive. These organizations have already invested heavily in the research, development, and deployment of their current technologies. If new standards mandate significant changes or the complete decommissioning of these assets, the financial burden can be immense. This includes not only the direct costs of building and launching new technologies but also the indirect costs associated with operational disruptions and potential revenue loss during the transition period.

In conclusion, a higher Technological Transition Risk, Negative Impacts such as increased waste for obsolete space objects or technologies, Risk arising from the possibility of new costs or financial losses, might represent barriers to the development of sustainable outer space standards.

2.3 Ratings for Outer Space Practices

Ratings play a vital role in the boost for sustainable practices in outer space. By providing a standardized, quantitative assessment of various space missions and technologies, it is possible to evaluate the environmental impact, safety, and efficiency of space operations. By establishing clear benchmarks and accountability, ratings encourage space-faring entities to adopt best practices and innovate towards more sustainable solutions.

Furthermore, they guide policymakers in crafting effective regulations and foster transparency and trust among stakeholders, including space agencies, private companies, and the public. Through comprehensive evaluation and continuous monitoring, ratings are essential tools in promoting a sustainable future in space.

2.3.1 General SSR Methodology

It is based on a points aggregation system in which more points contribute to a higher rating. It is formulated as a combined score based on the evaluation of individual modules, where different aspects of space sustainability are covered. Any satellite mission can be rated, regardless of the number of satellites, type of orbit, or mission phase.

According to the 73rd International Astronautical Congress (IAC) in 2022, the SSR system is divided into mainly three phases: *contractual phase*, *input gathering phase and computation*, *feedback and re-computation loops*.

The *contractual phase* sets a legal framework for which a non-disclosure agreement is signed, since the entity assessing the rating is a third party and the disclosure of information from the company is not mandatory.

The *input and gathering phase and computation* consists in providing all the information required according to the modules of the rating.

Finally, the *feedback and re-computation loops* are based on the principle of companies being able to increase their performance after the first assessment by the rating entity.

As written in the publication by SSR, *Promoting responsible space practices: A primer on the Space Sustainability Rating*[106] during the Aerospace Europe Conference 2023 – 10TH EUCASS – 9 TH CEAS, the process will be analysed in the following paragraphs.

[106] Space Sustainability Rating https://spacesustainabilityrating.org/wp-content/uploads/2023/08/AEC2023_SSR_Paper.pdf

a. IADC guidelines

To embark in the rating process, an entity has to perform a preliminary step by answering bare-minimum threshold that an operator has to reach before getting the rating.

Will your mission comply with IADC guideline 5.3 for post mission disposal?
Do you commit to passivate your spacecraft at the end of operations, as defined in IADC guideline 5.2.1?
Do you have a space debris mitigation plan, as defined in the IADC guideline 4?
Does your mission avoid the intentional destruction of any space object?
Do you commit to provide supporting documentation to the SSR issuer during the rating process?

Table 9: Minimum Threshold for SSR

The answers can either be yes/no/partially, providing a rationale for the latter.

b. Score computation

Each SSR score computation process can be divided into *data collection, data verification, score computation, and feedback loop.*

Data collection is fundamental especially because it's a voluntary-based practice: data should be accessible and shareable with the SSR issuer at any given time during the mission. Data verification is based on a points system, for which weights are given to a certain level of verification, following this formula:

$$points_{earned} = p_{input} \times factor_{\,verif}$$

The following table shows the weights attached to the type of verification:

Level of Verification	**Factor**
Assertion Affirmative statement by the applicant is provided, without supporting documentation	0.5
Technical documentation supporting the assertion	0.6

Supporting technical documentation on the mission design is disclosed to the SSR Entity	
Public release of the technical documentation Supporting technical documentation is submitted to a government or non-profit available for public review	0.8
Authority – Independent technical Review An independent technical review or the confirmation of the compliance by a third-party technical expert is provided	1

Table 10: Level of Verification and Factor Weights of SSR

Score computation is based on the score of each module.

The *feedback loop*, to conclude, is based on the issuer providing recommendations that the entity shall apply, and if it does then the issuer shall provide an additional opinion on the work performed.

c. *Rating modules*

The Space Sustainability Rating is a composite indicator that encompasses six different modules: Mission Index (MI), Collision Avoidance Capabilities (COLA), Data Sharing (DS), Detectability Identification and Trackability (DIT), Application of Design and operation Standards (ADOS), External Services (ES).

To each of them a weight is attached, according to the importance of the module.

Modules	**Weight**	**Type**
Mission Index	50%	*Quantitative*
Collision Avoidance Capabilities	16.5%	Qualitative
Data Sharing	16.5%	Qualitative
Detectability, Identification and Trackability	12%	*Quantitative*
Application of Design and Operation Standards	5%	Qualitative
External Services	Bonus	Qualitative

Table 11: Modules and Weights of SSR

Each module is given a score S_{module} according to the compliance to the rating.

$$S_{module} = \frac{\sum_{j=1}^{n}(p_{\ input\ j} \times \ factor_{\ verif\ j})}{available\ points_{\ module}}$$

Where $p_{\ input\ j}$ is the number of points awarded for the compliance to the input criteria, $factor_{\ verif\ j}$ is the one explained in the previous table, and $available\ points_{\ module}$ are the total number of points available in the evaluated module.

There is a special case for constellation, for which aggregated parameters are considered:

$$p_{p\ fleet} = \frac{p_{ps} \times N_{ps} + p_{pf} \times N_{pf} + p_{p}\ \text{design} \times N_{no}\ \text{attempt yet}}{N_{fleet}}$$

Where: p is the probability, PS is the "Passivation Success" scenario, PF is the "Passivation Failure" satellite scenario, N is the number of satellites for each scenario.

In the following paragraphs, to provide technical details on the computation of the SSR, the *quantitative* factors only will be analysed.

2.3.2 Mission Index

In the Publication *Promoting Responsible Space Practices: A Primer on the Space Sustainability Rating*, for the Aerospace Europe Conference 2023, the Mission Index is defined as a "quantitative model based on ESA's space debris index framework […]. It assesses the mission's risk as the product of the probability p_c and severity e_c (effect) of a collision, integrated over the object orbital lifetime"[107].

Broadly speaking, the formula is computed as follows:

$$risk = probability\ x\ severity = \ p_c\ x\ \ e_c$$

The probability terms show the likelihood of an object taking part in a "fragmentation event", and it changes according to the density of the objects located in each area:

$$p_c = 1 - e^{-\ \rho\ \text{x}\ \Delta\text{V}\ \text{x}\ \text{A}\ \text{x}\ \Delta\text{t}}$$

[107] Reference to definition of Mission Index https://spacesustainabilityrating.org/wp-content/uploads/2023/08/AEC2023_SSR_Paper.pdf

The formula shows that the probability of collision is directly proportional to the density of the object ρ, the impact velocity ΔV, and the area A, considering the timestamp increment value Δt. The overall output ranges between 0 and 1, after having followed a normalization process.

The severity instead quantifies the consequences of such an event, and it is calculated as follows:

$$e_c = \frac{1}{Atot} \sum_{i=1}^{Nt} p_c \ (t = 15ys)Ai$$

In the document is explained as "a weighted sum of the cumulated collision probability between the debris created and the targets. The weights are the ratio between the cross-sectional area of the objects present in the orbital region (i.e., in the bin) over the total cross-sectional area of all bins where targets are generated".

Therefore, the index value is expressed as follows:

$$I(t) = \ p_c \, x \ \ e_c$$

To compute the overall Mission Index, different sub-indexes are computed for each phase of the mission, resulting in the following formula:

$$I_{mission} = \sum_{i=1}^{n} (I_{early\ phases} + \ I_{\ operation} + \ I_{disposal})$$

2.3.3 Detectability, Identification and Trackability

The DIT parameter is defined as "the level of ability for observers to detect, identify and track the mission". The SSR, in the above-mentioned document, is not yet displaying the *identification* component, so the formula goes as follows:

$$S_{DIT} = \frac{1}{3}\, S_{detectability} \, x \, \frac{1}{3}\, S_{trackability} + \frac{1}{3}\, S_{questionnaire}$$

a. Detectability

Detectability can be based on two main components to gather data on satellites and other human-made objects: optical detection and radar detection.

Optical detectability is based on a binary scoring method which sets the threshold for detectability at a visual magnitude of 15, which stands for a telescope of 0.25 meters.

Radar detectability defines a "detection event" as the situation in which the returning radar signal from the detected object is strong enough to be distinguished form the background noise.

The scoring thresholds are summarized as follows:

Sub-components	Metrics	Scoring Thresholds		
		0	0.5	1
Optical detectability	Visual magnitude	/	< 15	> 15
Radar detectability	Probability radar detection	<50%	50-75%	>75%

Table 12: Scoring Thresholds of SSR

Therefore, overall detectability is computed in this way:

$$S_{detectability} = 0.5\ x\ S_{detectability}(optical) +\ 0.5\ x\ S_{detectability}(radar)$$

a. Trackability

Trackability, in the same document, is considered to be "the process in which the observer has already detected and identified a spacecraft and next seeks to monitor and predict the evolution of the orbit of the spacecraft over time". A fundamental assumption of the definition is that the observer does not have full knowledge of the orbital parameters, so it should be considered a level of uncertainty in the tracking process.

The formula used for trackability is the following:

$$S_{trackability} = \frac{1}{3}\ pass\ duration\ x\ \frac{1}{3}\ orbital\ coverage + \frac{1}{3}\ interval\ duration$$

The scoring thresholds are organized like this:

Metrics (both optical & radar)	**Scoring Threshold**			
	0	0.25	0.5	1
Pass duration	< 120”	120-180”	180-400”	>400”
Orbital coverage	<10%	10-25%	25-60%	>60%
Interval duration	>12h	/	12h-6h	<6h

Table 13: Scoring Thresholds of SSR

To sum up, we would choose the maximum between the optical trackability and the radar trackability:

$$S_{trackability} = \max\left(S_{trackability\ optical}; S_{trackability\ radar}\right)$$

2.3.4 Tier Scores, the final step

Whenever the whole process is brought to an end, a badge is awarded to the company, according to the score it received.

Tier Level	**Score**
Bronze	Between 40% and 55%
Silver	Between 56% and 70%
Gold	Between 71% and 80%
Platinum	Between 81% and 100%

Table 14: Final Score

2.3.5 Advantages of Space Sustainability Rating: Lower Compliance Costs and Investor Attraction

To follow the analysis, the advantages that can be found in rating sustainability in space activities will be seen from a Transition Risk perspective and an IRO perspective, as done for the standardization process.

From a Transition Risk perspective, the rating is important for mainly four reasons: Regulatory Compliance, Risk Mitigation, Long Term Planning, and Investor Attraction.

When it comes to regulatory compliance, showing adherence to potential future regulations related to space sustainability offers several critical benefits for companies. By complying with anticipated regulations, companies can avoid being caught unprepared by policy changes.

This lowers legal transition risks: companies that demonstrate compliance with anticipated regulations show a commitment to legal preparedness, reducing the risks associated with legal transitions. A strong sustainability rating can differentiate a company from competitors who may be slower to adapt. Early compliance can also open up opportunities to benefit from government incentives, grants, or preferential treatment in public contracts that favour sustainable practices. Attracting responsible investors becomes easier as investors increasingly prioritize sustainability and regulatory compliance in their investment decisions. Companies that demonstrate proactive compliance can attract socially responsible investors, potentially increasing their access to capital. The proactive reduction of legal and operational risks associated with regulatory changes makes a company more attractive to investors who are risk-averse and seek stability.

To stay within the transition risks perspective, another element that we shall consider is the Competitive Advantage that a rating creates for the users.

Market Risk is characterized by the possibility of the costs of raw materials rising or changing consumer behaviour due to climate change concerns.

The rising costs of raw materials can significantly affect a company's bottom line. For instance, materials required for satellite construction, such as metals and specialized components, may become more expensive due to supply chain disruptions, increased demand, or regulatory changes aimed at reducing environmental impact.

Other than this, changes in consumer behaviour also represent a significant market risk. As awareness of climate change grows, consumers and businesses are increasingly favouring products and services that are sustainable and environmentally friendly. This shift can affect demand for traditional products and services, compelling companies to adapt quickly to maintain market share. Businesses that fail to address these changes risk losing customers to more sustainably minded competitors.

In this context, a good sustainability rating can serve as a crucial differentiator for a company, especially in an emerging market like space services. A strong sustainability rating indicates that a company adheres to high environmental standards and practices responsible resource management. This can enhance the company's reputation and make it more attractive to environmentally conscious consumers and partners.

The latter argument brings the discussion towards Reputational related risks are managed as well: being rated as compliant, or in general being rated, gives a sense of trust and commitment to responsible space practices. This might entail a long-term ethical and up-to-date vision of the company, attracting new socially responsible investors.

In these terms, the attraction of new investors represents a financial opportunity for the company, from the IRO perspective. Financial risks are reduced as companies that comply with future regulations before they become mandatory avoid the risk of incurring fines, penalties, and other legal costs associated with non-compliance and it also allows for better budget planning and allocation of resources towards meeting regulatory requirements.

