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Space Sustainability: A View from the Global Space Industry

An IAF Industry Relations Committee White paper



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1. Introduction

The topic of sustainability has been thoroughly discussed, but its definition as it pertains to the space economy has not been fully explored. Space sustainability refers to the responsible, secure, resilient and peaceful use of space to ensure the long-term viability of space activities. This paper delves into the multifaceted aspects of space sustainability, exploring its definition, terrestrial, on-orbit, and environmental implications, as well as the unique role played by the space industry in addressing sustainability challenges. Governments and non-governmental agencies play a vital leadership role in space sustainability activities, and industry efforts depend on those efforts to support and enable overall success.

Space is often a hidden element in daily life. Without being fully aware, people may use 100 satellites every day. Space also has a unique ability to motivate and inspire human creativity and expand individual aspirations. And in the context of sustainability, scientific understanding and monitoring of climate change would be limited without space-based earth observations. The space sector is generally viewed as a key contributor to awareness of climate change. However, this is not the whole story. A more complete view of the space economy would include the impacts on the environment of manufacturing and operational processes across the value chain. The space industry is uniquely positioned to begin a meaningful dialog on space sustainability.

Preserving the space domain and developing it sustainably will assure future from all parts of the world are able to continue the legacy of innovation, creativity and respect for natural resources. In particular, the following areas depend directly on industry participation and value creation:

- **Science and Knowledge:** The sustainable exploration of outer space is crucial for expanding humanity's knowledge. Sustainable practices in space exploration ensure that future generations can continue to learn and benefit from space without depleting or irreversibly damaging space environments. Increased experimentation and the application of scientific advancements, such as in-situ resource utilization (ISRU) and astrobiology, have the potential to benefit life on earth. For example, insights gained from space exploration

lead to advances in medical technology, climate science, and materials engineering.

- **Economic Growth:** Space sustainability is closely tied to economic growth. Sustainable trade and commerce between space actors includes the regulation of space activities, the enforcement of laws on resource utilization and extraction, and the management of transportation networks in space. As the space economy grows, sustainable practices become essential for maintaining economic stability and growth. This includes the development of markets for space resources, the promotion of fair and transparent trade practices, and the establishment of legal frameworks that prevent the monopolization of space resources by a few powerful entities. Moreover, sustainable practices in space facilitate an economic environment that creates new industries and job opportunities, both on Earth and in space. The spin-off and spin-in process between space and non-space domains have widely demonstrated effectiveness, advancing and well-being of our societies [1].
- **Education and Inclusion:** Continuous education is fundamental to space sustainability. Educating the next generation about space and its potential ensures that the workforce of the future is equipped with the necessary skills and knowledge to maintain and advance space sustainability. Inclusion is equally important, as it allows diverse perspectives to contribute to sustainable solutions. This includes the participation of developing countries and non-STEM professions in space communities. By fostering a more inclusive space industry, we can ensure that the benefits of space activities are shared more equitably and that diverse viewpoints lead to more innovative and sustainable solutions.

2. Domains of Space Sustainability

Space sustainability is a multifaceted concept that begins on Earth and extends into orbit, encompassing the entire lifecycle of space activities. The space industry plays a pivotal role in each of these domains, contributing to sustainable practices that support both terrestrial and orbital environments. This section explores the key domains of space sustainability, emphasizing the industry's responsibility and contributions to each.

Sustainability on Earth through Space. The space industry significantly contributes to sustainability on Earth through the deployment and operation of space-based technologies and space-critical infrastructure. These technologies are essential for addressing global challenges such as climate change, disaster management, and sustainable development initiatives in other industries. Satellite imagery, for example, is indispensable for tracking environmental changes, monitoring natural disasters, and providing critical data for managing natural resources. Orbital infrastructures for navigation and telecommunication are essential for a stable and secure connectivity. The industry's advancements in Global Navigation Satellite Systems (GNSS) also enable sustainable transportation solutions, not only on Earth but potentially on the Moon and Mars as well.

