# SPACE SUSTAINABILITY: STRENGTHENING CAPABILITIES FOR STRATEGIC LONGEVITY

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The new space age has seen a steep increase in human activity in outer space. While the domain has become an integral part of society, from applications on daily activities to its strategic value, outer space has been integrated deeply into terrestrial endeavours. The 21st century will see further expansion and insight into the cosmos on the scientific and politico-economic futures of humankind. At the dawn of the space age, flights to the planets, ambitions of landing on the Moon, and strengthening global communications between 1957 and 1991 were driven by the tensions of the Cold War.[1] Since then, the investments in outer space have always been a combination of massive budgets for military-space exploitation. With the beginning of the new century, however, newer and cheaper technological capabilities have emerged, making outer space more accessible, while being more sparsely regulated than ever.[2] In the coming years, we will see advanced capabilities in exploration, higher-resolution imagery capabilities, tourism, increased

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1. S. Magazine, "How Cold War Politics Shaped the International Space Station", at https://www.smithsonianmag.com/science-nature/how-cold-war-politics-shaped-international-space-station-180975743/. Accessed on September 9, 2020.
2. "Sustainability in Space", at https://www.leidenlawblog.nl/articles/sustainability-in-space. Accessed on January 19, 2021.

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international participation, multi-planet economy, and extra-terrestrial mining. There is a distant potential of exploration of clean energy opportunities such as harnessing solar energy or the inexpensive disposal of nuclear waste in outer space. While some would say that the exploration of outer space is to have a Plan B for the possible extinction of life on Earth, others see it as a means of furthering strategic terrestrial-geopolitical interests into outer space.

Today, three countries have displayed human space flight capabilities, satellite capabilities have reached as far as 23.5 billion km away from Earth, and a vision to make space hotels, settling on the Earth's Moon, planetary colonies, constructing free-floating space stations, and making a permanent human presence in space, a reality.

In this context, the time is ripe to discuss the sustainable use of outer space. Keeping the current trends of legal regulation of space-based activities, it would be of paramount relevance to understand the domain from futuristic but essentially sustainability-driven, initiatives. Orbital crowding, the problem of space debris, space weather, and securing national space assets have been seen as the most important aspects of space sustainability. To broaden this scope, it is also essential to focus on the sustainability of the use of terrestrial resources for space-based activities, the impact of such activities on the Earth's immediate atmosphere, and the impact of increased space activities and capabilities on the space geography. How do we then define sustainability in outer space? What are the issues that could be identified as unviable trends in the long run? What are the existing legal and legislative initiatives that address the upcoming challenges?

## SUSTAINABILITY IN OUTER SPACE

The UN Committee on the Peaceful Uses of Outer Space (UNCOPUOS) had, by the year 2018, introduced a definition of the long-term sustainability of outer space activities. It defined sustainable outer space as "the ability to maintain the conduct of space activities indefinitely into the future in a manner that realises the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes," and places emphasis on its long-term exigency, "in order to meet the needs of the present generations while preserving the outer space environment for future generations".[3]

**Though it is impossible to have a universal definition or metrics to measure space sustainability, there are elements of sustainability that need to be specified with the objective of long-term sustainability.**

The Secure World Foundation details sustainability in outer space as "ensuring that all humanity can continue to use outer space for peaceful purposes and socioeconomic benefit now and in the long term."[4] While these definitions look at outer space broadly, through the idea of a secure, peaceful, long-term, and safe realm, they miss a few beats to define sustainability in its truest sense. Though it is impossible to have a universal definition or metrics to measure space sustainability, there are elements of sustainability that need to be specified with the objective of long-term sustainability.

The UN guidelines set in 2018[5] were intended to identify the general context of states and inter-governmental organisations to invest in sustainable practices while developing, planning, and executing their space activities. The guidelines, thus, reiterate the principles that were laid down by Article III of the Outer Space Treaty (OST), which requires states to perform their

3. "Peaceful Uses of Outer Space: Guidelines for the Long-term Sustainability of Outer Space Activities", *UNOOSA*, at https://www.unoosa.org/res/oosadoc/data/documents/2018/aac_1052018crp/aac_1052018crp_20_0_html/AC105_2018_CRP20E.pdf. Accessed on June 5, 2018.
4. Space Sustainability/Secure World, Secure World Foundation, at https://swfound.org/our-focus/space-sustainability/. Accessed on March 6, 2019.
5. COPUOS, U., "Guidelines for the Long-term Sustainability of Outer Space Activities". UNOOSA, at https://www.unoosa.org/res/oosadoc/data/documents/2018/aac_1052018crp/aac_1052018crp_20_0_html/AC105_2018_CRP20E.pdf. Accessed on June 5, 2018.

