Balancing the Space Economy and Sustainability: Legal Frameworks and Policy Initiatives for Responsible Space Activities

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ABSTRACT *The potential for space exploration to drive economic growth and innovation is immense, but it must be done in a way that ensures the long-term sustainability of outer space. This involves considering the environmental impact of space activities and how to maintain economic benefits over time. This paper addresses the economic opportunities provided by space activities while mentioning the potential risk if space sustainability is not viewed as being as important as the benefits gained from the space mission. This study investigates the regulatory framework of sustainability, which merges legally binding and non-legally binding frameworks. Besides the above, initiatives balancing the space economy and sustainability are discussed.*

KEYWORDS *Space economy, space sustainability, space law, space debris, space policy.*

Introduction

Sustainability and economy are not only related to Earth's problems. Today, these terms are also extended to outer space and make so much sense. Seeking higher levels of sustainability is crucial for a range of reasons, including social, political, and global ones. At the same time, we cannot dispute the amazing advantages that space offers us on Earth, from navigation and communications to the special insight that satellite imaging and geospatial data bring to various business sectors. Moreover, researchers in newer mission areas, such as space medicine and in-orbit manufacturing, will bring many benefits for our lives back on Earth and new opportunities for space settlements and exploration.

All of these advantages are in jeopardy if space sustainability is not given dedicated international attention. Space debris and its increasing threat to space safety are the most urgent issues to handle because they pose a risk to services and activities conducted in outer space, which in turn puts the space economy at risk. As a result, future opportunities in space must be preserved by taking space sustainability into account in every facet of what nations and or private entities perform in outer space. It is worth noting that, while providing the potential to increase access to the advantages of space applications on Earth, the fast growth

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of commercial space operations also presents new obstacles to maintaining a safe and sustainable operating environment in orbit.[1]

Before diving into this topic, a definition of the main terms is necessary. When it comes to the expression "space sustainability," it is becoming more and more used in the space sector, and it has caught the attention of many, not only legal researchers but also scientists, technologists and businesses.

We can state that, until recently, there was no agreed meaning for this term, one of the reasons being that international space law and, specifically, the Outer Space Treaty (OST) does not mention the word "sustainability" expressly. Nevertheless, the Guidelines for the Long-term Sustainability of Outer Space Activities were released in 2018 by the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) in response to this problem. Among these recommendations was the first draft definition of space sustainability, which goes as follows: "*The long-term sustainability of outer space activities is defined as 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, in order to meet the needs of the present generations while preserving the outer space environment for future generations*."[2]

As regards the term "space economy", it is defined by the OECD as "*the full range of activities and the use of resources that create and provide value and benefits to human beings in the course of exploring, understanding, managing and utilising space. Hence, it includes all public and private actors involved in developing, providing, and using space-related products and services.* [3]

After clarifying the concept of "sustainability," it is important to give a further explanation to distinguish between the three pillars of sustainability: *from*, *in*, and *for* space. Nevertheless, as this term is frequently used, the risk of confusion and misunderstanding of these types is high, making it essential to clearly explain sustainability and its three different cornerstones.

Starting with "sustainability *from* space", this phrase describes the use of space as a platform to directly or indirectly deal with worldwide challenges. In this context, pillar 1 addresses how the space sector may contribute to sustainable development by providing space data or by adopting more proactive steps like using space to generate energy. The key idea here is space as a service to be used in fields such as fair commerce, equality and justice, urban development, and climate monitoring. The new space economy is relying more and more on domains like Earth observation, navigation, and communication. This concept

[1] Kevin M. O'Connell, "Space Sustainability as a Business and Economic Imperative," *Geospatial World* (2022) https://www.geospatialworld.net/prime/business-and-industry-trends/space-sustainability-business-economic-imperative/.

[2] United Nations Committee on the Peaceful Uses of Outer Space, *Guidelines for the Long-Term Sustainability of Outer Space Activities*, Fifty-fifth Scientific and Technical Subcommittee, Vienna, Austria, 2018, A/AC.105/2018/CRP.20.

[3] OECD, "Introduction," in *The Space Economy at a Glance 2011* (Paris: OECD Publishing, 2011), https://doi.org/10.1787/9789264113565-4-en.

revolves around the notion of "space as a service" wherein the utilisation of space technology turns into a need for resolving Earth's pressing sustainability problems.[4]

Secondly, "sustainability *in* space" means using space as a natural resource for development, research, and preservation. This type addresses sustainable space usage, the fundamental belief here being that space is a resource that may be employed for human advantage, preserved for political or scientific reasons, or researched to find out more about our role in the cosmos. This implies that it covers subjects like manufacturing in orbit, servicing in orbit, recycling in orbit, re-entry and demise, legal and regulatory matters, space safety, space environment management, detection and mitigation of space debris, and sustainable use of space resources.[5]

Thirdly, "sustainability *for* space" refers to mitigating the effects of space operations on the Earth's ecosystem. This final pillar addresses the sustainability of the space industry overall based on its impacts on the Earth's ecology. Raw material extraction, production, launch, data processing and exploitation, disposal, and socioeconomic repercussions are a few potential impact areas. They also cover a space mission's entire life cycle.[6]

Going beyond these three pillars, we can also mention the sustainability *of* space as a single overarching pillar that may be formed by combining pillar 2 (sustainability *in* space) and pillar 3 (sustainability *for* space). In terms of the orbital and the Earth's environment, this refers to the management of ecological or other sustainability implications resulting from space sector operations.[7]