Current planetary defense actions are also key for sustaining the future of our planet. Monitoring near-Earth objects (NEOs) such as asteroids and comets is an essential component of planetary defense. Space-based systems enable early detection, which is crucial for developing defensive strategies and mitigating potential impacts. This relates to sustainability by directly addressing existential threats to human civilization and ecosystems. The collaboration between international space agencies and private industry is vital to ensuring these planetary defense mechanisms are continuously improved and updated.

Beyond these direct applications, the responsible use of space-derived data and technology is crucial for maximizing societal benefits. The space industry is at the forefront of developing and deploying these technologies, ensuring that they contribute to global sustainability efforts. For instance, satellite data can optimize agricultural practices, monitor carbon emissions, and enhance urban planning, all of which are critical for achieving the United Nations Sustainable Development Goals (SDGs).

Sustainability in Orbit. As space activities expand, maintaining sustainability in orbit has become increasingly chal-



lenging. The space industry must address the growing concerns related to orbital debris and the safe use of the orbital ecosystem. With the proliferation of mega-constellations and increased satellite traffic, the potential for collisions and debris accumulation is a significant threat to long-term space sustainability. In the context of sustainability in orbit it is also worthwhile to mention that radio frequency resources also need to be managed, as misuse or overuse might introduce further congestion and restrict the value of providing service from space.

The industry is actively engaged in developing solutions to these challenges. Government-led initiatives, such as Space Situational Awareness (SSA) systems and Space Traffic Management (STM) frameworks, are essential for tracking and managing objects in space. The private sector also plays a critical role, with companies pioneering technologies for active debris removal, satellite reuse and on-orbit assembly and manufacturing, and the implementation of circular space economy principles. These efforts are vital for preserving the orbital environment and ensuring the continued viability of space operations both for commercial and scientific purposes.

Space Sustainability on Earth. The environmental impact of space vehicle manufacturing and launch operations is an important aspect of space sustainability that the industry must address. Historically, the development of advanced materials and technologies for space exploration has involved practices that can have negative environmental consequences. As the space industry evolves, there is a growing recognition of the need to adopt more sustainable practices across the manufacturing, development, and operational lifecycle.

This includes initiatives to reduce the carbon footprint of launch activities, the use of green propellants, and the development of reusable launch systems. As well the use of materials and practices that will limit the number of debris creation on orbit or the danger of debris re-enter on populated areas on earth. The space industry is also exploring ways to minimize waste through the adoption of circular economy principles, where resources are reused and recycled. By integrating sustainability into its core operations, the industry can mitigate its environmental impact and contribute to broader global sustainability goals.

3. Importance of Industry in Space Sustainability

Defining sustainability in space requires close cooperation between the private and public sectors, especially as new technologies and sectors seek sustainable models. The industry's role in fostering a circular space economy—where resources are reused, repurposed, and recycled—cannot be overstated. The transition to sustainable practices in space will require significant investment in research and development, as well as the adoption of new business models that prioritize long-term sustainability over short-term profits and unified standards and interoperability. The seventeen United Nations Sustainable Development Goals (SDGs) [2] form a starting point for considering the unique perspectives of industry in the sustainable development of space systems and their impact on the terrestrial and space environment. Space sustainability can be considered an extension of the existing SDGs, particularly in how space technologies contribute to achieving these goals on Earth.

The global space industry encompasses a wide range of activities from satellite manufacturing to space exploration, and it plays a pivotal role in advancing sustainability and supporting the SDGs. In fact, the Secretary General of the International Telecommunications Union recently stated that “at least 40 percent of SDG targets rely on Earth observation, remote sensing, and global navigation satellite systems — a testament to how satellites have become critical infrastructure supporting sustainable life on Earth” [3]. We highlight several of the existing SDGs where the space industry aligns with and contributes to these global objectives, drawing on key insights from Cernev et al. (2024) [4]. The development of the Earth-for-space economy—focused on the infrastructure and activities on Earth that support space exploration—has significant potential to advance many of the UN's SDGs. This sector enables the space industry to create a more interconnected and sustainable global economy. For instance, international cooperation fostered by space projects can promote global peace, justice, and strong institutions (SDG 16), while also driving innovation and infrastructure development (SDG 9).