activities in outer space in conformance with International Law and the Charter of the United Nations. Additionally, Article I of the OST mentions that the use, exploration and probe of outer space—with the Moon and other celestial bodies—would be carried out for the benefit, and in the interest, of all countries. This would be "irrespective of economic or scientific development," and as "the province of all mankind," while keeping in mind that the defence and national security implications would have to be compatible with the principles and norms of International Law and the foundations of the Outer Space Treaty. Further, most guidelines for sustainability are seen as voluntary and not legally binding under International Law, with consistent efforts to put in place the applicable principles and norms for the implementation of these guidelines in accordance with existing standards. Significant emphasis is placed on voluntary responsibility and compliance measures through national agencies and procedures to ensure that these guidelines are implemented in accordance with the states' respective needs but consciously in accordance with their obligations to international standards.

In the Indian context, the focus of space sustainability has emerged alongside the need for responsible behaviour in outer space. In July 2022, India inaugurated the Indian Space Research Organisation (ISRO) System for Safe and Sustainable Space Operation and Management (IS4OM), with a specific focus on identifying potential collision and manoeuvring capabilities for collision avoidance. Labs have been dedicated for specific research on space debris mitigation and remediation, and compliance verification of the UN Inter-Agency Space Debris Coordination Committee (IADC) guidelines. Emphasis has been laid on various Research and Development (R&D) activities as a part of the IS4OM. India identifies the pressing need for safe and sustainable use of outer space in its "Space Situational Assessment 2021." In December 2020, a dedicated control centre for space situational awareness was set up within the ISTRAC (ISRO Telemetry, Tracking, and Command Network) called the NETRA. The NEtwork for space object TRacking and Analysis (NETRA) establishes India's Space Surveillance and Tracking Network using radars and optical telescopes. The facility is in Peenya, Bangalore.[6]

## DEFINING SPACE SUSTAINABILITY

The present-day activities in outer space are well beyond the national initiatives and involve multiple layers of engagement in outer space. This would mean that the question of sustainable practices or initiatives would need to be specifically defined keeping these differences in place.

In this context, sustainability in outer space would be defined as a vital aspect of every space mission to ensure the optimum usage of terrestrial resources and the space environment to meet the long-term needs of security, economy, society, and politics; derive new methods and practices to prioritise sustainable efforts in future missions; and develop or incorporate technology that protects space assets from possible damage in orbit. This would require the creation of specific guidelines and legal regimes to address the challenges of space weather, orbital debris, overcrowding, and the growing urgency of space situational awareness. Having issue-specific guidelines would be essential to ensure that the technical considerations are met and there is consensus among all the players in outer space.

### *Existing Legal Guidelines and Regulations*

As the activities in outer space increase,[7] more emphasis is being placed by national governments and inter-governmental organisations on self-regulation of sustainability protocols. This is also true in the case of security and the projection of issue-specific interests in outer space. There is an international race to set new standards in outer space to deal with the consequences of the competitive and congested environment that space has

6. "IS4OM Inaugurated: India Gives Boost to Self-Reliance in Safeguarding Space Assets," *The Economic Times*, at https://economictimes.indiatimes.com/news/science/is4om-inaugurated-india-gives-boost-to-self-reliance-in-safeguarding-space-assets/articleshow/92783668.cms. Accessed on July 10, 2022.
7. "Sustainability in Space: The Next Frontier", BSR (n.d.), at https://www.bsr.org/en/emerging-issues/sustainability-in-space-the-next-frontier. Accessed on July 10, 2022.

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become. The five foundational treaties have in the past laid out clear guidelines in outer space for "the expanding and increasingly complex tasks aimed at the exploration and use for peaceful purposes".[8] Further, the UN General Assembly has adopted resolutions and laid down various principles in addressing the central concerns of safe space activities.[9] However, both these methods of legal checks have failed to keep up with the pace of growth in outer space. The space domain has moved beyond the original space-faring nations. There are nations with great space-faring ambitions, the commercial space industry, with some larger than national space programmes, and the technical/physical capabilities of space exploration have increased.