To add to this, other financial opportunities and positive impacts might arise during the feedback and loop phase of the Sustainability Rating System (SSR).

A higher sustainability rating often correlates with better collision avoidance measures, known as COLA (Collision Avoidance). Companies with advanced collision avoidance strategies can reduce the risk of costly satellite collisions, which not only protects their assets but also minimizes operational disruptions. This proactive approach to preventing collisions can result in significant cost savings, as repairing or replacing damaged satellites is extremely expensive. Additionally, by preventing collisions, companies contribute to the reduction of space debris, furthering sustainability goals.

Another area is extending the mission lifetime of satellites. Implementing responsible end-of-life disposal practices and avoiding risky manoeuvres can significantly prolong the operational life of satellites. Longer mission lifetimes mean that satellites can continue to provide valuable services for extended periods, increasing the return on investment. This longevity reduces the frequency and need for launching replacement satellites, leading to cost savings and reducing the environmental impact associated with frequent launches.

Reduced operational risks are also a crucial benefit. By adhering to space sustainability guidelines, satellite operators can minimize the risks associated with space debris. Effective debris mitigation practices ensure that satellites remain safe and functional, avoiding financial losses and service interruptions that can occur from debris-related damage. This risk reduction translates into more stable and reliable operations, enhancing customer satisfaction and trust.

Therefore, during these phases, the company can enhance its performance leading to both financial benefits and positive impacts on the space environment.

Broadly speaking, the advantages are mostly similar to the ones of the Standardization process, but the feedback and loop phase is providing with much more possibilities to create a higher positive impact on the space environment and also create more financial opportunities.

2.3.6 Disadvantages in Ratings: Increased Technological Investments and Expectations Pressure

Rating outer space activities could imply disadvantages, which differently from the other types of disadvantages in Standardization, transition risks and IRO are overlapping in some cases.

To start the analysis, I will focus on the relative drawbacks transition risks perspective.

When it comes to reputational transition risks, the rising expectations of the public and stakeholders place companies under increased scrutiny. Higher expectation means that any failure to meet these standards can result in significant reputational damage. When companies fall short of public expectations, they risk losing the trust and confidence of their customers, investors, and the broader community. Firstly, reputational damage can result in decreased customer loyalty and reduced sales; secondly, failing to meet public expectations can negatively impact investor relations; thirdly, reputational damage can affect a company's ability to attract and retain top talent.

In summary, reputational transition risks are significantly influenced by the growing expectations of the public and stakeholders and can result in financial losses as well, representing a financial threat as well (from an IRO perspective).

For market transition risks, changes in market demand for satellite services could mean that longer mission lifetimes do not necessarily translate to increased profitability.

Concerning legal transition risk, there might be intersections with financial risks arising from IRO analysis. The major disadvantage that comes from it is the higher costs of being up to date with new technologies, processes and personnel. To add to this, a constant update on procedures and documentation might be resource-intensive, implying additional costs again. New technologies and infrastructures, especially if they must comply with e.g. COLA requirements, require much higher investments. Moreover, costs for: grating constant monitoring, collision avoidance measures, sophisticated algorithms and real-time decision-making capabilities (staff must be trained accordingly, which implies more time and resources) must be considered as additional operational expenses. Extending the operational life of satellites may require more frequent maintenance and potential upgrades, incurring once again in additional costs.

This entire argument is related to financial risks in the long run, from an IRO perspective.

Negative impacts instead might be related to disposal procedures.

Negative impacts might arise, particularly related to disposal procedures. As sustainability requirements become stronger, companies are expected to adopt technologies and practices that are more carbon-neutral and environmentally friendly. This shift means that older versions of satellites and other space-related objects, which may not meet these new standards, will become obsolete. Implementing a sound strategy to dispose of these outdated objects is both costly and necessary for sustainability.

Firstly, the disposal of older satellites and space debris involves significant expenses. Companies must invest in advanced technologies and procedures to safely deorbit or relocate these objects to graveyard orbits. Secondly, the disposal of outdated space objects must comply with international regulations and best practices to prevent further space debris generation. Failure to comply not only leads to financial penalties but also damages a company’s reputation and sustainability rating.

Moreover, the environmental impact of disposal procedures themselves cannot be overlooked. Even with the best technologies and practices, the process of deorbiting or relocating space objects generates emissions and consumes resources.

Summing up, the negative impacts associated with disposal procedures stem from the high costs and complex logistics involved in safely and sustainably managing obsolete space objects.

If a broader perspective is to be considered, some countries display a higher level of regulatory requirements, these regions will face higher costs. This dynamic brings competitive disadvantages, that would eventually increase global disparities.

Overall, more or less the same problems are being highlighted when it comes to standardization and rating processes.

2.4 Sustainable Outer Space Indexes

In the following paragraphs, I will be analysing two types of sustainability-tracking indexes: the SSI index and the CNES index.

The Space Security Index (SSI) is a collaborative project that assesses the security of outer space. It evaluates the global trends and developments affecting the security and sustainability of outer space activities. It is built on themes such as knowledge of outer space, access and usage of outer space… to which indicators are related.

The CNES Space Sustainability Index, developed by the French space agency CNES, focuses specifically on the sustainability of space activities. This index measures and tracks various factors related to the environmental impact, safety, and efficiency of space missions.

2.4.1 Space Security Index

The first Index that I will consider for tracking sustainable practices in space is the SSI index (Space Security Index).

It mainly focuses on the ability to grant Space Security, which reflects the intent of the 1967 Outer Space Treaty: "*The secure and sustainable access to, and use of, space and freedom from space-based threats*." It serves to provide a commonly accepted guide for space sustainable practices.

The most recent annual summit took place in 2019. Space Security Index 2019 is the 16th annual report, and most recent, on developments related to safety, sustainability, and security in outer space. The document drafted during the summit will be used as a reference: 2019 Executive Summary on Space Security Index108.

The SSI is composed of 17 indicators that are grouped according to different themes.

a. *Theme 1: Condition and Knowledge of the Space Environment*

The first indicator is called "Orbital debris" – indicator 1.1.

Its first position highlights once again the urge to assess space debris as one of the most important issues for sustainability in the field. As argued in the document, Orbital Debris is the main threat to operational spacecraft, e.g. the International Space Station. The index intends to assess the level of security according to this parameter, by providing data on the level of debris.

[108] Executive summary of the SSI Annual Report https://spacesecurityindex.org/wp-content/uploads/2019/10/SSI2019ExecutiveSummaryCompressed.pdf

The second indicator is named “Radiofrequency spectrum and orbital positions” – indicator 1.2.

The increasing trend of privatisation of space activities has brought new challenges even in radio frequencies and satellite orbit operations. Whenever two satellite systems require overlapping frequencies within the same coverage zone on Earth, problems might arise.

The third one is the “Natural hazards originating from space” – indicator 1.3.

This indicator is specifically related to Sun activity, for which if we experienced a strong solar flare the immediate result would be increased power surges in transmission lines and pipelines, and disruption of radio communications. This might also create energy blackouts, or increase drag on e.g. satellites, causing them to move to a lower orbit.

The fourth one from the first theme is “Space situational awareness” – indicator 1.4.

The indicator refers to the ability to detect, track, identify and catalogue objects in outer space e.g. space debris, active or non-active satellites.

b. Theme 2: Access to and Use of Space by Global Actors

The first indicator of this set is called “Space-based Global Utilities” – indicator 2.1.

As the SSI annual report says: “Millions of individuals rely on space applications daily for functions as diverse as weather forecasting; navigation; surveillance of borders and coastal waters; monitoring of crops, fisheries, and forests; health and education; disaster mitigation; and search-and-rescue operations.”

The second indicator is named “Priorities and Funding levels in Civil Space Programs” – indicator 2.2.

This indicator is relevant for the debris discussion because since the number of space actors has increased, the direct stake they have towards sustainability is higher. Also, civil space activities such as launching and managing satellites, conducting research and space exploration, would have a huge impact on space sustainability.

The third indicator is “International Cooperation and Capacity-Building in Space Activities” – indicator 2.3.

The latter is relevant since cooperation is essential for reaching the principle of safe space usage and freedom of access.

The fourth indicator is “Growth in commercial and private space activities” – indicator 2.4, which highlights the importance of space sector in technological advances.

“Public-private collaboration on Space Activities” is the indicator 2.5.

Once again, the importance of collaboration between private and public sector is fundamental to make sustainable practices possible in outer space. Additionally, it is relevant to national security, because most of the time spacecraft is a critical national infrastructure.
Lastly, the "Space based military systems" – indicator 2.6 stands for the space usage as for military purposes. This kind of practice might not be sustainable in the long run because might imply attrition between countries.

c. *Theme 3: Security of Space System*

The "Electromagnetic and cyber vulnerabilities" – indicator 3.2 tries to make a distinction between cyber-attacks and radiofrequency energy interference, for which once again the consequences would create interferences with space activities, causing potentially strong impacts as said before.
"Reconstitution and Resilience of Space Systems" – indicator 3.2 considers the ability of a spacecraft object to be rebuilt after or to be resilient to certain attacks, which entails longer life span and therefore higher sustainability level.
"Space-based negation-enabling capabilities" – indicator 3.4 aims at considering all the hostile use of space-based activities, that would create attrition among space participants and would put at risk the peaceful use of space itself.

d. *Theme 4: Outer Space Governance*

The first indicator "National Space Policies, strategies and Laws" – indicator 4.1 is considering the drafting and the publication of national policies and the different strategies to implement them.
The second one is the "United Nations forums for Space Security Governance" – indicator 4.2 which focuses on the importance of space management as a resource accessible to everyone and that can only be used for peaceful pursuits.
"Other initiatives" – indicator 4.3 relates to all the other space related initiatives that were not mentioned before, especially the activities related to diplomatic and governance initiatives.

2.4.2 CNES Space Sustainability Index

The French space agency, *CNES*, is exploring the integration of more comprehensive set of criteria into the already present framework (*IADC, ISO…*). These criteria aim to provide an evaluation of space missions, tailored to diverse contexts, and enhanced with descriptions and explanations that facilitate dialogue between operators and regulatory authorities. The index serves to provide a general assessment of the situation of space and give a tool to control the on-going activities.

To add to this, the French Space Operation Act (*FSOA*) ensures that space missions by French operators are safe and comply with strict technical regulations. Operators must meet 20 specific requirements to get their flight licenses. If they fail to meet even one, they can be denied a license, regardless of how minor the non-compliance is.

a. Metrics

The index is built upon three core metrics: the characteristics of the system, the producer of the index, and the destination of the index. Its primary objectives are to quantify the state of the space environment, evaluate the contribution of individual objects to the overall condition, support decision-making, and facilitate communication with external actors.

Quantifying the state of the environment involves measuring density in each orbital regime, assessing the impact on space services, activities, and use, and predicting re-entries and collisions. This comprehensive assessment helps in understanding the current conditions and potential future risks in space.

Evaluating the contribution of each object, or set of objects, to the general condition focuses on determining the level of present and future risk associated with these objects. This evaluation is crucial for identifying high-risk elements and prioritizing mitigation efforts.

The index also aids in making informed decisions regarding regulations, active debris removal (ADR), and other critical actions to maintain and improve space sustainability.

Moreover, the index serves as a communication tool with various external actors, including other space agencies, operators, economic and political decision-makers, media, and the public. By providing clear and quantifiable data, the index helps to foster collaboration, inform policy, and raise awareness about the importance of sustainable practices in space.

b. INDIGENE tool

The INDIGENE tool, analysed in the academic paper by Pierre Omaly et al.[109], could provide data to evaluate compliance with the requirements.

INDIGENE uses various criteria, like satellite design and mission planning, to calculate scores, it runs simulations to predict collision risks and other operational challenges, and each criterion gets a score between 0 (no impact) and 1 (maximum impact). Some scores might be adjusted (e.g., 1-x) to reflect positive outcomes like high success rates.

The final score is a weighted sum of all criteria, which helps compare different missions. The graphical output of INDIGENE shows how missions perform across different criteria, aiding safety engineers in their assessments. The tool also makes it possible to compare different missions and therefore understand the relative level of sustainable practices in act.

2.4.3 Advantages in using Space Indexes: between Traditional Investments and Socially Responsible Investments

Market sentiment shows a good moment for investing, due to the increasing importance of space sector, but might imply a higher risk due to volatility. But if we consider a sustainable space index, the volatility might be mitigated in the long-run due to the shift of the whole market towards sustainable practices, especially when it comes to financial implications. A sustainable space index highlights companies that are perceived as future-oriented and responsible, attracting a broader base of investors who prioritize sustainability alongside financial returns.

Firstly, I will be talking about transition risks, and then it will follow an IRO analysis.

The first concept that could be seen as an advantage is from a mitigation of Technological Transition Risk point of view: sustainability often drives innovation.

Companies focusing on sustainable practices are likely to develop cutting-edge technologies and processes that not only reduce environmental impact but also enhance profitability and efficiency.