Furthermore, the Earth-for-space economy can accelerate educational and vocational training (SDG 4), especially in

STEM fields, which are essential for advancing space technologies. The industry's commitment to ethical labor practices and gender equality (SDG 8) also ensures that economic benefits are broadly shared across all demographics. Additionally, by prioritizing sustainable launch technologies, such as green rocket fuels and reducing harmful chemical use, the space industry supports responsible consumption and production (SDG 12) and climate action (SDG 13). The space-for-Earth economy, which leverages space-based assets and technologies to benefit life on Earth by advancing sustainability on our planet, plays a crucial role in achieving various SDGs. Space-based observation systems, for example, are invaluable in monitoring climate change (SDG 13), managing natural resources (SDG 15), and supporting disaster risk reduction (SDG 11). These technologies provide critical data for weather forecasting, agricultural monitoring (SDG 2), and environmental protection (SDG 6).

In addition to observation, the space-for-Earth economy enhances global connectivity, which is essential for providing telehealth services (SDG 3), remote education (SDG 4), and bridging the digital divide (SDG 10). The potential for space-based solar power (SDG 7) and advanced industrial processes (SDG 9) further demonstrates how the space industry can lead in creating new, sustainable sources of energy and industrial practices that benefit society at large. The space-for-space economy focuses on activities and developments that occur entirely within the space domain, such as the use of space resources and the construction of space infrastructure. This emerging sector is paving the way for future sustainability of space exploration and settlement. Advances in space medicine, particularly in fields like cancer research, have the potential to contribute to global health (SDG 3), while technology transfers from space to Earth could revolutionize industries, including energy, materials science, and environmental management (SDGs 7, 9, and 11).

Moreover, the development of space resources, such as asteroid mining, could provide new materials for Earth-based industries while reducing the environmental strain on our planet (SDG 12). Establishing a self-sustaining space economy also positions humanity to mitigate existential risks by reducing our dependence on Earth alone (SDG 1). The space industry's contributions to the UN SDGs demonstrate its pivotal role in fostering global sustainability, both on Earth and beyond. By advancing Earth-for-space, space-for-Earth, and space-for-space economies, the industry not only drives technological innovation but also promotes ethical and sustainable practices that align with global development goals. As we look to the future, the space industry will continue to be a key player in building a sustainable, equitable, and resilient world, on Earth and in space. As a result, some have argued for the creation of a future SDG specifically related to space sustainability. Cernev et al. [4] raises the possibility of introducing a new SDG #18 focused on space sustainability. This proposed SDG emphasizes the need for responsible and sustainable use of outer space to ensure that space activities do not jeopardize the long-term viability of the space environment. From the perspective of the space industry, adopting such an SDG would formalize the industry's commitment to sustainability, encouraging the adoption of best practices in debris mitigation, resource management, and environmental protection.

The space industry's engagement with this proposed SDG would involve not only adhering to existing regulations but also taking a leadership role in developing new standards and technologies that promote sustainability. This could include advancing circular space economy principles, where resources in space are reused, repurposed, and recycled to minimize waste and reduce the need for additional launches. The industry's role in shaping this SDG would also involve advocating for international agreements that ensure equitable access to space and protect the interests of all space-faring nations.

The space industry is uniquely positioned to contribute to a wide range of SDGs by leveraging its technological innovations and global reach. From enabling clean energy solutions and climate action to fostering economic growth and reducing inequalities, the space industry's impact on sustainability is profound. As the industry continues to evolve, its commitment to sustainable practices, as well as its role in supporting a proposed SDG on space sustainability, will be crucial in ensuring that space remains a viable and beneficial domain for future generations.



4. The Future of Space Sustainability

As the space industry continues to grow and evolve, the future of space sustainability hinges on the collective efforts of governments, commercial entities, and international organizations. This section explores the current state of space sustainability and highlights the key areas where the industry is focusing its efforts to ensure a sustainable future in space.