The natural consequence of the increasing space activities and the proliferation of space objects is the growing risk of collisions. The orbital crowding of satellites and space debris has altered sustainable access to outer space. The 'hard law' that was collectively established for the few national space programmes six decades ago, established a selective micro scale of governance in outer space. Currently, the multiple space players operate on a deficit regulatory supervision of the international treaties, with a voluntary 'soft law,' practically a system that requires compliance measures to ensure sustainability and sustainable access to space exploration against the commercial/low-cost orbital activity. Thus, the legal scope for ensuring sustainability lies in the voluntary compliance of the entities with a non-binding outcome.

8. Space Law Treaties and Principles, UN Office for Outer Space Affairs, 2017, at https://www.unoosa.org/oosa/en/ourwork/spacelaw/treaties.html.
9. "Outer Space", UNODA (n.d.), at https://www.un.org/disarmament/topics/outerspace/. Accessed on July 10, 2022.

*Multiple Initiatives to Address Sustainability*

In 2016, the UN COPOUS formulated a working group for the Long-Term Sustainability (LTS) of outer space activities.[10] The group functioned with the objective to identify areas of concern for long-term sustainability. For this, it worked towards proposing measures that could enhance sustainable practices, and produce guidelines voluntarily to reduce the risks against long-term sustainability in outer space. Thus, the group identified five broad themes, starting with the utilisation of sustainable space that supports sustainable practices and developmental goals on Earth, tools and operations supporting collaborative space situational awareness, regulatory regimes and guidance for the various kinds of players in the space domain, and space weather. In 2016, the first 12 guidelines were finalised and in 2018, the next nine guidelines were finalised.[11] However, the plenary has not been able to reach consensus on the final report of these guidelines.

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In June 2018, at the commemoration of 50 years of the Outer Space Treaty, the meeting at Vienna posed timely and pertinent questions on the legal future of the outer space realm. The UNISPACE+50 conclusion emphasised greatly on the need for international collaboration and cooperation with an aim for the peaceful utilisation of outer space. The resolution mentioned the need for 'global governance' of space activities, while encouraging space science, technology and applications to offer solutions to Earth-bound Sustainable Development Goals (SDGs).[12] The meeting is important in

10. P. Martinez, "The UN COPUOS Guidelines for the Long-term Sustainability of Outer Space Activities", *Journal of Space Safety Engineering*, 8(1), pp. 98-107, at https://doi.org/10.1016/j.jsse. Accessed on March 2, 2021.
11. B. Skinner, "Guidelines for the Long-Term Sustainability of Outer Space Activities—Space Security Index", at https://spacesecurityindex.org/2020/11/guidelines-for-the-long-term-sustainability-of-outer-space-activities/. Accessed on November 24, 2020.
12. "UNISPACE+50 Concludes with Global Commitment to Cooperate in Space and Use Space for Sustainable Development", UN Office for Outer Space Affairs, at https://www.unoosa.org/oosa/en/informationfor/media/2018-unis-os-499.html. Accessed on June 2018.

reference to the applications of space technologies on terrestrial sustainable goals. Outer space is considered an enabler for Earth-bound sustainability goals. In this context, it would be interesting to explore the possibilities of space for sustainable goals.

While there have been commonly agreed practices that continue to ensure the smooth functioning of activities in outer space, the issues of Anti-Satellites (ASATs) and other possible destructive scenarios cannot be secured with the soft law approach. Even in the case of hard law regulations, the compliance successes have been minimal. However, the International Telecommunications Union, in the year 2010, came up with a regulatory framework for the environmental protection of the geostationary-satellite orbit, that required the satellite operators to divert their soon-to-die satellites in the geostationary orbit towards a higher graveyard orbit, which has seen a sizeable measure of compliance, first, due to increased scrutiny and, second, due to fear of accidents from space debris. Hence, the debris crisis has seen some form of enforcement. The pending LTS guidelines, when enforced, are likely to bring a legal certainty to divergent activities in outer space like accidents, disputes, lawsuits, insurance and allotment-related issues similar to what is called the 'hard law' of the international treaties of the 1960-70s.

In September 2022, the UN OEWG (Open-Ended Working Group) concluded its workshop on "Reducing Space Threats Through Norms, Rules and Principles of Responsible Behaviour." This was the second meeting following the first session in May 2022.[13] The focus was placed on the economy, society and security related space activities, largely in the civilian domain. The group placed greater emphasis on pragmatic solutions for safety and security in outer space. With the participation of 50 states from all the regions of the world, the OEWG falls under the UN General

13. Project Ploughshares, "The Open-Ended Working Group on Space Threats: Recap of the First Meeting", May 2022, at https://ploughshares.ca/pl_publications/the-open-ended-working-group-on-space-threats-recap-of-the-first-meeting-may-2022/. Accessed on September 6, 2022.