These innovations can provide a competitive edge, positioning companies in a sustainable space index as leaders in the industry and further stabilizing their financial performance over time.

[109] CNES Space sustainability index https://www.sciencedirect.com/science/article/pii/S0273117723001023

This shift towards sustainability can enhance long-term stability, drive innovation, and attract a broader range of investors. By focusing on sustainable practices, companies can reduce operational risks, comply with evolving regulations, and capture market demand, ultimately leading to more stable and predictable financial performance in the space sector.

Space indexes, whether they be tracking sustainable practices or not, are useful also to mitigate Market Transition Risk, arising from the change of sentiment due to new market users' requests (such as more ethical practices in terms of sustainability matters).

If we consider sustainable space indexes only, those highlight companies that are leading innovation, particularly in green technologies. Companies that prioritize sustainability are often more resilient in the face of market shifts. These companies tend to have better risk management practices, leading to more stable financial performance and reduced volatility, which is attractive to risk-averse investors. As the market continues to evolve towards sustainability, space indexes will play a crucial role in guiding investment and corporate strategies to align with future trends and demands.

Talking about IRO analysis, following an index gives away a clear signal of the general trends therefore it can help investors make the right decisions in terms of investments. Sector-specific indexes, such as those tracking the space industry, allow investors to have returns on innovative and high-growth sectors. As these industries evolve, investors can benefit from it. This results in a great opportunity from a financial perspective. Additionally, not only investors could be interested in investing in these companies, but also governments around the world are implementing policies to support sustainable development and green technologies and could be even more interested especially when considering a high-stake always evolving space sector.

Companies in a sustainability-focused space index are likely to benefit from such policies, including subsidies, tax incentives, and grants. These policies not only provide financial benefits but also create a more favourable environment for sustainable innovation and growth, enabling these companies to lead the way in building a more sustainable future for the space industry and beyond.

Overall, the main underlying driver for enhancing sustainable practices in space is always related to shifting investments towards sustainable-related activities. Indexes in the space sectors could certainly do that.

When investors prioritize sustainability, they effectively signal to companies that sustainable practices are not only desirable but necessary for securing funding and maintaining competitiveness. This creates a financial incentive for companies to adopt and enhance sustainable practices, driving innovation and leading to the development of new technologies and methods that minimize environmental impact.

In the context of space sector indexes focused on sustainability, these indexes can highlight companies that are leading the way in implementing sustainable practices, thereby attracting investment towards these firms.

Redirecting investments towards sustainable activities in the space sector can spur significant innovation. Companies that receive funding for sustainable projects are likely to invest in research and development of new technologies that reduce environmental impact, such as reusable rockets, more efficient propulsion systems, and sustainable satellite manufacturing processes. This process is enhanced by space sector indexes that focus on sustainability can play a crucial role in this process by directing capital and attention to companies that lead in sustainable practices.

2.4.4 Disadvantages for Indexes: A Narrow View

According to the traditional investment strategies, the main issues with indexes are linked to IRO analysis, meaning that if indexes are used as benchmarks to understand which investment direction to take, there always might be a risk in returns for the investors.

Besides, the biggest transition risk related to the use of indexes is the Market Transition Risk, for which I will provide analysis first.

These two indexes, both tracking sustainable activities in space and space companies, primarily include large-cap companies, potentially overlooking smaller companies that might offer higher growth potential or innovative technologies. This emphasis on large-cap firms may result in a missed opportunity to capture the advancements and rapid growth that smaller, more agile companies can bring to the table. Smaller companies, often driven by innovation and entrepreneurship, have the potential to develop breakthrough technologies that could impact the space industry. These firms might also be more adaptable and able to quickly implement sustainable practices and cutting-edge solutions.

Yet, due to the high entry barriers in the space sector, including the need for advanced technology and big capital investment, smaller companies may struggle to achieve the scale and visibility needed to be included in these indexes. This creates a paradox where the indexes, while providing a measure of stability and established performance through large-cap firms, might overlook the very innovations that could drive future growth and sustainability in the space industry.

This dynamic is clearly a cause of Market Transition Risks: while these indexes give a reliable picture of the current state of sustainable space activities, or space activities in general, and major players in the space industry, they may not fully represent the dynamic and evolving nature of the sector. Investors relying only on these indexes could potentially miss out on the high-growth opportunities and innovative advancements emerging from smaller companies that are less visible but equally important in shaping the future of space exploration and sustainability.

Historical data provides a record of past performance, but it may not account for recent innovations, emerging trends, or new technologies that are shaping the future of the industry. In the context of the space sector, this is particularly pertinent as advancements are happening at a fast pace. Companies that were not prominent in the past might become leaders due to breakthroughs in technology or shifts in market demand. Conversely, firms that dominated in previous years might not keep up if they fail to innovate or adapt to new environmental and technological standards. These include technological risks, such as the failure of new technologies, regulatory risks associated with evolving space law and international treaties, and geopolitical risks that can impact international cooperation and funding. Historical data might not adequately capture these risks, leading to an incomplete assessment of potential market dynamics.

Therefore, relying heavily on historical data can lead to misleading signals for long-run investment strategies. Investors looking at indexes to inform their long-term decisions might be basing their strategies on outdated information that does not reflect the current or future state of the market.

To conclude, investors must be aware of these limitations and consider adaptive strategies that incorporate forward-looking data to better navigate the real opportunities within the space industry.

2.5 Conclusions on the Metrics for Measuring Outer Space Activities

Standards, ratings, and indexes play distinct but also complementary roles in ensuring sustainable outer space practices, each contributing to the overall governance and management of space activities.

Standards, such as *ISO 24113:2023* and the *IADC Space Debris Mitigation Guidelines*, provide the foundational framework for sustainable space practices. These standards set clear, technical requirements that spacefaring organizations must follow to minimize the generation of space debris and mitigate its impact. By providing precise guidance, these standards ensure that all entities involved in space activities follow best practices.

Ratings systems, like the *Space Sustainability Rating (SSR) System*, offer a comprehensive evaluation of a space mission's sustainability. The SSR system assesses missions across multiple dimensions, including mission type, collision avoidance strategies (COLA), data sharing, and adherence to design and operation standards. By providing a sustainability score, the SSR not only incentivizes better practices but also enables stakeholders to compare the sustainability performance of different missions. This rating system thus serves as both a benchmark and a motivator for continuous improvement, pushing organizations to go beyond simple compliance with standards.

Indexes, such as the *Space Security Index (SSI)* and the *CNES Space Sustainability Index*, serve a critical role in monitoring and regulating the broader space environment. These indexes aggregate data on various aspects of space activities, offering a comprehensive overview of the current state of space security and sustainability. By tracking trends, identifying emerging risks, and highlighting areas for improvement, these indexes provide policymakers, researchers, and industry leaders with the insights needed to make informed decisions. The transparency and accountability promoted by these indexes are crucial for increasing international cooperation.

In summary, standards set the rules, ratings measure adherence and incentivize improvement, and indexes monitor the overall health of the space environment. Together, they create a robust and interlinked system that is essential for promoting and maintaining the sustainability of outer space activities.

Chapter III: Regression on Space Companies Performances

3 Context of the ESG evaluation

The relationship between ESG (Environmental, Social, and Governance) scores and financial performance has been extensively studied over the years due to its significant implications for both corporate strategy and investment decisions. The growing interest in sustainability in the financial world has led many researchers to investigate more on the relationship between ESG (Environmental, Social, and Governance) scores and financial performance across various industries.

As concluded in the academic paper of Sandra A. Waddock and Samuel B. Graves, *The Corporate Social Performance-Financial Performance link*[110], there were presented two hypotheses: Better financial performance results in improved CSP (Corporate Social Performance), ceteris paribus; Improved CSP leads to better financial performance, ceteris paribus. For the regression, the variables chosen to assess financial performance were return on assets, return on equity and return on sales. The control variables were size, risk and industry and the data analysed were taken from S&P 500 firms. The findings explain that the relationship between them, in both cases, is positive, providing a reinforcing positive loop.

Another crucial finding, that supports he positive relationship hypothesis is the one found in the paper *Corporate Social and Financial Performance: a meta-analysis*[111], by Marc Orlitzky et al. the sample size to analyse CSP-CFP relationship (hypothesis 1: Corporate social performance and financial performance are generally positively related across a wide variety of industry and study contexts) was of 33,87 elements.

The finding states as follows: "*This meta-analysis has shown that (1) across studies, CSP is positively correlated with CFP, (2) the relationship tends to be bidirectional and simultaneous, (3) reputation appears to be an important mediator of the relationship […]. Corporate virtue in the form of social and, to a lesser extent, environmental responsibility is rewarding in more ways than one.*"

On the other hand, in literature there has been evidences that support the opposite thesis.

As shown in the academic paper *Does it really pay to be good, everywhere? A first step to understand the corporate social and financial performance link in Latin American*

[110] Positive relationship https://onlinelibrary.wiley.com/doi/epdf/10.1002/%28SICI%291097-0266%28199704%2918%3A4%3C303%3A%3AAID-SMJ869%3E3.0.CO%3B2-G

[111] Positive relationship file:///C:/Users/Beatrice.Peghin/Downloads/OrlitzkyMeta-Analysis-03.pdf

controversial industries[112] by Pablo Rodrigo, Ignacio J. Duran and Daniel Arenas, it suggests partial evidence of a negative bidirectional association (or non-significant at best) between Corporate Social Performance (CSP) and Corporate Financial Performance.

Another evidence provided against the corporate responsible practices liked to a higher performance was provided by the paper of Kenneth Aupperle et al., *An Empirical Examination of the Relationship between Corporate Social Responsibility and Profitability*[113].

Once again, these two findings bring on the debate whether the effects of ESG-intensive activities are financially better off.

Therefore, it is in this environment that I will perform my empirical study. The regression will be conducted on companies belonging to indexes in the space sector, to provide evidence that not only immediate action is necessary to tackle the growing debris crisis, but also that sustainable practices, if incorporated into daily operations, can foster long-term benefits for the industry.

This research is particularly relevant because the space sector faces unique environmental challenges, such as space debris and resource scarcity, which demand innovative and responsible solutions. By adopting sustainable Environmental, Social, and Governance (ESG) practices, companies in this field can not only mitigate these risks but also enhance their long-term financial performance. This hypothesis aligns with the work of Orlitzky et al., which suggests that firms with robust Corporate Social Performance (CSP) programs benefit internally by building stronger resources, capabilities, and competencies, thus improving organizational efficiency. Externally, these companies can cultivate a positive reputation, fostering better relationships with stakeholders such as governments, investors, and the general public. The space sector, being a high-stakes and highly visible industry, can significantly gain from these synergies, leading to a more sustainable and financially stable future.

3.1 Chosen Space Indexes and Regression Setup

The relationship between ESG scores, that can serve as a proxy for a company's overall sustainability, and its financial performance is particularly interesting in the space sector,

[112] ESG score and financial performance link https://onlinelibrary.wiley.com/doi/10.1111/beer.12119

[113] Negative relationship https://www.researchgate.net/publication/325001131_An_Empirical_Examination_of_the_Relationship_between_Corporate_Social_Responsibility_and_Profitability

especially when the debris issue is considered. Companies that demonstrate strong governance and innovative environmental management may achieve higher ESG scores, potentially leading to better financial performance. Understanding how these sustainability practices influence financial outcomes in the space sector could provide valuable insights for investors, stakeholders, and policymakers, emphasizing the importance of integrating ESG considerations into strategic decision-making.

Therefore, in the following paragraph, I will analyse the stock market indexes that currently track the performance of space-related companies. Using the individual companies within these indexes, I will conduct a regression analysis to examine the relationship between ESG risk scores and financial performance.

The chosen indexes are the following ones:

EURONEXT Helios	Helios, the first stock index for Europe's space industry, was launched on 24 January 2023 by Euronext in cooperation with European Commission, ESA and Promus Ventures.	NLIX00000983
S&P Kensho Global Space Index	The S&P Kensho Global Space Index wants to measure the performance of global companies that act on space travel and exploration.	KMARSP

Table 15: Selected Space Indexes

This chapter conducts an empirical study on the above-mentioned indexes, therefore on a sample of 57 companies. The corporate ESG ratings in the analysis come from LSEG Data & Analytics (formerly Refinitiv)[114], and the financial performance-tracking data come from Yahoo Finance[115], as well as from Orbis[116] platform.

All the variables were chosen to assess whether a space enterprise performance is influenced positively by a higher level of ESG rating.