All three of the sustainability pillars or types we identified in this paper may incorporate the idea of the space economy. Each of the mentioned pillars covers the following elements of the space economy: starting with sustainability *from* space, via offering data and technology that aid in addressing global issues, the space industry supports this pillar. For instance, Earth observation satellites offer vital information for resource management, disaster response, and climate monitoring, all of which promote Earth's sustainable development.[8] Regarding the second pillar, sustainability *in* space, managing and using space resources sustainably, this pillar directly affects space economy. This entails creating and upholding regulations for space operations, controlling space debris, guaranteeing orbital usefulness in the long term, and prudently using space resources to avoid contaminating or exhausting the space environment, with

[4] Andrew Ross Wilson and Massimiliano Vasile, "The Space Sustainability Paradox," *Aerospace Centre of Excellence, Department of Mechanical & Aerospace Engineering, University of Strathclyde* (September 14, 2023), https://doi.org/10.1016/j.jclepro.2023.138869.

[5] *Op. cit.*

[6] *Op. cit.*

[7] *Op. cit.*

[8] See National Aeronautics and Space Administration (NASA). "*Earth Observation for Sustainable Development Goals*." https://www.nasa.gov/mission_pages/sustainability/earth_observation_for_sustainable_development.html.

necessary control over economic activity.[9] As regards sustainability *for* space, that third pillar is also impacted by the space economy as it affects how space operations influence Earth. This entails reducing the negative effects of space missions on the environment, including emissions during launches, production procedures, and spacecraft disposal. This pillar benefits from initiatives to create greener technology and use resources in the space sector more effectively.[10]
Overall, sustainability is part and parcel of the space economy, entailing activities and industries involved with exploring, utilizing, and commercializing outer space. This connection arises because the further growth and success of the space economy depend on the responsible use of space resources and minimizing harm, both in orbit and on Earth. Space activities can be viable in the long term only if their principles and practices are responsible, with sustainability ensuring the space economy's growth without causing irreversible harm to orbital environments, celestial bodies, or Earth's ecosystems.[11]

This paper will explore this evolving topic by addressing the following questions: **How would sustainability in outer space impact the space economy and vice versa?** This emergent topic will be addressed by the paper, underpinned by a mixed-methodological approach. First, the paper will apply an empirical methodology to pinpoint tangible benefits and opportunities derived from activities in outer space. This methodology will be composed of a real-life data analysis that shows how the space economy develops due to variety and can be long sustainable because of sustainability principles **(1).** Second, the normative methodology will be used to analyse the legal and regulatory framework that governs sustainability in outer space. This paper will mainly focus on international treaties, in particular, the Outer Space Treaty, and the non-legally binding instruments. It will also identify the potential gaps and areas for improvement in the legal framework to make sure that economic growth is in line with the principles of sustainability **(2)**. Finally, it will highlight some policies and initiatives for balancing the space economy and sustainability **(3)**.

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[9] See Secure World Foundation (SWF), "Ensuring the Long-term Sustainability of Outer Space Activities."
Online:https://www.unoosa.org/documents/pdf/copuos/stsc/2022/statements/4_SWF_ver.4_14_Feb_PM.pdf.

[10] NASA, "Green Propellant Infusion Mission: Advancing Sustainable Space Technology." *NASA*. Accessed June 5, 2024.
https://www.nasa.gov/mission_pages/tdm/green/index.html.

[11] Alessandro Paravano, Matteo Patrizi, Elena Razzano, Giorgio Locatelli, Francesco Feliciani, and Paolo Trucco, "The Impact of the New Space Economy on Sustainability: An Overview," *Acta Astronautica* 222 (2024): 162–173. online: https://doi.org/10.1016/j.actaastro.2024.05.046.

1. Overview of the Space Economy and Its Sustainability
1. 1 Proliferation of Space Economy Aspects

Before diving into the details of this part, it is crucial to mention that the proliferation of economic resources from space is also mirrored by the proliferation and constant growth of space economy actors, which reinforces the idea that the sector is experiencing a major shift. In contrast with formerly being "*the preserve of the governments of a few spacefaring nations*,"[12] it now involves a growing number of public and private players engaging in a diverse range of activities. New countries, the commercial sector, academia, and even private individuals appear among the actors, working to develop military and security intelligence, monitor climate change, improve navigational capabilities, and establish space tourism companies.[13]

1. 1. 1 Launch Industry

By far the most significant market category is the launch industry. After all, the space sector would not exist without rockets. Let us keep in mind that 1957 saw the first rocket launch into space, Sputnik I. Economically speaking, it is estimated that by the year 2024, the global space economy will be at US$600 billion and have a growth rate of about 8% annually.[14] Its increase underlines the the role of the space sector in terms of global economic growth. The volume of the space launch service industry alone attained 17.3 billion USD in 2023 and it plays as a major contributor. According to projections, this market will develop at a CAGR of 12% to reach $38.2 billion in 2030.[15] From a technological perspective, the last twenty years or so have seen enormous changes in this sector due to advancements in rocket technology. With its Falcon 9 rockets, SpaceX successfully developed and implemented reusable rocket technology, which profoundly affected the sector. Reusability challenged conventional disposable rocket models by enabling the use of the same parts for many missions, which

[12] ESA defines Space 4.0 as follows: "*Space 4.0 era is a time when space is evolving from being the preserve of the governments of a few spacefaring nations to a situation in which there is the increased number of diverse space actors around the world, including the emergence of private companies, participation with academia, industry and citizens, digitalisation and global interaction*." https://www.esa.int/esatv/Videos/2016/11/United_Space_in_Europe/(lang)/es

[13] OECD (2012), OECD Handbook on Measuring the Space Economy, OECD Publishing. http://dx.doi.org/10.1787/9789264169166-en.