Assembly's (UNGA's) Prevention of Arms Race in Outer Space (PAROS).[14] While PAROS has been an arms control initiative, with the OEWG, significant focus is being placed on responsible behaviour in outer space. The discussion in May mentions a moratorium on ASAT testing, which is a question like the nuclear Non-Proliferation Treaty (NPT), that may remove the access to fair development of capabilities for growing space powers. Under the guiding principles section, the group has given priority to "improved/shared space situational awareness for verification/attribution," and "data sharing to monitor near space/mitigate space debris, and pre-notifications," "exchange of information/warnings on orbital parameters of space objects," avoiding "intentional destruction of any on-orbit spacecraft," "intentional creation of space debris," or "harmful interference with satellite systems," as well as "interference with control space systems/critical services," including the "rules for the interaction of satellites/rendezvous-and-proximity operations,"[15] notably all of which refer to sustainable practices in outer space. The second meeting of the OEWG was focussed on the current and future threats to space systems. By the end of 2023 or early 2024, one may expect a detailed report of these discussions.

### *Guidelines for Debris Mitigation*

The IADC (Inter-Agency Space Debris Coordination Committee) has developed mitigation guidelines on a voluntary basis. These seven guidelines are listed here: first, "limit debris released during normal operations;" second, "minimise the potential for break-ups during operational phases"; third, "limit the probability of accidental collision in orbit"; fourth, "avoid intentional destruction and other harmful activities"; fifth, "minimise the potential for post-mission break-ups resulting from stored energy"; sixth, "limit the long-term presence of spacecraft and launch vehicle orbital stages in the Low-Earth Orbit (LEO) region after the end of their missions"; and

14. UN General Assembly (75th sess. : 2020-2021), "Prevention of an Arms Race in Outer Space", United Nations Digital Library System, at https://digitallibrary.un.org/record/3895439?ln=en. Accessed on December 16, 2020.
15. n. 13.

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seventh, "limit the long-term interference of spacecraft and launch vehicle orbital stages with the Geosynchronous Earth Orbit (GEO) region after the end of their missions".[16]

These guidelines ensure cost-effectiveness, better design and planning standards, and reduction of debris creation. The members of IADC are currently only those with national space programmes, and these include large and medium scale space powers only. To ensure better applicability of these guidelines, the private space players must be represented. While the enforceability of these practices is limited, it is essential to take up measures that would encourage compliance by all the players in the space domain.

## CONTRIBUTORS AND CHALLENGES TO SUSTAINABLE OUTER SPACE

### *Space Situational Awareness*

Space Situational Awareness (SSA) is the idea of documenting and preparing a knowledge base of the space environment that includes the function, location, trajectory, and speed of space objects, with the coordinated networks of ground-based and space-based systems. SSA functions on the objective of providing information, database, and services on the space objects, primarily on the Earth orbits. SSA covers three broad areas: surveillance and tracking of man-made space objects; monitoring of near-Earth natural space objects; and forecast and monitoring of space weather. Popularly, there are initiatives undertaken by the US, Europe,

16. IADC, ed., "IADC Space Debris Mitigation Guidelines, NASA Gov Library on Orbital Debris", at https://orbitaldebris.jsc.nasa.gov/library/iadc-space-debris-guidelines-revision-2.pdf. Accessed on March 2020.

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Russia, and a global initiative to track and predict satellite/space object behaviour. The US Strategic Command (USSTRATCOM) has a space surveillance network that has ground-based sensors and tracking systems. It is known as the Space Object Catalogue, and has an SSA Sharing Programme to promote data-sharing. The Russian Military Space Surveillance Network (SKKP) is the equivalent of the USSTRATCOM, which predicts location while it tracks and catalogues objects in orbit. Similarly, the European Space Agency has an active SSA network.[17] India has been working on its project NETRA that aims at enhancing SSA for space objects. An international organisation called the Space Data Association was set up in the year 2009 on a membership basis. It works with satellite operators, to enhance coordination with "accuracy and timeliness of collision warning notifications."[18]

SSA, hence, would enhance the understanding of space objects and their trajectory, giving the operators an insight into the potential threat to their systems. This prediction mechanism is the need of the hour and requires a coordinated effort by the agencies to retain knowledge of satellites' behaviour and their movement. However, data-sharing among national agencies, private entities and other satellite launch systems, along with the ground-analysis networks requires trust-building measures. There are instances where data-sharing might become a concern of national security. A mechanism to include these concerns for the development of SSA networks becomes essential.