[114] LSEG Data & Analytics https://www.lseg.com/en/data-analytics
[115] Yahoo finance website https://finance.yahoo.com/
[116] Orbis platform https://login.bvdinfo.com/R1/Orbis

a. Dependent variables

The dependent variables selected for the model in three different regressions were profit margin (PM), return on assets (ROA), and return on equity (ROE). These variables were chosen because they provide distinct measures of a company's financial performance. Profit Margin reflects the company's ability to convert sales into profit, highlighting operational efficiency. ROA measures how effectively a company uses its assets to generate earnings, offering insight into asset management efficiency. ROE indicates how well a company generates profit from shareholders' equity, reflecting financial leverage and overall profitability. By incorporating these three independent variables, the regressions aim to comprehensively evaluate the financial factors that represent potential influence on overall ESG performance.

b. Explanatory variable

The explanatory variable chosen for this model is ESG scores.

c. Control variables

The control variables chosen for all the regressions in the model include market capitalization, total revenue, total assets, debt-to-equity ratio, and market-to-book ratio. These variables are crucial for providing a robust model to understand how ESG factors influence a company's performance in the space industry.

ESG scores are directly related to the model's aim, as they measure a company's environmental, social, and governance practices, which by hypothesis should impact financial performance.

Market capitalization and total revenue offer insights into the company's size and market presence, while total assets help understand the overall scale of operations.

The debt-to-equity ratio provides a measure of financial leverage and risk, which can affect a company's stability and performance.

Lastly, the market-to-book ratio indicates how the market values a company compared to its book value, reflecting investor perceptions and expectations.

By including these control variables, the model accounts for various factors that might influence financial performance, ensuring a more accurate assessment of the relationship between ESG ratings and company success in the space field.

Variable type	*variable name*	*variable symbol*	*variable definition*
Dependant variable	*return on assets*	*ROA*	how profitable a company is relative to its total assets
	return on equity	*ROE*	how a company is converting its equity financing into profits
	profit margin	*PM*	degree to which a company or a business activity makes money
Explanatory variable	*ESG score*	*ESG*	ESG rating
Control variable	*market capitalisation*	*MKT CAP*	the total value of a company's shares of stock
	total revenue	*TR*	how much money a business generates before expenses
	total assets	*TA*	the value of all of a company's assets is added together
	debt to equity	*DTE*	compares a company's total liabilities with its shareholder equity
	market to book ratio	*MTB*	compares a business's book value to its market value

Table 16: Variable Definitions

d. Model setting

The model used to analyse the relationship between ESG ratings and company performance in the space industry is represented as follows:

$$Financial\ Performance = \beta_0 + \beta_1\, ESG + \beta_2\, Controls + \varepsilon$$

In this model, three proxies are used to measure financial performance: return on assets (ROA), return on equity (ROE), and profit margin (PM), which represent different aspects of a company's financial performance. The intercept, β_0, represents the baseline level of performance when all other variables are zero.

The coefficient β_1 represents the impact of the ESG scores on these performance metrics, reflecting how environmental, social, and governance practices may influence financial outcomes.

The control variables in the model (market capitalization, total revenue, total assets, debt-to-equity ratio, and market-to-book ratio) are represented by the coefficients β_2. These control variables are included to account for other factors that can affect financial performance, helping to isolate the specific impact of ESG ratings.

The error term, ε, captures any unexplained variation in the model.

By incorporating both ESG scores and relevant control variables, the model provides a more accurate understanding of how ESG practices influence financial performance, as measured by ROA, ROE, and PM, in the space industry.

3.2 Euronext Helios Space Index Overview

The Euronext Helios Space Index was launched on 24 January 2023, it was created by the collaboration between the European Commission, Promus Ventures and ESA. It is the first European Space-related index tracking the performance of various companies, summed up in the following table, as displayed in the official website of Euronext Helios[117], as of 29/08/2024.

Component	**ISIN**	**Trading Location**	**Issuer Country**
AEROVIRONMENT INC.	US0080731088	Nasdaq Global Securities	United States of America
AIR LIQUIDE	FR0000120073	Euronext Paris	France
AIRBUS	NL0000235190	Euronext Paris	Netherlands
ASML HOLDING	NL0010273215	Euronext Amsterdam	Netherlands
BABCOCK INTL GROUP	GB0009697037	London Stock Exchange	United Kingdom

[117] Euronext Live Market https://live.euronext.com/en/product/indices/NLIX00000983-XPAR?_gl=1*15z0c8m*_ga*MTI4OTAzMzkxOS4xNzE1MDAxODkw*_ga_PMEFBR6CSF*MTcxOTM4OTg3MS4xLjEuMTcxOTM5MDAyMy4wLjAuMA..*_ga_WYRYLMR662*MTcxOTM4OTAyNS4xLjEuMTcxOTM5MDAyMy4wLjAuMA..*_gcl_aw*R0NMLjE3MTUwMDE5MzkuRUFJYUlRb2JDaE1JZ2EyeDc0XzVoUU1WbmxCQkFoMkw0Z3JsRUFBWUFTQUFFZ0pDOF9EX0J3RQ..*_gcl_au*MTQwMjEwNjY5NS4xNzE1MDAxOTM5#index-composition

BAE SYSTEMS PLC	GB0002634946	London Stock Exchange	United Kingdom
BARNES GROUP	US0678061096	New York Stock Exchange	United States of America
CHEMRING GROUP	GB00B45C9X44	London Stock Exchange	United Kingdom
DASSAULT SYSTEMES	FR0014003TT8	Euronext Paris	France
FUGRO	NL00150003E1	Euronext Amsterdam	Netherlands
HARMONIC DRIVE SYST.	JP3765150002	Tokyo Stock Exchange	Japan
HENSOLDT AG	DE000HAG0005	Deutsche Börse Xetra	Germany
INDRA SISTEMAS SA	ES0118594417	Bolsa de Madrid	Spain
INFINEON TECHNOLOGIE	DE0006231004	Deutsche Börse Xetra	Germany
ISPACE INC	JP3102360009	Tokyo Stock Exchange	Japan
KONGSBERG GRUPPEN	NO0003043309	Oslo Børs	Norway
LEONARDO	IT0003856405	Euronext Milan	Italy
MTU AERO ENGINES AG	DE000A0D9PT0	Deutsche Börse Xetra	Germany
NORDIC SEMICONDUC	NO0003055501	Oslo Børs	Norway
QINETIQ GROUP PLC	GB00B0WMWD03	London Stock Exchange	United Kingdom
RHEINMETALL	DE0007030009	Deutsche Börse Xetra	Germany
ROLLS-ROYCE HOLDINGS	GB00B63H8491	London Stock Exchange	United Kingdom
SAAB AB B	SE0021921269	Stockholm Stock Exchange	Sweden

SAFRAN	FR0000073272	Euronext Paris	France
SES	LU0088087324	Euronext Paris	Luxembourg
SMITHS GROUP PLC	GB00B1WY2338	London Stock Exchange	United Kingdom
SPIRE GLOBAL INC.	US84857L1017	New York Stock Exchange	United States of America
SPIRENT COMMUNIC.	GB0004726096	London Stock Exchange	United Kingdom
STMICROELECTRONICS	NL0000226223	Euronext Paris	Netherlands
TE CONNECTIVITY LTD.	CH0102993182	New York Stock Exchange	United States of America
THALES	FR0000121329	Euronext Paris	France
VIRIDIEN	FR0013181864	Euronext Paris	France

Table 17: EuroNext Helios Space Index Composition

The aim of the index is to enhance the visibility of companies and grant them the possibility to create products for the market. It also aims at expressing financial market behaviours, and thus guiding investors.

It offers a benchmark for management companies, allowing users to compare the space sector's performance with other indices like France's CAC40. Finally, it seeks to encourage participation from individuals who are less familiar with the space sector in public markets, contributing to the general growth of the sector.

The index is also able to provide investors with information about the companies, whether they perform upstream or downstream activities in the industry through.

For upstream activities, the main covered areas are design and manufacturing of space systems and related launch vehicles, ground networks and software creation.

For downstream activities, companies focus on communications, and Earth observation.

The selection of companies follows four steps: the company must be listed; it must have a daily traded volume lower than 2mln € and companies with a free float market capitalization lower than 200 million €; either European companies or extra-EU companies that are benefitting from EU; no single company's weight can exceed 10% during periodic reviews.

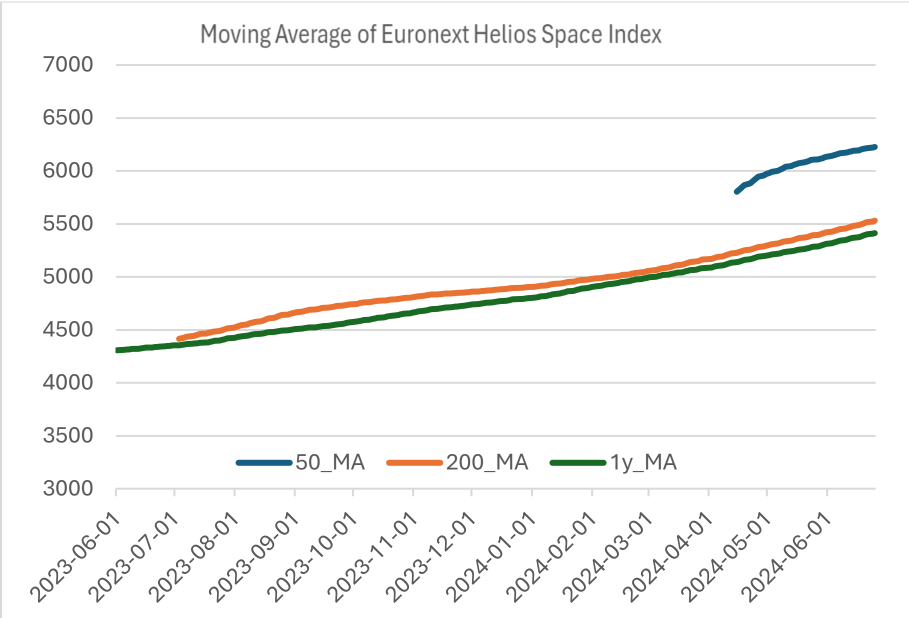
The following graph, broadly speaking shows the trend for which the index is showing a general increase, with a steep rise between January and March[118].

Image 7: EuroNext Helios Space Index Prices Fluctuations

For providing further depth on the ongoing trends of the index, I have analysed the closing prices of the index for a year from 1st June 2023 to 1st June 2024. By computing the moving average and the standard deviation, I divided the data into three categories: 50 days, 200 days, and 1 year[119].

The following results were produced, respectively for moving average and for standard deviation.

[118] Graph by the official website of EuroNext https://live.euronext.com/en/product/indices/NLIX00000983-XPAR?_gl=1*15z0c8m*_ga*MTI4OTAzMzkxOS4xNzE1MDAxODkw*_ga_PMEFBR6CSF*MTcxOTM4OTg3MS4xLjEuMTcxOTM5MDAyMy4wLjAuMA..*_ga_WYRYLMR662*MTcxOTM4OTAyNS4xLjEuMTcxOTM5MDAyMy4wLjAuMA..*_gcl_aw*R0NMLjE3MTUwMDE5MzkuRUFJYUlRb2JDaE1JZ2EyeDc0XzVoUU1WbmxCQkFoMkw0Z3JsRUFBWUFTQUFFZ0pDOF9EX0J3RQ..*_gcl_au*MTQwMjEwNjY5NS4xNzE1MDAxOTM5
[119] Excel document on which the analysis was made EN HELIOS SPACE_historical_price.xlsx



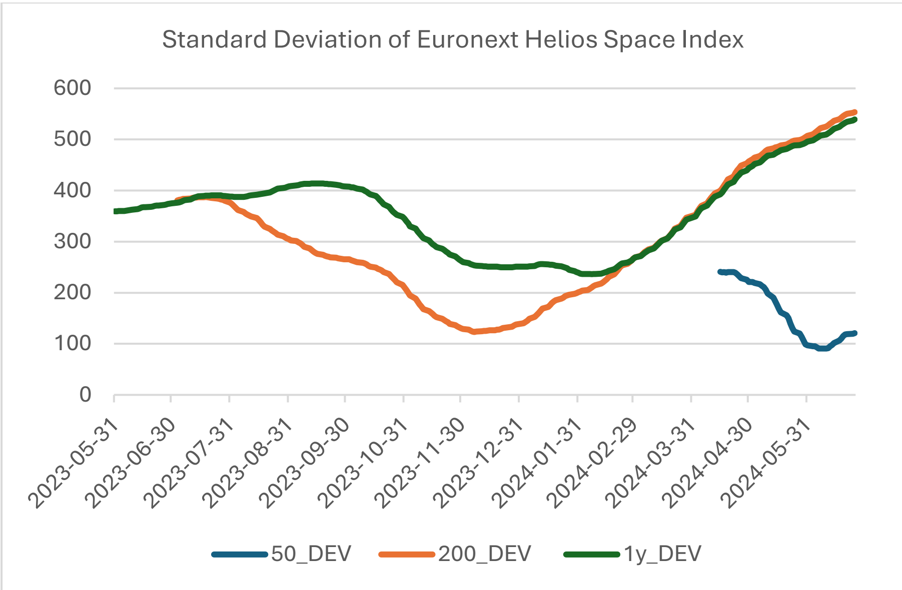


Image 8 and 9: Moving Average and Standard Deviation of EuroNext Helios Space Index

The moving average graph shows that in general the index sees a rising trend. Both 200 days and 1-year lines depict a similar increasing pace, instead the 50 days line shows a strong short-term uptrend, implying that investor sentiment has become more positive recently. The market participants are likely pushing the price higher, showing a positive sentiment towards investing in the index.