[14] Space Foundation, "The Space Report 2024 Q2." *Space Foundation*, July 18, 2024, https://www.spacefoundation.org/2024/07/18/the-space-report-2024-q2/.

[15] Cognitive Market Research, "Space Launch System Market Report 2024." *Cognitive Market Research* (2024). https://www.cognitivemarketresearch.com/space-launch-system-market-report.

not only decreased launch costs[16] but was also a significant step toward sustainability.

1. 1. 2 Satellite Industry

Satellites in the past were big, highly expensive machines using very advanced technology and requiring powerful rockets; hence, their cost was tens or hundreds of millions of dollars. All that has dramatically changed over the last two decades. With the significant development of electronic components and the reduction of launch costs per kilogram, satellite technology has been revolutionized. With these more compact, relatively affordable satellites, it is now possible for startups, academia, and almost anyone to participate in space missions and data gathering at a few thousand dollars. [17] Even students can design simple satellites at their universities, and some have begun doing so. We can be frank and say that the small satellites of today are the main players. Some businesses have deployed large constellations with a mindset of offering communications services, Earth observation, and internet coverage worldwide, among other uses. The numbers we are seeing now were not seen before. [18]

1. 1. 3 Benefiting from Satellite Data, Applications, and Services

The downstream industry has enormous potential to improve human lives, preserve the environment, and provide income. To what extent has the business sector been able to access this market? The scope is broad and noteworthy, but in this paper, we will talk mainly about two: Remote Sensing and Broadband.

Remote Sensing

Commercial stakeholders are using space technology insights more and more. Numerous businesses, including Planet, Maxar Technologies, and Airbus Defence and Space, have created and managed fleets of Earth observation satellites that provide government agencies with services in addition to providing commercial services to other businesses and customers. As space services are becoming more widely recognised and more usual, a growing number of businesses are turning to space for high-resolution photography and data

[16] Jeff Foust, "SpaceX Gaining Substantial Cost Savings from Reused Falcon 9," *SpaceNews*, April 5, 2017, https://spacenews.com/spacex-gaining-substantial-cost-savings-from-reused-falcon-9/.

[17] Bryce. *Launch Sites 2024*. Accessed June 15, 2024. https://elearningunodc.org/pluginfile.php/73502/mod_scorm/content/27/scormcontent/assets/Bryce_Launch_Sites_2024.pdf.

[18] UNOOSA, "Space Economy - Introduction to Space Economy," *UNOOSA*, accessed June 5, 2024, https://elearningunodc.org/course/index.php?categoryid=78.

analytics. Among the most popular uses are smart agriculture, raw resources and energy, urban planning, and climate action. [19]
In the next 10 years, we might expect thousands more satellites to help generate revenues not only in the downstream Earth observation market but also across the launch and manufacturing streams. Commercial companies are now procuring satellites and they are launching and operating them in space, focusing on the analytics of raw data that come from space, and engaging in both aspects, operating a satellite and analysing their own data in-house. Since the data analytics business model is well-established and highly regarded by investors and customers alike, it presents a strong commercial opportunity for both start-ups and established businesses.[20]

Broadband

When satellite internet first became accessible in the early 1990s, many of the early attempts failed, and the excessive cost prevented a sustainable industry from developing. Large constellations in low Earth orbit were the new method of broadband delivery that companies began to envision in the 2010s. Early on, observers were not sure if this would succeed, but the commercial sector is moving quickly forward. Despite advancements over the past 15 years, 2.6 billion people, according to the International Telecommunication Union, are still not online.[21] Thus, it is anticipated that the satellite connection industry will expand quickly through 2030. These are compelling reasons for the space industry to take control of the market. It still needs to be seen if it can provide its services at a cost that makes sense for the places it strives to serve.[22]

1. 1. 4 Space Tourism

We must keep in mind that the trend of commercial space travel is growing; SpaceX conducted the first-ever completely commercial mission to low-Earth orbit in September of 2021. The launch altitude for the Inspiration4 mission was 585 kilometres. Although the precise cost is unclear, it was proven to be less than $200 million for a crew of four. For USD 55 million per passenger, a start-up company called Axiom Space is offering commercial flights to the ISS.[23] These days, suborbital travel exists as well. Virgin Galactic and Blue Origin successfully launched their separate spacecraft in July 2021, setting new records

[19] UNOOSA, “Space Economy - Introduction to Space Economy.”
[20] UNOOSA, “Space Economy - Introduction to Space Economy.”
[21] International Telecommunication Union, “Facts and Figures 2024." Press release, November 27, 2024. https://www.itu.int/en/mediacentre/Pages/PR-2024-11-27-facts-and-figures.aspx.
[22] UNOOSA, “Space Economy - Introduction to Space Economy.”
[23] Vicky Stein and Scott Dutfield, “Inspiration4: The First All-Civilian Spaceflight on SpaceX Dragon,” *Chicago Tribune*, January 5, 2022, https://www.space.com/inspiration4-spacex.html.

for space tourism. For a Virgin Galactic voyage, the starting ticket price was around USD 200,000, but the price was later changed to USD 450,000. Blue Origin charges different fees.[24] While the rise of commercial space travel is unmistakable, it should also be underlined that, in most aspects, the regulatory framework for safety already exists as the FAA Commercial Space Launch Regulations[25] (U.S.) cover vehicle design, crew training, and safety zones for safe launches and re-entries; nevertheless, the regulations may require further refinement. But again, long-term viability will ultimately depend on market dynamics. Regulators should be cautious about intervening in market processes, especially within the U.S., where a free-market approach to the space industry is encouraged. Especially in the next ten years, commercial tourism is expected to grow at a relatively uneven rate. However, almost all the estimates are above USD 3 billion, creating an interesting opportunity.[26]