Currently governments play a crucial role in shaping the framework for space sustainability through intergovernmental initiatives, self-binding frameworks, and national regulations. These efforts are aimed at mitigating environmental impacts and promoting responsible space exploration. Examples include international agreements on space debris mitigation, national regulations for sustainable launch practices, and collaborative efforts to enhance Space Situational Awareness (SSA) and Space Traffic Management (STM). These initiatives provide the foundation upon which industry efforts are built, creating an environment that encourages sustainable practices in space activities. In addition to policy and regulatory activities, governments are funding research and development and enabling the technology that will create a sustainable space environment (not just devising frameworks/regulations), which is essential to mitigate and manage the “tragedy of the commons” issue.

Standards and interoperability of space infrastructures will be a must for a navigable, resilient and sustainable space environment. Spacefaring nations should collaborate to develop regulatory frameworks to oversee this emerging industry and incentivize good behavior, ensuring safety, equity, and sustainability. The Artemis Accords, the Astra Carta Charter, and related international initiatives are building momentum to pave the way for strong frameworks for ensuring space sustainability. Space agencies, private companies, and international bodies need to collaborate on standards, safety protocols, and joint missions to ensure the industry’s growth. Organizations like the International Astronautical Federation (IAF) are an important route through which to convene stakeholders, build consensus, and ensure momentum around critical issues that will drive sustainable activities in space over the coming decades. On the commercial side, the space industry is increasingly recognizing the importance of sustainability and is actively working to incorporate eco-friendly practices into its operations. Companies are exploring innovative technologies and processes to minimize the environmental impact of their activities. This includes adopting sustainable manufacturing and launch practices, such as using green propellants, developing reusable launch vehicles, and implementing circular economy principles in the design and production of space systems. By aligning their operations with sustainability goals, commercial entities are driving the industry towards a more responsible and sustainable future. Companies are also actively developing technologies to address space sustainability challenges, such as debris removal, in-orbit refueling solutions, satellite tracking, etc.

As the landscape of space activities expands, industry is strategically concentrating its efforts on several critical domains to ensure that growth does not come at the expense of long-term sustainability, including program management, sustainable supply chains, and efficiencies gained by employing Artificial Intelligence capabilities.. These focus areas represent the industry’s proactive approach to addressing the environmental and operational challenges associated with space exploration and utilization. Table 1 summarizes the enduring needs and current industry initiatives related to the various dimensions of sustainability.

Table 1. Critical actions the space industry is taking in space sustainability.

Sustainability Region	Enduring Need	Space Industry Initiatives
Earth Sustainability	Tracking and monitoring changes to the Earth's environment, including climate change, weather patterns, and marine science. Provide critical data that supports global sustainability initiatives, enabling better decision-making and resource management on Earth.	Industry is at the forefront of effort to promote sustainability on Earth through space-based technologies enabling Earth observation and remote sensing, tracking and monitoring changes to the Earth's climate, weather patterns, and marine science. Industry supports global sustainability initiatives, enabling better decision-making and resource management on Earth.
Orbital Sustainability	Long-term sustainability of the orbital environment. This includes better coordination in the use of various orbits, enhanced Space Situational Awareness (SSA), and the development of Space Traffic Management (STM) systems [5].	Companies are investing in technologies for space debris mitigation, such as active debris removal and satellite servicing and reuse, to reduce the risk of collision and preserve the orbital ecosystem.
Space Infrastructure Sustainability	Ensuring the longevity and resilience of space infrastructure.	Development of in-orbit servicing mechanisms, which allow for the repair, refueling, and upgrading of satellites and other space assets. Sustainable manufacturing practices, such as reusing and repurposing materials and modular designs, are building infrastructure that can adapt and evolve over time.

As the industry looks beyond Earth orbit to missions on the Moon and Mars, the sustainable utilization of space resources is becoming increasingly important. Commercial initiatives are exploring the extraction of minerals from celestial bodies and the development of infrastructure beyond Earth orbit. These efforts must also consider environmental impacts and sustainability, and industry needs to have a strong voice in developing guidelines and technologies that ensure the responsible use of space resources that balance economic opportunities with the need to protect the space environment.