The standard deviation graph instead provides a picture of a volatile index, which might go in contrast with the positive sentiment deducted from the previous graph. A higher volatility implies a higher risk for investors, meaning that the returns are less predictable, and thus make the index less appetible.

Both the 200 days and 1 year line follow similar trends but with the 1-year line consistently higher until mid-2024, instead the 50 days standard deviation shows much more pronounced peaks and troughs compared to the 200 days standard deviation, indicating that short-term volatility is more sensitive to recent price changes.

Overall, considering the high volatility and yet the increasing trend for moving average I would conclude that the combination of high volatility and rising moving averages suggests that while the space sector is experiencing significant growth, it is also subject to considerable fluctuations. Investors may be optimistic about the prospects of space companies but should be prepared for potential short-term volatility.

To add to this, the upward trend indicates that there are opportunities for high returns. However, the high volatility means that these returns come with increased risk. Investors should weigh the potential rewards against the risks.

3.1.1 EuroNext Helios Space Index Companies Performance Regression

a. Description of Statistics

The following table presents the descriptive statistics for the primary variables, on a sample size of 31 companies.

	average	*min*	*max*	*median*
ROA	0.03901	-0.1024	0.1212	0.0461
ROE	0.08653	-0.7987	0.4857	0.124
PM	-0.0176	-0.6672	0.265	0.0639
ESG	64.65	7	92	70
MKT CAP	49936.5	198.19	357590	18250
TR	15158	107.22	66610	6060
TA	24049	246.825	276000	7765
DTE	0.53654	-2.25	2.4575	0.3935
MTB	-2474.3	-157148	14067.02	860.6881

Table 18: Results of descriptive statistics for the main variables.

The table provides descriptive statistics for key variables used in the regression analysis to examine the relationship between ESG ratings and financial performance of companies listed in the EuroNext Helios Space Index.

For the dependent variables, the average return on assets (ROA) is 0.03901, with a minimum of -0.1024, a maximum of 0.1212, and a median of 0.0461. The return on equity (ROE) has an average of 0.08653, a minimum of -0.7987, a maximum of 0.4857, and a median of 0.124.

The profit margin (PM) shows an average of -0.0176, indicating some companies are operating at a loss, with a minimum of -0.6672, a maximum of 0.265, and a median of 0.0639.

For the independent and control variables, the average ESG score from LSEG Data & Analytics is 64.65, ranging from a minimum of 7 to a maximum of 92, with a median of 70. Market capitalization (MKT CAP) has an average of 49,936.5 million, with a wide range from 198.19 million to 357,590 million, and a median of 18,250 million. Total revenue (TR) has an average of 15,158 million, with a median of 6,060 million. Total assets (TA) show an average of 24,049 million, and a median of 7,765 million. The debt-to-equity ratio (DTE) has an average of 0.53654, ranging from -2.25 to 2.4575, with a median of 0.3935, indicating varying levels of leverage among companies. Finally, the market-to-book ratio (MTB) shows significant variation, with an average of -2474.3, a minimum of -157148, a maximum of 14,067.02, and a median of 860.6881, suggesting differences in market valuation relative to book value across companies.

b. Regressions Results on aggregated ESG

The regression results indicate a statistically significant relationship between LSEG scores (ESG ratings) and the financial performance of companies in the EuroNext Helios Space Index.

The coefficients for LSEG scores across the three models, 0.001171, 0.009873, and 0.008520 demonstrate that higher ESG ratings are positively associated with improved financial metrics.

Specifically, the coefficient of 0.001171, significant at the 5% level (**), suggests a positive but relatively modest impact of ESG scores on one of the dependent variables. The coefficients of 0.009873 and 0.008520, both significant at the 1% level (***), indicate a very strong and more robust positive relationship with the other two financial performance measures. These results imply that as companies improve their ESG practices, their financial performance, as measured by ROA, ROE, or PM, tends to improve significantly.

The numbers in parentheses below each coefficient represent the standard errors, which are relatively small (0.000432, 0.001884, and 0.001423, respectively), indicating that the coefficient estimates are precise and reliable. The statistical significance of the coefficients, combined with their positive values, suggests that higher LSEG scores (better ESG performance) are consistently associated with better financial outcomes for companies in the space industry.

	(1) ROA	*(2) ROE*	*(3) PM*
ESG	0.001170883**	0.009872676***	0.008520203***
	(0.000432)	(0.001884)	(0.001423)
MKT CAP			
TR			
TA			
DTE			
MTB			

Numbers in parentheses are Standard Errors, *,**, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 19: Regression Results

3.3 S&P Kensho Space Index

The S&P Kensho Space Index (Bloomberg Ticker: KGMARSP), launched in December 2018, was created to track the performance of companies driving innovation and advancements in the space industry. This index is important because it provides investors with a benchmark to assess the financial health and market potential of businesses that are shaping the future of space exploration and technology. The index includes a diverse range of companies involved in various sectors of the space industry, such as satellite communications, rocket and spacecraft manufacturing, space tourism, and satellite-based imagery and data analytics. By capturing the growth of these pioneering companies, the S&P Kensho Space Index offers a comprehensive view of the rapidly evolving space economy and its increasing relevance in both technological and financial markets.

The following table shows all of the components of the index, as of 29/08/2024.

Company	**Symbol**
Rocket Lab USA, Inc.	RKLB
Lockheed Martin	LMT
Planet Labs PBC	PL
HEICO Corp	HEI
Moog Inc A	MOG.A
Ducommun Inc	DCO
RTX Corporation	RTX
ESCO Technologies Inc	ESE
Teledyne Technologies Inc	TDY
Boeing Co	BA

Amphenol Corp	APH
Ball Corp	BALL
Booz Allen Hamilton Holding Corp	BAH
BWX Technologies Inc	BWXT
Crane NXT Co	CXT
Elbit Systems Ltd	ESLT
ESCO Technologies Inc	ESE
L3Harris Technologies Inc	LHX
HEICO Corp	HEI
Hexcel Corp	HXL
Honeywell International Inc	HON
Coherent Corp	COHR
Jacobs Solutions Inc	J
Lockheed Martin Corp	LMT
Northrop Grumman Corp	NOC

Standex International Corp	SXI
TE Connectivity Ltd	TEL
Teledyne Technologies Inc	TDY
TransDigm Group Inc	TDG

Table 20: Components of S&P Kensho Space Index

The performance of the S&P Kensho Space Index has generally improved in recent years, showing a five-year-return of 7.82% and reflecting the growing interest in and investment in the space sector. Since its inception in December 2018, the index has tracked the stocks of companies at the forefront of space-related technologies, including satellite communications, rocket manufacturing, space tourism, and space data analytics. The increasing demand for satellite-based internet services, advancements in reusable rocket technology, and the commercialization of space exploration have all contributed to the growth of companies within this index.

3.2.1 S&P Kensho Space Index Regression

a. Description of Statistics

The following table presents the descriptive statistics for the primary variables, on a sample size of 26 companies.

The table presents descriptive statistics for various financial and non-financial variables used to analyze the performance of companies in a given dataset. The key financial performance indicators include Return on Assets (ROA), Return on Equity (ROE), and Profit Margin (PM).

The average ROA is 0.0412, with a minimum of -0.1361 and a maximum of 0.1053, indicating a moderate level of asset efficiency across the companies, with a median value of 0.0484. The average ROE is 0.1112, suggesting a reasonable return on equity, although it ranges widely from -0.5664 to 0.8739, with a median of 0.0959. The Profit Margin (PM) shows an average of 0.0493, indicating that, on average, companies maintain a positive profit margin despite a minimum value of -0.5926, which suggests some companies are operating at a loss, and a maximum of 0.304, with a median of 0.0763.

For the non-financial variables, the average ESG score from LSEG is 56.12, with a range from 16 to 78 and a median of 57, suggesting a big range. Market capitalization (MKT CAP) shows a wide dispersion, with an average of 100,871.8 million, a minimum of 799.62 million, and a maximum of 1,580,000 million, indicating a significant diversity in company sizes, with a median of 19,640 million. Total revenue (TR) averages 16,794.31 million, ranging from 228.43 million to 73,560 million, with a median of 6,960 million, while total assets (TA) show an average of 259,792.95 million, ranging from 419.86 million to 2,171,000 million, and a median of 27,808.5 million.

The debt-to-equity ratio (DTE) has an average of 0.4035, with a wide range from -7.1 to 3.3513 and a median of 0.5724, highlighting varying levels of leverage among the companies. Finally, the market-to-book ratio (MTB) displays considerable variability, with an average of 9,043.03, a minimum of -3,660.96, a maximum of 211,796.25, and a median of 451.19, suggesting a wide range in how the market values these companies relative to their book values. These statistics provide a comprehensive overview of the financial health, market valuation, and ESG practices of the companies in the dataset.

	average	*min*	*max*	*median*
ROA	0.041176923	-0.1361	0.1053	0.0484
ROE	0.111219231	-0.5664	0.8739	0.0959
PM	0.049319231	-0.5926	0.304	0.0763
ESG	56.11538462	16	78	57
MKT CAP	100871.795	799.62	1580000	19640
TR	16794.31038	228.43	73560	6960
TA	259792.9542	419.86	2171000	27808.5
DTE	0.403542308	-7.1	3.3513	0.5724
MTB	9043.026686	-3660.958904	211796.2466	451.1945264

Table 21: Statistic Descriptions of Variables

b. Regressions Results

The regression results highlight a significant relationship between LSEG scores (ESG ratings) and the financial performance indicators of companies, as measured by Return on

Assets (ROA), Return on Equity (ROE), and Profit Margin (PM). The coefficient for the LSEG scores is positive and statistically significant across all three models, indicating that higher ESG ratings are associated with better financial performance.

In Model (1), the coefficient for LSEG scores is 0.001261, which is significant at the 10% level (*), suggesting a positive relationship between ESG scores and ROA.

In Model (2), the coefficient for LSEG scores increases to 0.004615 and is statistically significant at the 5% level (**), indicating a stronger positive impact on ROE.

Similarly, in Model (3), the LSEG score coefficient is 0.005337, also significant at the 5% level (**), demonstrating a positive association with PM. The standard errors reported in parentheses under the coefficients, 0.000681, 0.001924, and 0.002282, respectively, are relatively low, indicating that the coefficient estimates are precise.

Additionally, the Debt-to-Equity (DTE) ratio in Model (2) has a coefficient of 0.1072, which is highly significant at the 1% level (***), suggesting that these companies with a higher DTE ratio tend to have a higher ROE. This finding indicates that leverage might play an important role in enhancing returns on equity for companies with higher ESG scores.

Moreover, the significance of this finding in the context of companies with higher ESG scores suggests that such companies might be better positioned to manage debt effectively. Companies with strong ESG practices may benefit from lower borrowing costs due to lower perceived risk, better relationships with lenders, or access to green financing options. As a result, they can leverage debt more effectively to boost their ROE.

Overall, these results suggest that companies with better ESG performance, as measured by LSEG scores, tend to experience improved financial performance, particularly in terms of ROE and PM. The significant positive coefficients support the hypothesis that adopting strong ESG practices can positively influence a company's profitability and asset efficiency in the space sector.

	(1) ROA	(2) ROE	(3) PM
ESG	0.001261*	0.004615358**	0.00533713**
	(0.000680706)	(0.001924264)	(0.002281983)
MKT CAP			
TR			
TA			
DTE		0.107199601***	
		(0.020955917)	
MTB			

Numbers in parentheses are Standard Errors, *,**, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

Table 22: Regression Results S&P Kenso Space Index

3.4 ESG breakdown

To gain deeper insight into the relationship between ESG components and financial performance, the analysis was further broken down by individual ESG pillars. The table below shows the all-positive coefficients, in brackets their standard error and p-values. Firstly, the EN Helios Space Index results will be shown, and secondly, the S&P Kensho Space Index ones.

EN Helios	E	E p-value	S	S p-value	G	G p-value
ROA	0.000555 (0.000362)	0.139043	0.000964** (0.000378)	0.017746	0.000929** (0.000386)	0.024215
ROE	0.006027*** (0.001727)	0.00189	0.007334*** (0.0018529)	0.000586	0.006669*** (0.0019782)	0.002531
PM	0.005333*** (0.0013410)	0.000559	0.006718*** (0.0013727)	5.44E-05	0.004435** (0.0017339)	0.017278

Table 23: EN Helios ESG Breakdown

The analysis of ESG components for *EuroNext Helios Space Index* and their impact on financial performance within the space sector highlights the increasing importance of sustainability in driving financial profitability.

Although the Environmental (E) rating shows a positive relationship with *Return on Assets* (ROA) (coefficient 0.000555), its lack of statistical significance (p-value 0.139043) suggests that environmental practices in this context still need more attention in the sector, as the thesis is suggesting. This could indicate that while sustainability initiatives are crucial, their effects on financial outcomes in the space sector might require more awareness to be first addressed and then to produce the desired effects. To be sustainable is to be more long-term focused.