1. 1. 5 Space Resources

Space mining companies and states can extend their operations and generate new revenue streams by extracting precious resources from celestial bodies, such as water and rare metals. In fact, the space mining market is expected to increase at a Compound Annual Growth Rate (CAGR) of 20.48% to reach USD 5,068.06 million by 2029 from its value of USD 1,141.62 million in 2021, according to Data Bridge Market Research.[27] Also, if mining is already profitable on Earth, then colonizing other planets has the enormous potential to bring far higher profits. Building space mining colonies would open new possibilities for resource discovery and utilization, resulting in previously unheard-of technological advancements and economic growth, in addition to expanding the volume of resource extraction. Moreover, according to some experts, space mining colonies are just like "*establishing markets in space*".[28]

1. 1. 6 Classifying Space Economic Activities

At this stage, we can say that to benefit humanity as a whole, whether from an economic, social, cultural, or scientific perspective, the space economy is a complex and effective generator that combines components from multiple

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[24] UNOOSA, "Space Economy - Introduction to Space Economy."

[25] Federal Aviation Administration. *Aerospace Forecast: Fiscal Years 2024-2044, Commercial Space*, U.S. Department of Transportation, 2024. https://www.faa.gov/dataresearch/aviation/aerospaceforecasts/commercial-space.pdf.

[26] UNOOSA Space Economy, *op. cit.*

[27] Data Bridge Market Research, "Space Mining Market Size, Share & Global Analysis by 2029," *Data Bridge Market Research*, 2023, https://www.databridgemarketresearch.com/reports/global-space-mining-market.

[28] Matthew Weinzierl, "Space, the Final Economic Frontier," *Journal of Economic Perspectives* 32, no. 2 (2018): 173–192, HTTPS://DOI.ORG/10.1257/JEP.32.2.173.

markets. Depending on what has been presented, these different activities that contribute to the creation of a strong space economic capability can be classified into three main segments.

1. The **upstream segment** includes research and development, space manufacturing and ground systems, launch, and space exploration.
2. The **downstream segment** involves activities related to the application and use of space-derived data and services on Earth. It concerns applying space-based technology to real-world problems (such as weather forecasting, remote sensing, Earth observation, communications, and location, navigation, and timing).
3. The **space-related segment** covers space applications, as well as products and services that are dependent on satellite technology yet are produced as spin-offs or technology transfers from the space industry.[29]

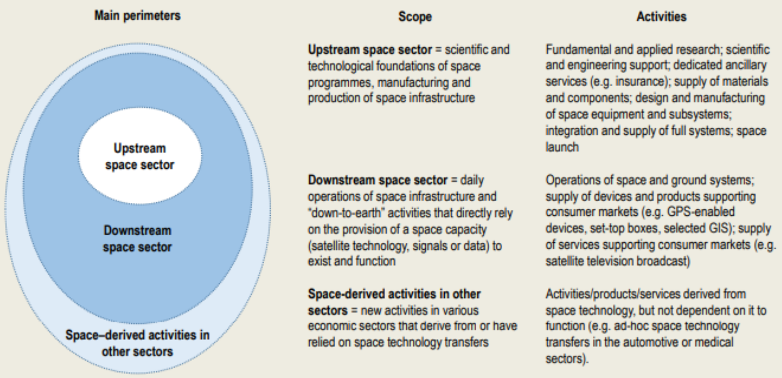

Figure 1.3. Main perimeters of the space economy

Source: OECD (2022[14]), *Handbook on Measuring the Space Economy, 2nd Edition*, http://doi.org/10.1787/8bfef437-en.

1. 2 The Intersection of Space Sustainability and Space Economy

In light of the above, it becomes crystal clear that the spreading of the different aspects of the space economy testifies to the rise in the economic value of the space sector. However, the question of sustainability cannot be set aside, first and foremost, because it has two facets: ensuring the sustainability of outer space itself while conducting economic activities and understanding how sustainability influences the durability of economic benefits derived from the space sector.

It is to be taken into account that sustainability in outer space involves critical areas such as space traffic management, mitigation of space debris, and space resource activities, all of which pose serious regulatory challenges. These range from the establishment of efficient traffic management systems, mitigation of debris, and responsible utilization of resources. Emphasizing these fields raises

[29] UNOOSA, "Introduction to The Guidelines for the Long-term Sustainability of Outer Space Activities (LTS Guidelines)," *UNOOSA eLearning Courses*, accessed September 5, 2024, https://elearningunodc.org/course/index.php?categoryid=74.

awareness of pressing issues that require international action and point to the need for proper legal regulation.[30]
First, let us start with a simple question: What is space debris? To answer this question, we can say that it is "*All nonfunctional man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere*".[31]
Space operations are becoming more and more important. Although these operations have numerous advantages, maintaining a sustainable and safe operating environment in orbital space presents challenges. Accidental collisions, breakups, and the intentional destruction of satellites have created millions of debris fragments, which, orbiting at a high speed in space, can damage or destroy any functioning spacecraft that crosses their path. This theory is further proved by the evidence stated by Don Kessler, a space debris expert at NASA: after a certain critical mass, the total amount of space debris would constantly grow because collisions would create more debris, [32] which in turn would cause more collisions. Later, the term "Kessler syndrome" was borrowed to describe such an incident specifically.[33]
From an economic point of view, space debris has multi-layered costs. The satellite operators have to undertake collision avoidance manoeuvres quite frequently, which uses up precious fuel and decreases the lifespan of the satellites. Also, the insurers charge higher premiums because of the increased risk associated with operation in orbits where there is a high population of debris. Such costs are passed on to end-users, increasing the expense of space-dependent services. In addition, the higher demand for, and hence the rarity of, available orbital slots in low Earth orbit (LEO) has considerably raised the costs of launching and operating new missions.[34] As private companies and national space agencies compete for these increasingly valuable orbital slots, taking the example of the race to deploy mega-constellations, such as Starlink and OneWeb, to meet the demand for global broadband connectivity has led to a sharp increase in the number of satellites in LEO. The increased financial pressures may discourage