In addition to considering in-space resources, the evolution and sustainment of space assets impacts the long-term sustainability of space operations. As space missions and infrastructures grow in complexity, servicing and maintaining in-space infrastructure becomes essential. In-space servicing, assembly, and manufacturing (ISAM) technologies will allow for the refurbishment, repair, and upgrading of satellites and space stations, extending their operational life and reducing the need for launching new assets. These practices not only lower costs but also contribute to the reduction of debris and waste in space, fostering a circular space economy that supports sustainability on a broad scale.

5. Vision for a Future Sustainable Space Enterprise

As the space industry looks ahead, a sustainable space enterprise is no longer a distant vision but a necessary evolution. The industry is actively exploring innovative strategies and technologies that align with the principles of sustainability, ensuring that space activities can continue to thrive without compromising the environment or future opportunities.

Longevity and Reusability in Space:

Extending the operational lifetime and repurposing of spacecraft is an emerging strategy for sustainability in space. By focusing on life extension, servicing and reusability, the industry can reduce costs, minimize risks, and better manage terrestrial resources. This approach not only lowers the environmental impact associated with the frequent launch of new spacecraft but also enhances the economic viability of space missions. Companies are increasingly investing in technologies that allow for the refurbishment, repair, and reuse of spacecraft, fostering a sustainable and circular space economy.



In-Space Servicing, Assembly, and Manufacturing (ISAM):

ISAM represent a transformative approach to space operations that significantly reduces the environmental impact associated with traditional space activities. ISAM technologies enable the repair, upgrade, and extension of spacecraft lifespans, thereby enhancing sustainability by reducing the need for frequent launches of replacement systems. Servicing allows for in-orbit maintenance, ensuring that spacecraft can continue to operate efficiently for longer periods, reducing waste and supporting a circular space economy. Assembly in space further minimizes the need to launch fully assembled spacecraft from Earth, as components can be transported more efficiently and assembled in orbit. This approach also allows for the construction of larger and more complex structures that would be impractical to launch as a single unit.

Manufacturing in space, a key component of ISAM, involves producing parts and materials directly in orbit, using resources that are either launched from Earth or extracted from space environments. This reduces the environmental footprint of space activities, as it lowers the frequency and volume of launches required. ISAM not only supports sustainability by minimizing resource consumption and waste but also opens new avenues for innovation, enabling the development of adaptable and modular systems that can be easily upgraded or repurposed in space.

Sustainable Use of Space Resources:

As humanity expands its reach beyond Earth, the sustainable use of space resources becomes increasingly critical. The extraction and utilization of extraterrestrial materials, such as lunar regolith or asteroids, offer opportunities to reduce reliance on Earth's resources. However, it is imperative that these activities are conducted in a manner that ensures long-term sustainability. The industry is exploring methods to extract resources responsibly, with an emphasis on minimizing environmental impact and avoiding the depletion of space resources. Sustainable resource use not only supports ongoing space exploration but also contributes to the broader goal of a sustainable space economy.

Better Tracking of Spacecraft and Debris:

The safety and sustainability of space operations depend heavily on our ability to track and manage objects in space. Advanced tracking and warning systems are essential for preventing collisions, managing space traffic, and ensuring the long-term sustainability of the orbital environment. The industry is working on developing more sophisticated Space Situational Awareness (SSA) and Space Traffic Management (STM) systems to enhance the monitoring of spacecraft and debris. These technologies play a crucial role in maintaining a safe and sustainable space environment, reducing the risk of debris generation, and preserving the orbital ecosystem for future activities.

Paradigm Shift in Planetary Protection:

As humanity ventures deeper into space, the concept of planetary protection is evolving. Traditionally focused on safeguarding Earth, industry is now considering broader ethical responsibilities to protect all celestial bodies. This paradigm shift reflects a growing recognition of the need to preserve the environments of other planets, moons, and asteroids from the potential impacts of human activities. By adopting a more expansive approach to planetary protection, the space industry can ensure that space exploration is conducted in a manner that respects and preserves the integrity of celestial environments.