In contrast, both the Social (S) and Governance (G) pillars show more significant effects on ROA. Strong Social practices (coefficient 0.000964, p-value 0.017746) positively influence ROA, reflecting the growing importance of employee welfare, customer relations, and community engagement in enhancing operational efficiency and asset returns, which is coherent with the present trends. Similarly, Governance (coefficient 0.000929, p-value

0.024215) demonstrates a significant positive impact, indicating that transparency, ethical leadership, and strong oversight are crucial for asset management and financial stability in a high-tech, innovation-driven industry like space.

The analysis of *Return on Equity* (ROE) further strengthens the case for ESG's positive financial impact in the space sector. The Environmental (E) rating (coefficient 0.006027, p-value 0.00189) shows a strong positive relationship with ROE, suggesting that space companies investing in sustainable practices are rewarded with higher returns for their shareholders. This could be due to reduced operational risks, and a positive public image, all of which are valuable in a sector that faces growing issues over environmental impact.

The Social (S) component (coefficient 0.007334, p-value 0.000586) has an even stronger influence on ROE, indicating that socially responsible companies generate higher shareholder returns. In the space sector, where innovation, talent acquisition, and stakeholder engagement are critical, firms that emphasize fair labor practices, ethical sourcing, and strong community involvement are better positioned to foster loyalty and trust. This, in turn, leads to stronger financial outcomes. The Governance (G) pillar (coefficient 0.006669, p-value 0.002531) similarly shows a positive and significant relationship with ROE, further highlighting the importance of robust governance frameworks in aligning shareholder interests and ensuring long-term stability and profitability.

Finally, the analysis of Profit Margins shows a strong and consistent relationship between ESG factors and profitability. The Environmental (E) rating (coefficient 0.005333, p-value 0.000559) demonstrates a highly significant link, suggesting that space companies focusing on sustainability, through energy efficiency and eco-friendly innovations, are not only cutting costs but also attracting customers and investors who value environmental responsibility. This aligns with growing global demands for more sustainable operations, particularly in sectors like space exploration and satellite development, where space debris issue is increasing.

The Social (S) pillar (coefficient 0.006718, p-value 5.44E-05) shows the strongest impact on profitability, underscoring how socially responsible practices directly translate into higher profit margins. Space companies excelling in social responsibility likely benefit from enhanced brand value, reduced risks, and stronger customer loyalty, which are essential in a sector where long-term relationships and trust are key to success. Governance (G) (coefficient 0.004435, p-value 0.017278) also plays a critical role in boosting profitability, as well-governed companies are better equipped to manage risks, avoid costly missteps, and foster investor confidence.

Here the table with the results of the regressions performed on the *S&P Kensho Space Index*, reported as follows.

Kensho Space	E	E p-value	S	S p-value	G	G p-value
ROA	0.00083282 (0.000542818)	0.1414518	0.0008214 (0.0005801)	0.172994312	0.0010934 (0.00071624)	0.14333975
ROE	0.003200155* (0.001543042)	0.0519212	0.00332419* (0.00164289)	0.057332098	0.00346891 (0.00210828)	0.11633565
PM	0.00435597** (0.001749558)	0.0222146	0.003981* (0.00193053)	0.053142105	0.003365632 (0.00254243)	0.201282856

Table 24: ESG Breakdown for S&P Kensho Space Index

For ROA, the Environmental (E) factor has a positive coefficient of 0.00083282 with a standard error of 0.000542818 and a p-value of 0.14145. Although the coefficient suggests a positive relationship between environmental factors and ROA, the p-value indicates that this relationship is statistically insignificant (p-value > 0.05), similarly, the social (S) and the Governance (G) factor with a coefficient of 0.0008214 with respectively a standard error of -0.0005801 and a p-value of 0.17299 and a coefficient of 0.0010934 with a standard error of -0.00071624 and a p-value of 0.14334.

In the case of ROE, the Environmental (E) factor shows a coefficient of 0.003200155 with a standard error of 0.001543042 and a p-value of 0.05192. Although this p-value is slightly above 0.05, it is close enough to be considered marginally significant, suggesting that environmental factors may positively influence ROE. The Social (S) factor has a coefficient of 0.00332419 with a standard error of 0.00164289 and a p-value of 0.05733, which is also marginally significant, indicating a positive relationship between social factors and ROE. The Governance (G) factor, with a coefficient of 0.00346891, a standard error of

0.00210828, and a p-value of 0.11633, shows a positive but statistically insignificant relationship. Overall, both the environmental and social factors display a positive and marginally significant influence on ROE, whereas governance does not significantly impact ROE in the space sector.
For profit margin, the environmental (E) factor has a coefficient of 0.00435597 with a standard error of 0.001749558 and a p-value of 0.02222. This suggests a statistically significant positive relationship between environmental performance and profit margin, as the p-value is below 0.05. The social (S) factor shows a coefficient of 0.003981 with a standard error of 0.00193053 and a p-value of 0.05314, indicating a statistically significant positive relationship, at 10% level. Meanwhile, the governance (G) factor, with a coefficient of 0.003365632, a standard error of 0.00254243, and a p-value of 0.20128, does not show a significant impact on profit margins. In conclusion, environmental performance has a strong and statistically significant positive effect on profit margins in the space sector, while social factors show a marginally significant impact. Governance does not appear to have a significant effect on profit margins.

3.5 Conclusions on Regressions

The analysis suggests that while Environmental practices (E) in the space sector show a positive relationship with financial performance, particularly with ROA and ROE, the evidence is not as strong as that for Social (S) and Governance (G) factors. The coefficient for environmental ratings is positive, indicating potential for financial gains, but the lack of statistical significance (especially in the case of ROA) suggests that the sector may not yet be fully leveraging the benefits of environmental sustainability. This could imply that the space industry has unused potential in environmental sustainability.
Given that environmental concerns like space debris and carbon emissions from launches are growing issues, it would be profitable in the long run for space companies to invest in eco-friendly innovations. The evidence points to the idea that although environmental sustainability isn't yet yielding immediate, robust financial returns in all aspects, companies that invest in this area would benefit from enhanced public image, regulatory advantages, and eventually, improved profitability and benefit from it in the near future.
On the other hand, social and governance factors show consistently stronger and statistically significant relationships with financial performance. The findings show that space companies already excelling in social responsibility (through employee welfare, community

engagement, and ethical practices) are seeing direct financial benefits. The same is true for governance, where well-governed companies are more profitable and financially stable. These factors suggest that, if space companies are unable to immediately implement or improve their environmental practices, focusing on social and governance sustainability offers a clear path to improving both financial performance and sustainability.

Thus, the results suggest an approach based on two perspectives: space companies should increase their focus on environmental sustainability to unlock its financial potential over *long-run*, while maximizing their efforts on social and governance aspects to drive *short-run* profitability. In doing so, they would not only improve their ESG scores but also secure a more sustainable and profitable future.

To conclude, both indices show a positive relationship between ESG performance and financial outcomes, but the strength and statistical significance of this relationship vary. The EuroNext Helios Space Index results suggest a more consistently strong impact of ESG scores across all financial metrics, with coefficients significant at the 1% level for both ROE and PM, indicating a robust link between ESG practices and overall financial health. In contrast, the S&P Kensho Space Index results reveal a more nuanced picture: while ESG performance positively influences ROA, ROE, and PM, the impact is strongest on ROE, particularly in the presence of higher leverage. The significance of the DTE ratio in the S&P Kensho Space Index highlights the role of capital structure in maximizing returns, suggesting that companies with higher debt relative to equity can leverage ESG performance to achieve superior financial outcomes.

Chapter IV: Proposal of Sectorial Standard Aerospace, Defence and Service Sector in the Manufacturing Sector Group

4. Sector-Specific Outline

In this chapter, I present a proposal for establishing a sector-specific standard for the aerospace industry, modeled on the framework of sectorial standards developed by EFRAG, such as those for the Oil and Gas industry, which draft was approved by the Sustainability Reporting Board in September 2024.

As the aerospace sector increasingly plays a critical role in global sustainability challenges, especially concerning space debris and greenhouse gas (GHG) emissions, the need for standardized metrics and disclosures is essential.

This proposal aims to outline key policies, actions, and reporting requirements that align with international sustainability goals, ensuring transparency and accountability in mitigating environmental impacts while fostering responsible innovation within the aerospace industry. The proposed standard serves as a foundational tool for addressing both current and future challenges, offering a roadmap for sustainable aerospace practices.

As a general disclaimer, it must be considered that the following proposal of standard is focusing more on the Aerospace side of the sector, due to the obvious delicate implications of the sector when talking about Defence side, especially in terms of possibility of providing information and military involvements.

4.1 Aerospace & Defence Proposal for Sectorial Standard, in line with the Proposed Sectorial Standards on Oil and Gas drafted by EFRAG.[120]

4.1.1 Description and Classification of the Sector Group[121]

A classification of the Sector is mandatory whenever drafting a proposal of a standard, to provide the just scope of action of the standard itself.

[120] The proposal of the standard was drafted by me, it is in line with the Sectorial Standard of Oil and Gas (OG). In this process I was supervised by my senior EFRAG colleagues. To add to this, the drafting process had inputs from Angela Serra, the Senior Emissions Technical Advisor of Baker Hughes.

[121] The classification paper, published on the 4th of June 2024, is available in the official website of EFRAG, https://www.efrag.org/en/projects/sector-classification-and-approach-sec1-standard-setting/research-phase?page=meeting_documents in the following PDF format: https://www.efrag.org/system/files/sites/webpublishing/Meeting%20Documents/2405070938330278/04-02%20-%20Sector%20Classification%20SEC%201%20-%20SRB%20240604.pdf.
The EFRAG members involved in the draft are Didier Andries, Pedro Faria, Gemma Sanchez Danes, Fredré Ferreira, Chiara Del Prete.

The categorization process is intended to be providing a point of reference for the undertakings that will have to disclose according to the standard. The overall approach is focusing on materiality, the proposed datapoints are a way to assess it and therefore be transparent about it.

According to *Sector Classification SEC 1*, paper 04-02, published in June this year, the classification of the Manufacturing Group is defined as a Sector that has as main characteristic the "physical or chemical transformation of materials, substances, or components into new products, although this cannot be used as the single universal criterion for defining manufacturing".

Aerospace, Defence and Service Sector is part of it, and it is defined as the sector that includes "manufacturers of commercial aircraft, aircraft parts, aerospace and defence products, as well as defence prime contractors".

4.1.2 Most Material Sustainability Matters to the Sector[122]

The Manufacturing Group, as described above, relates to transformation of materials into new products, with the relative implications that the transformation brings. This is crucial when considering the scope of the activities of the sector.

Impact Materiality, defined as company's actions impacting environment and society[123], might be found in: GHG emissions due to the overall Life Cycle of the products but especially to launches; noise pollution for the same category of activities; high-energy need for the production and/or launch of aircrafts, spacecrafts; impact on biodiversity especially in the testing sites due to possible errors and failures; the impact related to sourcing of raw materials, even more if they are rare; end of life disposal and waste management. Instead, for the impacts on society the issues might arise from: labour conditions; conflicts with communities for sourcing of materials; government involvement and potential bribery incidents.

In the following paragraphs I will be providing the standards that will tackle these main material topics.

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[122] Sustainability matters for the AD Sector are defined in the following paper https://www.efrag.org/sites/default/files/sites/webpublishing/SiteAssets/Working%20Paper%20Draft%20ESRS%20SEC1%20Sector%20Classification%20Standard[1].pdf

[123] CSRD reference to double materiality "Building on the double materiality principle, standards should cover all information that is material to users of that information", art. 37, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32022L2464

4.1.3 Aerospace & Defence Proposal for Sectorial Standard, in line with the Proposed Sectorial Standards on Oil and Gas drafted by EFRAG.

General disclosures

SBM1 AD

1. The undertaking shall report a breakdown of its net revenue for the reporting period in the following NACE activities:

(a) H51.2 - Freight air transport and space transport

(b) H51.2.1 - Freight air transport

(c) H51.2.2 - Space transport

2. The undertaking shall disclose its production targets corresponding to the years specified in its GHG emission reduction targets and shall include:

(a) production forecast of GHG emission

(b) production targets of GHG emission

Cross topical

AD 1. Mapping of launch sites

3. The undertaking shall disclose a list of its significant launch sites which are either under its financial or operational control, with specification of the sustainability matters to which they are connected.

4. The objective of this Disclosure Requirement is to enable an understanding of which significant launch sites relate to specific material sustainability matters.