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[30] See Balázs Bartóki-Gönczy, Mónika Ganczer, and Gábor Sulyok, "Space Sustainability: Current Regulatory Challenges," *Hungarian Journal of Legal Studies*, 2024. https://doi.org/10.1556/2052.2024.00552.
[31] UNOOSA, "Introduction to The Guidelines for the Long-term Sustainability of Outer Space Activities (LTS Guidelines)."
[32] NASA, *Orbital Debris Quarterly News*, 2023, https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv27i1.pdf. NASA, *Orbital Debris Quarterly Review* 14, no. 2 (April 2010), https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv19i1.pdf.
[33]Donald J. Kessler and Burton G. Cour-Palais, "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt," *Journal of Geophysical Research* 83, no. A6 (1978): 2637-2646.
[34] NASA. *Economic Development of Low Earth Orbit*. Washington, D.C.: NASA, 2016. https://www.nasa.gov/wp-content/uploads/2016/01/economic-development-of-low-earth-orbit_tagged_v2.pdf?emrc=d47202.

investments in new technologies and slow down the pace at which innovation in the space sector occurs.[35]

However, the relationship between the space economy and sustainability is complex and works both ways: the economic dynamics that may drive growth motivate innovation in sustainable technologies and policies.
In this respect, the space economy might contribute to sustainability in many ways by improving technology with a view to both mitigating space debris and increasing resource efficiency. For example, those private companies currently engaged in developing reusable rockets, such as SpaceX, show how cost-effective solutions can be environmentally friendly at the same time.[36] Moreover, reusable launch systems reduce not just the cost of access, but also the volume of debris resulting from the ditching of rocket stages. New satellite designs now use the concept of modularity and reparability, along with de-orbit materials for controlled de-orbit at end-of-life. Indeed, such innovation is often driven by economic incentives, including reduced operation costs and competitive advantages.[37]

Besides technological development, other economic mechanisms that undergird the space industry have the potential to spur responsible behaviour. Market-based schemes, such as "debris credits"[38] or financial liability, could give monetary incentives for companies to reduce the quantity of debris produced. Indeed, financial instruments like this are similar to carbon markets in environmental policy, where polluters have to pay a price for their greenhouse gas emissions while sustainable players are rewarded. If established, these could create a culture of responsibility in which all players take more care.

2. Overview of the Legal Frameworks

After presenting what is space sustainability and how space can be a source for the economy, it is important to mention the provisions in the law that protect space sustainability, as they are crucial for keeping the space economy going.

[35] J.-C. Liou, "An Active Debris Removal Parametric Study for LEO Environment Remediation," *Advances in Space Research* 47, no. 11 (2011): 1865–76. https://doi.org/10.1016/j.asr.2011.02.003.

[36] José Alfredo Pérez Martínez, "Study of commercial Reusable Launch Vehicles business model: case study of Terran R from Relativity," (Bachelor's thesis, Universitat Politècnica de Catalunya, 2024).

[37] Valerio Carandente and Raffaele Savino, "New Concepts of Deployable De-Orbit and Re-Entry Systems for CubeSat Miniaturized Satellites," *Recent Patents on Engineering* 8, no. 1 (2014): 2–12.

[38] V. Gopalakrishnan and S. Prasad, "Space Debris Remediation – Common but Differentiated Responsibility," In *Proceedings of the 64th International Astronautical Congress, Beijing, China*, vol. 14. 2013.

2. 1 UN Space Treaties and Space Sustainability

The term "sustainability" as such is neither defined nor addressed in any way in the UN space treaties. Yet, it would be inconsistent with the spirit of the UN space treaties to deny that they would incorporate any aspect of environmental concern that looks forward. Sustainability as such is not officially mentioned. Undoubtedly, the UN space treaties encompass the fundamental premise of the safe and sustainable use of outer space, which is the push towards usability, responsible behaviour, and risk limitations in space operations. Consideration should be given to the Outer Space Treaty's (OST) provisions in this discussion, as they are important and relevant to the current worldwide discussion on space sustainability.[39] The Preamble, for instance, speaks of the "*common interest of all mankind in the progress of the exploration and use of outer space for peaceful purposes*." Even if it is not a binding rule, the Preamble creates various legal implications.

Additionally, Article IX of the OST appears also to mirror the concept of space sustainability that can also be taken into consideration while conducting economic activities in outer space. From a certain viewpoint, Art. IX of the OST was enacted to address safety and environmental concerns in space "by creating a "*proscriptive positive legal obligation' for States to (1) avoid harmful contamination of celestial bodies and (2) undertake international consultations in advance before any potentially harmful interference may arise from their activities*".[40]

However, the provision is criticised for failing to be adequately specific regarding the type of degradation it shall prohibit and to what extent. It is especially felt that it would barely cover "*alteration of the topography and geology of a celestial body, which could be a consequence of large-scale human activities such as space mining*".[41] A more detailed view of Art. IX of the OST would reveal that the wording is ambiguous and ill-suited to serve the need for an efficient regime of environmental space protection, since no specific and legally binding regulations can be implied with respect to space sustainability as such.[42] For instance, Art. IX does not explain when contamination of the Outer Space, including the Moon and other celestial bodies, is harmful, whether all contaminations shall be considered as harmful, or what kind of adverse changes in the Earth's environment it is necessary to avoid.