The benefits of these initiatives highlight the fact that space sustainability is not just an appealing concept; it's a pivotal component of our future in space. The space industry is creating a shift from short-lived, one-off missions to a sustainable, enduring presence in space [6]. Companies around the world are making space sustainability a core part of their value propositions with support and cooperation from governments and non-governmental organizations. These investments are creating new capabilities in space and a sustainable and interconnected future above and beyond our planet.

6. Conclusion: Industry Position

The space industry plays a pivotal role in advancing space sustainability, complementing and enhancing government-led initiatives. As the primary driver of technological innovation and implementation, the industry's commitment to adopting sustainable practices across the entire lifecycle—from design, manufacturing and development to operations—is crucial for ensuring the long-term viability of space activities. Industry-led initiatives, grounded in real-world applications and economic imperatives, provide the practical solutions necessary for achieving sustainability goals. By embracing sustainability, industry not only mitigates environmental impacts but also fosters resilience and innovation, setting the standard for responsible space stewardship.

However, it is important to recognize that sustainability is not merely an idealistic pursuit but a complex and challenging transition that requires significant investment, global coordination, and long-term commitment. The push towards sustainability must also acknowledge the challenges. As seen in other industrial sectors, sustainability initiatives often face setbacks due to fluctuating market conditions, geopolitical conflicts, and the inherent costs associated with green transitions. For example, the energy crisis caused by the Ukrainian war forced some companies to revert to coal, undermining their sustainability objectives. Similarly, the automotive industry's shift towards electric vehicles (EVs) has encountered hurdles such as high production costs, dependency on scarce materials, and uncertainties about long-term viability. These challenges illustrate that sustainability in any sector, including space, requires stable global rules, consistent market conditions, and careful planning to ensure that efforts do not falter under economic or political pressures.

Despite the challenges, the space industry must continue to identify and pursue opportunities for sustainable growth. It is essential that the space industry actively engages in identifying and pursuing future opportunities for collaboration and innovation. International organizations such as the IAF provide a forum and platform for leading and facilitating these efforts. Through ongoing discussions and forums, the IAF brings together diverse stakeholders—from commercial enterprises and government agencies to academia and non-governmental organizations—to explore the risks, benefits, and potential of sustainable space practices.

The IAF enables space industrial partners to align their sustainability efforts and share progress in their efforts around space industry practices as outlined before creating sustainable supply chains, program management, AI applications towards sustainability, and other efforts. This collaborative approach aligns global efforts, identifies emerging challenges, and develops strategies that balance economic growth with environmental responsibility, ensuring a sustainable future for space exploration and utilization. By acknowledging the potential obstacles and actively working to mitigate them, the industry can build a more resilient foundation for a space enterprise that is responsible, inclusive, and sustainable.

References

- [1] Simpson, M., "Spin-Out and Spin-In in the Newest Space Age," Institute of Space Commerce. <https://change.space>. Accessed Sep 2024 (2010).
- [2] United Nations. "The 17 Goals." United Nations Sustainable Development. <https://sdgs.un.org/goals>. Accessed Aug 2024 (2024)
- [3] Bogdan-Martin, D., "Space sustainability: Why ITU? Why now?" Opening Keynote for the ITU Space Sustainability Forum, 11 September 2024.
- [4] Cernev, T., Bland, J., Zilgalvis, G., Kaleagasi, B., de Zwart, M., Tzachor, A., Richards, C., Chesley, B., McClintock, B., Agachi, A. "Assessing benefits and risks between the space economies and the sustainable development goals," *Frontiers in Space Technologies*, 5:1375830, (2024 March), doi: 10.3389/frspt.2024.1375830, Lausanne, Switzerland.
- [5] B. McClintock, et al., "International Space Traffic Management: Charting a Course for Long-Term Sustainability," RAND Research Report 1949-1 (2023).
- [6] M. Shar, "How orbital refueling will unlock humanity's potential in space," *The Space Review*, www.thespacereview.com, 2 October 2023.