Metrics

5. For each of the significant launch sites in the list, the undertaking shall include:

(a) basic description, including name and a description of the activities and main characteristics of each site;

(b) location (NUTS region in the EU, country + region outside EU);

(c) type of control: financial or operational control;

(d) status of site (active; undergoing closure; closed and rehabilitated; or closed and not rehabilitated);

(e) material impacts related to social or environmental matters to which launch site is connected to, including:

i. whether the site is located in or near the protected areas or a key biodiversity area. If so, the undertaking shall specify the impacts to the affected habitats and ecosystems and describe biodiversity management and adaptive management activities in place;

ii. whether the site is located in areas of high-water stress.

iii. whether the material impacts on the local community are connected to;

1. indigenous peoples;
2. land rights;
3. hazardous waste storage or disposal;
4. voluntary or involuntary resettlements that have been taking place or are ongoing near the site, subject to legal restrictions on the disclosure;

ii. whether the site is in or near the conflict-affected or high-risk areas; and

iii. whether the site has implemented works councils, occupational health and safety committees and/or other worker representation bodies to deal with impacts.

AD 2. Launch sites

6. The undertaking shall disclose its active launch sites.

Metrics

7. The undertaking shall disclose the total active sites for launches, it shall include:

(a) in or near protected areas and key biodiversity areas; and

(b) in areas of high-water stress.

(c) in countries with high risks of corruption, money laundering and financing of terrorism;

(d) in or near conflict-affected or high-risk areas;

(e) in or near the indigenous land.

8. The undertaking shall disclose the total active sites for launches per country.

AD 3. Industrial hazards

9. The undertaking shall disclose information related to industrial hazards.

10. When reporting its policies, actions and targets related to industrial hazards the undertaking shall specify whether and how they address:

(a) GHG emissions and other chemicals used in operations;

(b) management of the latter;

(c) managing impacts from past accidents for which environmental remediation especially when considering in-orbit collisions that may still be on-going, including any actions that are planned for short, mid and longterm, if applicable.

ESRS E2 Metrics

11. The undertaking shall disclose the following metrics related to pollution during the reporting period:

(a) for water pollution:

i. total number and volume (in barrels) of hydrocarbon spills to water;

ii. total number and volume (in m3) of other chemical spills to water.

(b) for soil emissions:

i. total number and volume (in barrels) of hydrocarbon spills to soil;

ii. total number and volume (in m3) of other chemical discharges to soil.

(d) number of underground storage tanks (UST) for petroleum and hazardous substances;

(e) number of UST releases requiring clean up

ESRS S1 Metrics

12. The undertaking shall disclose the following information if its workforce is exposed to respectively chemical, physical or ergonomic hazards:

(a) for chemical hazards, a list of the substances of very high concern (SVHCs), that workers are exposed to in its own operations;

(b) A list of key physical or ergonomic hazards associated with aerospace operations, including those related to handling space debris, high-risk environments, or prolonged exposure to space-related activities. The company should also disclose whether these hazards are managed within its health and safety management system.

AD 4. Closure of assets

13. The undertaking shall disclose information related to the closure of assets.

Metrics

14. With regards to liabilities for closure of assets:

(a) The financial liabilities recognized on the balance sheet, including:

i. The undiscounted monetary value of liabilities, disaggregated by time horizon (e.g., short, medium, and long-term liabilities).

ii. The discount rate applied to calculate the present value of these liabilities.

(b) Contingent liabilities, which may arise but do not yet meet the accounting recognition criteria at the reporting date. These liabilities may include expected costs for:

i. Environmental monitoring and remediation post-launch, including any space debris mitigation and removal.

ii. Social and environmental responsibilities for post-closure monitoring and aftercare, including the safe deorbiting of space objects and measures to manage long-term space debris risks.

Environmental disclosures

AD Climate change

Policies, actions and targets

15. When reporting its policies, actions, and targets related to climate change mitigation, the undertaking shall specify whether and how they address:

(a) The implementation of systems to detect and repair leaks in aerospace operations, including the reduction of GHG emissions from propulsion systems and other fuel-related processes.

(b) Measures to address and mitigate emissions detected during regular monitoring of spacecraft, launch operations, and manufacturing processes, including efforts to prevent emissions from contributing to space debris or orbital contamination.

(c) The management and reduction of GHG emissions, with particular focus on emissions generated by aerospace manufacturing, space launches, and satellite operations.

(d) GHG emissions from Scope 3, particularly those associated with the use of aerospace products, such as emissions from propulsion systems during launch and in-orbit operations, and the impact of space debris on long-term environmental sustainability.

16. The undertaking shall disclose its:

(a) monetary expenditures for the reporting year on research and development of technologies, solutions and business models that can address the undertaking's risks related to climate change ('transition-related R&D expenditures')

17. The undertaking shall disclose a breakdown of its GHG emissions for the reporting period as follows:

(a) Total Scope 1 GHG emissions, including a breakdown into total CO2 emissions and methane emissions resulting from aerospace operations, such as launches and manufacturing.

(b) Scope 1 GHG emissions by type of source, specifically:

i. Stationary combustion related to manufacturing facilities and ground operations;

ii. Emissions from launch activities or testing;

iii. Emissions related to the venting of gases from spacecraft or ground-based propulsion systems;

iv. Fugitive emissions, including leaks from fuel storage or aerospace equipment during operations or testing;

v. Other emissions, including any emissions linked to space debris mitigation efforts and satellite or space object operations.

Metrics

18. The undertaking shall disclose how it expects the management of climate change-related risks and opportunities to impact its medium and long-term financial position, performance, and development, it shall include:

(a) Capital expenditure (CapEx) plans related to the development and deployment of technologies aimed at reducing GHG emissions from aerospace operations, including spacecraft launches and satellite maintenance.

(b) Expected changes in investment levels (monetary amount) for the development of low-carbon aerospace products and services, such as cleaner propulsion systems and innovative solutions for reducing space debris.
(c) CapEx plans for the development of new infrastructure projects related to sustainable aerospace technologies, including emissions reduction systems and space debris mitigation infrastructure.
(d) Potential write-off situations arising from the early decommissioning of aerospace assets that do not meet the criteria for accounting recognition at the balance sheet date.
(e) Anticipated early closure of existing aerospace assets and the corresponding effects on their useful life, including satellites, spacecraft, and launch infrastructure, particularly in response to climate-related regulations or environmental sustainability initiatives.

19. The undertaking may disclose the number of satellites involved in providing data for climate change related phenomena.

AD Pollution

Metrics

20. The undertaking shall disclose the following metrics related to its aerospace operations:
(a) The percentage of space launches or aerospace operations for which public disclosure is made regarding the types of propellants, fuels, or chemicals used, particularly those contributing to GHG emissions.
(b) The percentage of aerospace operations or launch sites where environmental quality, including air and atmospheric conditions, has deteriorated compared to baseline measurements, with a focus on GHG emissions and space debris generation.
(c) The total volume of propellant or fuel used in aerospace operations (in cubic meters) during the reporting period, particularly for launches, orbital adjustments, and space debris mitigation efforts.
(d) If there are phasing out existing space operations and/or stopping operational investments that contribute to space debris in critical orbits, particularly in regions of high satellite traffic or near sensitive orbital zones.

AD Water and marine resources

Policies, actions and targets

21. When reporting its policies, actions, and targets related to environmental resource management, the undertaking shall specify whether and how they address:

(a) The management on launches close to shared resources as international waters and water-stressed areas.

(b) Reducing the impact of re-entering phase, when landing on water.

AD Biodiversity and ecosystems

Policies, actions and targets

22. When reporting its policies, actions, and targets related to space environments and ecosystems, the undertaking shall specify whether and how they address:

(a) Whether their activities are harming key biodiversity areas

(b) Minimizing the impact on the orbital environment and Earth's atmosphere from current and future aerospace operations, including the mitigation of space debris and GHG emissions resulting from launches, spacecraft operations, and satellite decommissioning.

(c) Achieving no net increase or a net reduction in space debris in orbital zones through debris mitigation measures, including the retrieval or deorbiting of defunct satellites and the responsible management of aerospace assets.

AD Circular economy

Metrics

23. The undertaking shall disclose the percentage of materials resulting from decommissioning activities related to space assets, facilities, and infrastructure (such as satellites, spacecraft, and ground stations) that are re-used or recycled. The undertaking shall also disclose the following volumes for the reporting period:

(a) Volume (in cubic meters) and percentage of propellants and fuels used in space operations, categorized by: i. satellite propulsion; ii. launch vehicle propulsion; iii. other aerospace uses;

(b) Tons of space debris retrieved or mitigated through active debris removal efforts or deorbiting measures;

(c) Tons of waste generated from aerospace manufacturing and launch operations;

(d) Tons of hazardous materials from decommissioned spacecraft and satellite components;

(e) Tons of non-recyclable components from decommissioned aerospace assets;

(f) Tons of materials recovered or recycled from decommissioned aerospace infrastructure, such as launch platforms and satellite ground stations.
(g) The material used for spacecrafts and whether they follow standards as Space Safety Framework for the design of the object and for the resilience of the materials.

Social disclosures

AD Own workforce

Policies, actions and targets

24. When reporting its policies, actions, and targets related to its own workforce, the undertaking shall specify whether and how they address:
(a) Provision of adequate facilities for its workforce, including access to essential services such as clean water, sanitation, electricity, and communication services, especially for workers stationed at remote aerospace operation sites, such as launch facilities or mission control centers.
(b) Management of working hours and work-life balance for employees involved in round-the-clock operations, including satellite monitoring, launch operations, and space debris tracking, particularly in high-demand periods or during remote and extended space missions.

AD Workers in the value chain

Policies, actions and targets

25. The undertaking shall specify whether and how they address the applicability of its own health and safety management system to value chain workers and whether and how the undertakings monitors the health and safety metrics for the value chain workers whilst working on site.

AD Affected communities

Metrics

26. The undertaking shall disclose the following metrics in relation to its activities impacting space environments and communities:
(a) Whether it has been involved during the reporting period in a process of seeking approval or consultation from affected communities, including indigenous peoples, for activities such as the construction of aerospace facilities or the launch of space missions that may have environmental or social impacts.

AD Consumers

27. The undertaking shall disclose:

(a) the number of open cases before courts or other competent authorities at the end of the reporting period that concern misleading business-to-consumer commercial practices, in particular misleading environmental claims, or public communication related to sustainability.

28. The undertaking that provides satellite-related services shall disclose:

(a) the number of vulnerable consumers, as to provide the impacts of a potential stop of service in areas where the undertaking is the only provider for i.e. internet connection.

(b) the risk of potential dual use of data (as additional use we consider i.e. military use) especially if data are handed in to governmental organizations consumers that work in the defence field.

Governance disclosures

AD Business conduct

29. The undertaking shall disclose the amount it spent during the reporting period on lobbying activities related to aerospace operations. This should include activities addressing material impacts, risks, and opportunities identified in its materiality assessment.

The proposed sectoral standards for the Aerospace and Defence (AD) industry, inspired by EFRAG's initiatives in the oil and gas sector, aim to establish a comprehensive framework for integrating sustainability into the high-impact aerospace field.

It is particularly relevant especially in terms of climate challenges, because the space sector entails satellite companies that are fundamental for the provision of data in the monitoring of Earth’s climate. By setting these disclosure requirements across environmental, social, and governance aspects, the standards will increase transparency and accountability in aerospace operations. They address critical issues such as greenhouse gas (GHG) emissions, industrial hazards, space debris management, and the sustainable use of launch sites, so that the sector contributes to global climate change mitigation efforts and biodiversity preservation. To add to these topics, the inclusion of metrics related to workforce safety, indigenous land impacts, and environmental remediation reflects the sector's responsibility to mitigate its broader social and environmental impacts.

By adopting these standards, aerospace and defence companies can align themselves with global best practices in sustainability reporting while addressing pressing challenges associated with space exploration and defence activities.

This proposal represents a significant step towards a more sustainable and responsible future for the sector, ensuring that it can continue to innovate while also protecting the planet, its ecosystems, and the communities affected by its operations.

Chapter V: Conclusions

5 Context, aim, and motivation

As we begin the conclusive chapter of this thesis, it is important to reflect on the foundational elements discussed in the introductory chapter, which provided a comprehensive framework for understanding the complex challenges and opportunities within the evolving space economy. The thesis commenced with a detailed exploration of space sustainability, establishing a clear definition and examining the current state of the sector.

Central to this discussion is the pressing issue of space debris, which has emerged as the greatest challenge facing the space economy in the coming century. The introductory analysis offered a range of solutions, emphasizing the critical role of regulatory approaches in addressing the escalating problem of orbital debris. These approaches underscore the urgent need for a unified international framework to manage and mitigate the accumulation of space junk through new technologies and methods.

Regulatory approaches are crucial in creating a sustainable framework for space activities. The development of a Space Sustainability Rating (SSR) system by the World Economic Forum's Global Future Council on Space Technologies is a significant step towards ensuring that all space missions adhere to sustainability principles. This rating system, which evaluates missions based on factors such as collision avoidance and debris mitigation, provides a clear and transparent mechanism for promoting responsible space behavior.