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[39] V. C. M. Adilov et al., "Space Mining: What Will Be the Market and Technical Drivers for the Space Mining Industry?"

[40] Chung Gordon, "The Emergence of Environmental Protection Clauses in the Outer Space Treaty: A Lesson from the Rio Principles," in *A Fresh View on the Outer Space Treaty*, ed. Annette Froehlich (Cham: Springer, 2018), 95–112.

[41] Mahulena Hofmann and Federico Bergamasco, "Space Resources Activities from the Perspective of Sustainability: Legal Aspects," *Global Sustainability* 3 (2020), https://doi.org/10.1017/sus.2019.27.

[42] Minna Palmroth, J. Tapio et al., "Toward Sustainable Use of Space: Economic, Technological, and Legal Perspectives," *Space Policy* 57 (2021) http://dx.doi.org/10.1016/j.spacepol.2021.101428.

Simultaneously, the outer space treaty does not foresee any special liability regime for environmental damage as a general rule or for the damage that can occur as an outcome of the violation of Article IX.
Considering the hardship with which this rule could be used as a basis for the application of environmental recovery,[43] Art. IX of the OST has even been regarded "as an impotent provision because it fails to set standards in the field of the space environment or, at a minimum, entrust a regulatory body to do so".[44]
In theory, a general obligation derives from Art. IX. It could have been that, for example, Art. IX of the OST, aiming at the protection and preservation of the outer space environment, was set aside; however, contrarily to that, space actors co-operated in the development of common standards, in order to allow the practical implementation of the initial environmental concern of the OST.[45]

2. 2 The Role of Non-Binding Agreements in Regulating the Sustainable Economy of Space

Due to the fact that the UN space treaties do not include profound rules on how to develop the legal and behavioural mechanisms to implement the underlying principles of space operations, including sustainability, the latter are blurry. For the past couple of decades, the main idea underlying space sustainability has been how to reduce space debris; as a result, norms on responsible behaviour in space emerged. This realization of the fact that unregulated growth in space debris would adversely affect the operations of space for all players, governments, private companies, and new actors alike necessitates stronger regulations.[46]
The first step towards behavioural management was not the enactment of legislation, but rather the release of a non-binding set of technical recommendations, or guidelines, by the Inter-Agency Space Debris Coordination Committee (IADC).[47] These guidelines later served as the foundation for other, similarly non-binding documents, such as the COPUOS Space Debris Mitigation Guidelines.[48] The need to mitigate space debris has only gradually made its way

[43] Michael W.Taylor, "*Orbital Debris: Technical and Legal Issues and Solutions,"* (LL.M. Thesis, McGill University, 2006.)
[44] Gordon, The Emergence of Environmental Protection Clauses in the Outer Space Treaty: A Lesson from the Rio Principles."
[45] Anthi Koskina and Konstantina Angelopoulou, "Space Sustainability in the Context of Global Space Governance," *Athena: Critical Inquiries in Law, Philosophy & Globalization* 2 (2022): 29.
[46] V. C. M. Adilov et al., "Space Mining: What Will Be the Market and Technical Drivers for the Space Mining Industry?".
[47] IADC is an international forum of governmental bodies for the coordination of activities related to the issues of man-made and natural debris in space. The guidelines were first released in 2002 and then revised in 2007. The revised version of the guidelines was published on September 1, 2007.
[48] Committee on the Peaceful Uses of Outer Space, Space debris mitigation guidelines, 2007. Endorsed by the United Nations General Assembly as an annex to the International

into binding law with the development of modern national space laws. Appropriate space debris reduction techniques are becoming a usual requirement for licencing nongovernmental space operators under several nations' space legislation. As a result, national regulations frequently include different technical principles through references that are either more or less detailed. When a national law refers to a non-binding document as a "state of the art" requirement, there is a unique relationship between technical standards and positive legislation. In the context of space debris mitigation, in particular, a study by Soucek and Tapio highlights that the practical and legal issues that may arise from this coupling are not always anticipated.[49] It is remembered that after an extended debate on space debris, the general concept of "space sustainability" at last attracted intergovernmental attention in 2010 when the UN COPUOS[50] began debating the rules about space sustainability in a comprehensive way in a multilateral setting. It sparked a lively discussion and a process toward reaching a consensus on ideas that ought to result in a more sustainable and safe use of space for the first time in the space era.

The UN COPUOS adopted the Guidelines for the Long-term Sustainability of Outer Space Activities[51] (LTS Guidelines) in 2019 after a ten-year process that highlighted the political factors supporting space sustainability.[25] The LTS Guidelines address a range of topics related to space sustainability and, within this framework, define long-term sustainability as already mentioned above: "*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, in order to meet the needs of the present generations while preserving the outer space environment for future generations*".[52] While several LTS Guidelines are more futuristic

Cooperation in the Peaceful Uses of Outer Space, December 22, 2007, UNGA Res A/RES/62/217.

[49]Alexander Soucek and Jessica Tapio, "Normative References to Non-Legally Binding Instruments in National Space Laws: A Risk-Benefit Analysis in the Context of Domestic and Public International Law," in *Proceedings of the International Institute of Space Law*, (Den Haag: Eleven International Publishing, 2019), 553–580.

[50] Committee on the Peaceful Uses of Outer Space, Report of the scientific and technical subcommittee on its 47th session, 2010. Vienna, February 8–19, 2010, A/AC.105/958, paragraph 181.

[51] United Nations Committee on the Peaceful Uses of Outer Space, Guidelines for the long-term sustainability of outer space activities, report by the committee, annex ii, 2019. A/74/20, July 3, 2019, http://www.unoosa.org/res/oosadoc/data/documents/2019/aac_105c_1l/aac_105c._1l_366_0_html/V1805022.pdf. The LTS Guidelines were "welcomed with appreciation" by the UN General Assembly in the yearly "omnibus resolution" pertaining to International Cooperation in the Peaceful Uses of Outer Space, UN General Assembly, Resolution adopted by the General Assembly on December 13, 2019, 74th session, A/A/RES/74/82.

[52] LTS Guidelines, Preamble, I Context of the guidelines for the long-term sustainability of outer space activities, para. 5.

inventions, others are compliant legally or represent common practice. Despite this, a number of people believe that significant topics remain unexplored, particularly those related to proximity operations and space debris management. These topics may still be included if the UN COPUOS settles on how to proceed with these unresolved matters.[53]

Nevertheless, the LTS Guidelines will, at most, add one more piece to the multitude of “soft law” rules that have developed since space activity treaty-making came to a stop in the 1980s. For the foreseeable future, a worldwide legal duty that can be enforced to achieve and preserve orbital sustainability will remain a pipe dream. That being said, this does not preclude laws and policies from being used in conjunction with other strategies to achieve the same goal. The best course of action for ensuring sustainable space operations going forward is to apply and enforce the non-legally binding instruments through national space laws, but not completely eliminate the chance of returning momentum to treaty-making.[54]

We have to mention that the 17 Sustainable Development Goals[55] (SDGs) are also applied in the space area to guarantee its sustainability and boost its economy. In 2015, the United Nations Member States approved the 2030 Agenda for Sustainable Development, which offers a common roadmap for promoting peace and prosperity for both people and the environment in the present and the future. The 17 SDGs and their 169 specific goals form the basis of the agenda. All nations must move quickly to fulfil the SDGs, which are the roadmap to a brighter and more sustainable future for all. In addition to addressing climate change and attempting to protect our seas and forests, they understand that measures to eradicate poverty and other forms of deprivation must also include measures to enhance health and education, reduce inequality, and promote economic growth. Current legal practices raise concerns about whether the best course of action is to interpret, apply, and enforce space sustainability through national legislation or whether uniform regulation and avoiding local solutions to a global problem require binding international regulation.[56]

III. 3. Initiatives Balancing Space Economy and Sustainability

Space actors, both public and private, are aware of the strong nexus between space sustainability and space economy, as one directly supports the other. In

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[53] United Nations Committee on the Peaceful Uses of Outer Space, Guidelines for the long-term sustainability of outer space activities, report by the committee 2019, especially paragraphs 165–168; These paragraphs envisage the establishment of a dedicated working group, which is still in progress at the time of review of this article in November 2020.

[54] V. C. M. Adilov et al., “Space Mining: What Will Be the Market and Technical Drivers for the Space Mining Industry?”.

[55] UN, Transforming Our World: the 2030 Agenda for Sustainable Development, https://sdgs.un.org/2030agenda.

[56] V. C. M. Adilov et al., “Space Mining: What Will Be the Market and Technical Drivers for the Space Mining Industry?”.

other words, if space sustainability is neglected in conducting space activities, the area could no longer support such activities. As a result, no services could be offered from space; no economic benefits could be gained. This understanding has led to the creation of initiatives that aim to improve the balance between the space economy and space sustainability.

3. 1 ESA's Strategic Vision

3. 1. 1 The ESA Business Applications Programme

This initiative supports space-based services to develop into commercial opportunities, thus most significantly contributing to the space economy. Together with encouraging innovation, it underlines sustainability with projects utilizing minimal space debris and responsibly sourced materials. With the dual focus on space economy growth and minimizing its impact on the environment of space, ESA tries to balance economic development against environmental protection in space.[57]

3. 1. 2 ESA's Zero Debris Approach and Zero Debris Charter

This is another indicative of the proactive stance taken by ESA in issues relating to space debris management. As space debris is already becoming a real risk to satellite operations, the ESA has pursued policies for its mitigation and removal. Building on over ten years of ESA-wide collaboration, the Zero Debris approach is ESA's ambitious revision of its internal space debris mitigation requirements. It will boost the development of technologies needed to achieve debris-neutrality by 2030. To add to this approach and under the Zero Debris Charter, ESA works with international counterparts to establish standards for responsible satellite disposal and debris management; the Charter contains both high-level guiding principles and specific, jointly defined targets to get to Zero Debris by 2030.[58]

3. 1. 3 The ESA Report on the Space Economy 2024

The report summarizes recent developments in the space sector in Europe, focusing on economic growth linked to satellite services, telecommunications, and space exploration. However, ESA emphasizes the indispensability of sustainability for such development. According to ESA, it also needs to aim at space resources being recycled, reused, with efficient active management of space debris through a circular economy. This approach will ensure that the

[57] Alessandro Paravano, Matteo Patrizi, Elena Razzano, Giorgio Locatelli, Francesco Feliciani, and Paolo Trucco, The Impact of the New Space Economy on Sustainability: An Overview."