In addition, to tackle the debris crisis, a combination of technological, market-based, and regulatory instruments is essential. Active Debris Removal (ADR) technologies, such as the upcoming *ClearSpace-1* mission, represent critical steps towards physically reducing the amount of debris in orbit. Space Situational Awareness (SSA) and Space Traffic Management (STM) are also crucial tools to track and mitigate potential collisions. These technical approaches could be complemented by market-based instruments, such as pollution taxes both on LEO and on Earth, or orbital usage fees, which can incentivize responsible behaviour in space. Together, these instruments form a comprehensive toolkit that can help manage and reduce the risks associated with space debris, ensuring that space remains accessible and safe for future generations.

Unfortunately, this might not be sufficient, for such an ambitious goal.

Moreover, the involvement of private companies, which are increasingly pivotal in developing innovative technologies and practices, was identified as a key driver in advancing sustainable practices within the sector. Their contributions are essential to shaping the future dynamics of space sustainability.

Private companies play an increasingly important role in addressing the space debris crisis. Companies like Astroscale, Surrey Satellite Technology Ltd., and Northrop Grumman are pioneering new technologies and services that contribute to space sustainability. These include active debris removal, satellite life extension, and space situational awareness services. The involvement of the private sector is therefore crucial as it brings innovation, agility, and significant investment to the table.

However, even if private companies are essential in this context, this thesis also highlights the trade-offs between the pursuit of space exploration and the need of maintaining Earth's sustainability, the so called "space paradox".

The Space Paradox highlights the inherent tension between using space to achieve sustainability goals on Earth and the potential for these activities to create unsustainable conditions in space, and on Earth as well. As space exploration might help reaching 2030 sustainability goals as seen in paragraph 1.1.8, the intensive use of space does entail that space environment will resent of the activities, and Earth as well (i.e. GHG emissions from launches). This paradox is particularly evident in the case of space-based technologies that support Earth's sustainability, such as satellites used for climate monitoring and communications, which themselves contribute to the growing problem of orbital debris.

The growing significance of this issue is further underscored by the proposal of a new Sustainable Development Goal, the 18th one, "*Space for All*", it reflects the growing recognition that space sustainability is integral to global sustainability. This goal would emphasize the importance of ensuring that space remains accessible and safe for all nations and future generations. It would also promote the responsible use of space resources and the development of international frameworks to manage space activities sustainably.

Space sustainability, as the core of this thesis, is defined as the ability to conduct space activities indefinitely into the future, while ensuring equitable access to space benefits and preserving the outer space environment for future generations. This concept, as articulated by the *UN Committee on the Peaceful Uses of Outer Space* (UN COPUOS), forms the ethical and operational framework within which all space activities should be conducted. It emphasizes the importance of considering long-term impacts, not just immediate gains, in the exploration and utilization of space. This definition serves as a guiding principle for the

development of policies and practices that ensure the sustainability of space activities, including the prevention of space debris and the protection of orbital environments.
International cooperation and shifting towards a more sustainable ethic when performing any activity in space is the only option, if we want to consider long-term viability of space. Earth's orbit is increasingly congested with both operational satellites and space debris, leading to significant risks for current and future space missions. The rapid expansion of space activities, particularly with the rise of private companies, has exacerbated the problem, making the management of orbital debris mandatory. In this regard, the thesis highlighted the *Kessler Syndrome*, where collisions between debris create more debris in a cascading effect, is a great reminder of the potential long-term consequences of inaction. Current estimates indicate that thousands of debris objects, some as small as 1cm, pose serious threats to spacecraft and satellites due to their high velocities (on average 10km/s).

5.1 Existing metrics for sustainability in the space industry

In the following paragraph, I will summarize the existing standards, rating systems, and indexes that provide a solid foundation for a sustainability framework in the space field.
Implementing standardized rules, such as *ISO 24113* for space debris mitigation and *ISO 26900*, is crucial for effectively addressing the growing problem of space debris. The lack of universal guidelines and inconsistent sharing of space data have heightened the risks of satellite collisions and additional debris, threatening both individual missions and the future of space activities. As the space sector expands, especially with the increase of private companies in the field, establishing common practices has become increasingly complex. Each entity, whether governmental or private, follows its own standards and procedures, making it difficult to achieve a universally accepted approach to space sustainability.
Standards like *ISO 24113* offer a comprehensive framework for mitigating space debris by setting clear requirements for the design, operation, and disposal of spacecraft. Similarly, *ISO 26900* aims to enhance the coordination of space activities by standardizing orbit data exchange formats. To add to this, the *Consultative Committee for Space Data Systems* (CCSDS) and the *IADC* Space Debris Mitigation Guidelines also contribute by providing best practices for limiting debris generation through responsible space operations, including end-of-life disposal and collision avoidance strategies.
Moreover, establishing common rules and standards helps create a global community that collaborates and innovates together. When all parties follow the same guidelines,

international cooperation becomes more efficient, leading to more effective space operations. This collective effort not only protects the space environment but also ensures that the benefits of space activities are preserved for future generations.

In addition to standards, rating systems like the *Space Sustainability Rating* (SSR) enhance sustainability in space. The SSR operates on a points-based system, with higher scores indicating better overall sustainability practices. The SSR score is determined through data collection, verification, and computation, reflecting a mission's alignment with sustainable practices. Companies are awarded badges Bronze, Silver, Gold, or Platinum based on their performance, signalling their commitment to advancing sustainability in space.

Finally, indexes discussed in the thesis provide further methods for tracking sustainability in space. The *Space Security Index* (SSI) monitors sustainable practices and evaluates developments in safety, sustainability, and security in outer space. Complementing the SSI, the *CNES Space Sustainability Index*, developed by the French space agency, uses comprehensive criteria to evaluate space missions, assess the space environment, and support decision-making for sustainable practices.

In conclusion, these metrics ensure that the space industry evolves in a way that not only meets current demands but also preserves the space environment for future generations. They help create a balanced approach where technological advancement, economic growth, and environmental protection go hand in hand, securing a sustainable and prosperous future for space exploration and utilization.

5.2 Main findings

The analysis presented in this thesis shows that Environmental, Social, and Governance (ESG) factors play an important role in the financial performance of space companies, though the effects differ across these areas. Environmental efforts, like reducing space debris or lowering carbon emissions, have potential to improve financial outcomes, such as Return on Assets (ROA) and Return on Equity (ROE). However, some of the results are not as statistically strong as hoped, but this only suggests that space companies haven't yet fully taken advantage of the financial benefits of going green. This means there's room for growth, especially as environmental concerns become more urgent. Companies that invest in eco-friendly innovations could see long-term financial gains, better public reputation, and even regulatory benefits.

The main reasons on why the relationship holds are the enhanced perceived value due to the company being more sustainable: investors might want to choose such companies both for ethical choices, and for faith in a long-term perspective of profit.

To add to this, companies tend to be in line with sustainable practices not only for higher investor attraction, but also for higher level of financing possibilities, especially when considering *European Green Deal Investment Plan (Sustainable Europe Investment Plan) Funding*[124]. Over the 2021-2030 period, the European Commission will try to redirect funds (whether they be Eu budget related funds, private sector…) towards sustainable investments, and the estimated number of investments will be €1 trillion. This huge change in Europe will inevitably create a dynamic for which companies are more interested in keeping a higher ESG profile to receive these financings.

Therefore, being sustainable in Europe is now more important than ever, especially from a financial point of view.

On the other hand, the analysis shows that Social and Governance factors have a more immediate and noticeable impact on financial success. Companies that focus on social responsibility (like taking care of their employees, engaging with communities…) are already seeing financial benefits. Similarly, companies with strong governance, or well-structured leadership and management tend to be more profitable and stable. This suggests that, while environmental practices may pay off in the long run, focusing on social and governance aspects can lead to quicker financial improvements, providing short-term financial benefits.

As for the practical implications, the results suggest therefore that space companies should take a two-part approach.

In the *short term*, they should prioritize social and governance practices to boost profitability and build a stronger sustainability profile in the present. At the same time, they should work on improving their environmental practices, which will help taking advantage of financial potential in the *long term* as the industry faces increasing environmental challenges. By managing both areas, space companies can improve their ESG ratings and create a more sustainable and financially successful future.

Therefore, sustainability is indeed on of the most precious tools to ensure broadly speaking higher financial performance, but if we ever were to make a distinction between long-term

[124] Investment plan for sustainable transition https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-european-green-deal-investment-plan

and short-term, then companies in the sector would have to focus on E pillar for the long-term and S, and G pillars for the short-term.

The first case relates to the fact that the results for E are showing a lower impact mainly in the S&P Kensho Space Index, on the financial performance, at least less than the other two pillars, meaning that the opportunity of investing for having higher environmental scores and therefore financial performance is there, and it must be exploited, especially when considering long-term.

Instead, for the short-term, higher S and G scores already showing a strong direct proportion to financial performance suggest that the companies should at least keep the same level of focus on them in the present to preserve the threshold.

But this might change according to the different studied indexes.

When comparing two indices, the EuroNext Helios Space Index and the S&P Kensho Space Index, we see that the EuroNext Helios Space Index has a stronger connection between ESG performance and financial performance. In particular, it shows significant results for ROE and profit margin at a high level of confidence. This means that companies within this index, that commit to all aspects of ESG, are likely to perform better financially.

Looking closer at Environmental scores, the connection to financial performance is still to fully develop. Space companies that focus on sustainability (like reducing space debris or cutting emissions) show potential for better financial results, especially when it comes to ROA and ROE. However, the evidence is not as strong as it is for social and governance factors, meaning the space industry hasn’t fully benefited from environmental initiatives yet. This shows that there is still unused potential in environmental sustainability. As concerns like space debris and emissions become more pressing, companies have the chance to invest in green technologies. These investments could help improve their financial standing in the long term, even if the immediate benefits aren’t obvious yet. Going green would also boost a company’s reputation and help them stay ahead of future regulations, avoiding potential regulatory transition risks.

Meanwhile, social and governance factors are already paying off. Companies that are excelling in areas like employee well-being, ethical business practices, and strong management are seeing direct financial benefits. This is backed by data showing that companies with strong governance and social responsibility are generally more stable and profitable.

The takeaway for space companies is to focus on improving their environmental practices to unlock long-term financial benefits while also continuing to invest in social and governance initiatives for quicker returns. By balancing these efforts, they can improve their ESG scores and secure a more financially profitable and sustainable future.

5.3 Final Conclusions

The main goal of this thesis has been to highlight the relevance of sustainability in the Aerospace and Defence sector, especially given the increasing environmental and social impacts associated with the industry's growth. As space exploration activities continue to expand, the need to incorporate sustainable practices has become more urgent than ever. While the aerospace sector has traditionally been focused on innovation and technological advancements, it must now prioritize sustainability to tackle issues such as space debris and greenhouse gas emissions.

Throughout this thesis, I have explored various sustainability frameworks, standards, rating systems, indexes and practices to show that the future of the aerospace industry depends on its ability to operate in a sustainable manner.

By proposing a Sector-Specific Standard, drawing inspiration from those already established in industries like oil and gas, this thesis outlines how aerospace companies can better address environmental, social, and governance (ESG) challenges. These standards offer a clear path towards greater transparency and accountability, encouraging companies to reduce their environmental footprint while still fostering innovation and growth.

With space becoming more crowded and the environmental consequences of aerospace activities becoming more pronounced, adopting sustainable standards is no longer just an option but would become a necessity.

Only through these efforts the sector can continue to advance while ensuring the protection of our planet's ecosystems and the sustainability of space for future generations. This means that the Aerospace & Defence industry must actively participate in shaping a future where technological progress is balanced with environmental stewardship. It is not enough to simply innovate, the sector must take responsibility for the long-term consequences of its actions, particularly when it comes to the fragile environments it operates in, both on Earth and in space.

An interesting research topic that was proposed in this thesis would be how Space Paradox could be avoided, providing the just balance between space exploration and Earth's environment preservation.
One potential solution could be investing in extremely advanced space stations that also can provide services such as the building of spacecrafts directly in the LEO region, therefore avoiding the huge impact in terms of carbon dioxide emissions during the launch. The main issue with the latter solution is linked to the provision of the materials and equipment needed to create the product. The study could give deeper insights on how, economically and environmentally speaking, the launch of smaller objects in space could balance out the environmental impact of the launch of bigger spacecrafts.
Another topic of interest could be providing empirical evidence on the SD measure, that might be a tool to understand the effective future implications of intensive usage of some areas in space, providing an objective measure of how much dangerous the said area is due to space debris.
To conclude, another proposal for further discussion might relate to the study of Space Traffic Management (STM), which certainly will be needed when the privatisation of the sector will develop up to its full potential.
By giving priority to sustainability, the Space Sector can contribute to the preservation of Earth's ecosystems, reducing its carbon footprint and mitigating the risks associated with pollution and industrial hazards.
This includes investing in cleaner technologies, developing more efficient systems, and establishing regulatory frameworks, such as the one I proposed, that protect both space and Earth.
Ultimately, only by committing to these sustainable practices the Aerospace and Defence industry will secure its place as a leader in global innovation, while also playing a key role in safeguarding the future of our planet and space for generations to come.

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