[58] European Space Agency. *Zero Debris Approach* and *Zero Debris Charter*. (Paris: European Space Agency, 2024).

development of the space economy is not at the expense of the space environment.[59]

3. 1. 4 The 2024 ESA Annual Space Environment Report

It reviews the growing risks associated with space debris and the impact space activities have on the environment of space. The report calls for international collaboration in the mitigation of debris and underlines the leadership of ESA in the same direction. Since space is getting crowded, managing debris is not simply an environmental concern but also one important question for the space economy, due to the fact that satellite operations may be jeopardized by collisions.[60]

3. 2 NASA's Multiple Research Projects

In 2022, NASA provided funding for three academic teams to work on studying the economic, social, and policy dimensions of space sustainability.[61] The first project developed an open-source model that forecasts the long-term growth of debris in space and evaluates the efficacy of different prevention mechanisms.[62] The so-called MIT Orbital Capacity Assessment Tool was introduced to the community at the December 2023 OECD Space Forum and presented to industry partners such as Privateer Space and the Aerospace Corporation. A second effort relates to the development of integrated assessment models, which link satellite orbit dynamics with the economic behaviour of space actors.[63] This tool will be used to assess various policy options contributing to the solution of the problem of orbital congestion, which is becoming increasingly important with multiplying constellations of satellites. A third research project investigated the public's willingness to pay for space debris mitigation. The study follows similar methodologies to that outlined in Chapter 3 of the OECD report on space

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[59] European Space Agency. *The Space Economy in 2024: Market Trends and Growth Opportunities*. ESA Business Applications and Space Solutions Office, 2024. https://space-economy.esa.int/documents/b61btvmeaf6Tz2osXPu712bL0dwO3uqdOrFAwNTQ.pdf.

[60] European Space Agency. *ESA's Annual Space Environment Report 2024*. European Space Operations Centre, 2024. https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf.

[61] N. Adilov, P. Alexander, and B. Cunningham, "An Economic 'Kessler Syndrome': A Dynamic Model of Earth Orbit Debris," *Economics Letters* 166 (2018): 79–82. https://doi.org/10.1016/j.econlet.2018.02.025.

[62] M. Undseth, C. Jolly, and M. Olivari, 2020. "Space Sustainability: The Economics of Space Debris in Perspective," *OECD Science, Technology and Industry Policy Papers*, no. 87. OECD Publishing, Paris. https://doi.org/10.1787/a339de43-en.

[63] European Space Agency (ESA). 2023. *Annual Space Environment Report 2023*. ESA Space Debris Office. https://www.sdo.esoc.esa.int/environment_report/Space_Environment_Report_latest.pdf.

sustainability and provides a good understanding of public support for funding space sustainability initiatives. These projects encourage international cooperation and collaboration between universities, space agencies, and private sector actors to increase comparability and policy relevance.[64] In so doing, such work attempts to contribute to the future of space governance by bringing together diverse perspectives on space debris and sustainability.[65]

3. 3 The OECD Project on the Economics of Space Sustainability

As highlighted by the OECD 2024 report entitled "*The Economics of Space Sustainability: Delivering Economic Evidence to Guide Government Action*",[66] in 2019, the OECD Space Forum of the Directorate for Science, Technology and Innovation launched a significant undertaking related to space sustainability, with a particular focus on the economics of space debris. This was supported by key members including NASA, the Canadian Space Agency, the UK Space Agency, CNES, and the German Aerospace Center in addition to several commercial satellite operators, to further bring on board a multitude of industry perspectives. Through Phase 1 (2020-2021), the Forum did the first comprehensive economic analysis of space debris. This resulted in the seminal report by Undseth, Jolly, and Olivari (2020) laying the foundation for further exploration of this issue. This call expanded in Phase 2 (2022-2023) to include global academic contributions, welcoming master's and PhD students, faculty, and researchers to provide thought leadership on three key questions: the value of space-based infrastructure, the economic consequences of space debris, and costs and benefits for various policy approaches. Combined, over the two phases, close to 30 research teams from 11 countries gave multifaceted views ranging from engineering to law, environmental management, and economics.[67]

Conclusion

In light of the above, while the emergent space economy offers great opportunities for technological development and economic growth, it is equally challenging to sustainability. The increasing proliferation of space activities, commercial and international, underlines the responsibility taken for the continuity of space as a viable domain for future generations. Sustainability in space is described not just as mitigating further space debris and preserving the

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[64] P. Anz-Meador, J. Opiela, and J. Liou. 2022. *History of On-Orbit Satellite Fragmentations: 16th Edition*. NASA/TP-20220019160. NASA Orbital Debris Program Office. https://orbitaldebris.jsc.nasa.gov/library/hoosf_16e.pdf.

[65] OECD. 2024. *The Economics of Space Sustainability: Delivering Economic Evidence to Guide Government Action*. OECD Publishing. Paris. https://doi.org/10.1787/b2257346-en.

[66] OECD, "*The Economics of Space Sustainability: Delivering Economic Evidence to Guide Government Action*."

[67] OECD, "*The Economics of Space Sustainability: Delivering Economic Evidence to Guide Government Action*."

orbital environment but also in terms of long-term economic growth that does not compromise the environmental integrity of space. Ultimately, it requires integration on all levels in space operation and activities if the space economy is to develop sustainably without compromising the space environment: from regulatory measures that stimulate responsible behavior to technological innovations with minimum environmental impact and internationally coordinated management of the Common Heritage of Mankind. A balance between economic growth and environmental stewardship will be key to whether space exploration, commercialization, and settlement can continue to advance while making the benefits of space accessible for future generations.