17. *Space Briefing Book* (n.d.), Space Foundation Organisation, at https://www.spacefoundation.org/space_brief/space-situational-awareness/. Accessed on July 10, 2022.
18. Space Data Association, Space Data Centre, at https://www.space-data.org/sda/. Accessed on May 27, 2022.

***Space Debris***

Space debris is a growing threat to space safety. However, mitigating space debris is more of an economic challenge than a question of sustainability. Space clutter is a result of positive space activities since 1957. Natural space debris consists of small pieces of asteroids or cometary material called meteorites. Artificial space debris emerges from two processes: first, the end cycle of a satellite's life; and, second, from the damage caused by tests like an ASAT test. Space debris is one of the primary issues of sustainability in space as it has seen increased public attention from the ASAT tests. However, the artificial space debris/orbital junk comes from a few different sources. These include satellites that have reached the end-of-life, objects from failed missions or satellites, remnants of the multiple rocket stages of launched satellites, nose cones, payload covers, shrouds, bolts and other launch hardware, solid propellant slag, wrenches, and other space activity castaways, deterioration particles such as peeling paint, scraps from exploding batteries, or fuel tanks, and fragments from collisions.

The primary concern of space junk is the potential damage it could cause when it collides with active or functioning satellites or spacecraft. While the collision probability from meteoroids is very low, the chances of a spacecraft suffering from a collision with artificially created debris is high. Most space-faring nations have identified the problem of space debris and have started to take measures to reduce the creation of more debris in their future activities. In June 2007, the UN General Assembly (UNGA) adopted seven space debris mitigation guidelines which have been listed earlier.[19] Very few initiatives have been undertaken to reduce the amount of debris that is in orbit. However, the commercial space industry has begun to invest in management of the debris in orbit.

Estimates have shown that any fragment of debris that is larger than one centimetre is likely to penetrate the walls of a satellite/spacecraft. This

19. UNOOSA (n.d.), "Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space", UN Office for Outer Space Affairs, at https://www.unoosa.org/pdf/publications/st_space_49E.pdf. Accessed on July 10, 2022.

is due to the high velocity at which the particles are moving in orbit. Pieces of debris that are of a size less than 1-10 mm would likely cause erosion of optical surfaces. Like sun blasting, such debris would ruin telescope mirrors and decrease the efficiency of solar cells. In the first couple of months of the activation of the James Webb Telescope, it was impacted by 19 small pieces of space rocks or micrometeoroids. These are said to have scratched the surface of the telescope and left a noticeable damage on one of the 18 gold-plated mirrors. To address the problems and risks of space debris, four categories of mitigation strategies are being looked at: first, avoiding the creation of new debris; second, improving the capabilities in SSA; third, establishing coordinated space traffic management capabilities; fourth, investment in technologies for active debris removal.

As of September 2022, it was revealed that there are about 8,000 metric tonnes and over 900,000 pieces of space junk orbiting in space. Every piece is potentially lethal to satellites. Experts have estimated 30,000 pieces of space junk large enough and with high speeds having the potential to cause some form of a disaster.[20] The biggest contributors to the present-day space junk are the active space powers: the US, Russia and China. The major components that form space junk include defunct satellites, damaged parts of satellites, lost/ dismembered equipment, spent stages, and debris from collisions. In its 23 years mission time, the International Space Station has had to avoid space debris over thirty times, and has seen minor damage that has occurred from small debris particles. However, with the fast rate of satellite launches, the likelihood of a Kessler's Syndrome scenario increases.[21] At altitudes less than 200 km, the rate of 'decay' becomes rapid. All small pieces of debris burn up before they enter the atmosphere. Hence, many experts recommend breaking down the pieces of debris sufficiently to vapourise before reentry. Below 2,000 km, the objects are subject to an atmospheric drag and slowly reduce the altitude. Hence, the objects in LEO experience a gradual orbital

20. "Global Risks Report 2022" (n.d.), World Economic Forum, at https://www.weforum.org/reports/global-risks-report-2022/in-full/chapter-5-crowding-and-competition-in-space/. Accessed on July 15, 2022.
21. ProCon.org, "Space Colonization—Pros & Cons", at https://www.procon.org/headlines/space-colonization-top-3-pros-and-cons/. Accessed on November 7, 2022.

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decay. Satellites from orbits higher than that are usually directed towards the graveyard orbit.

The private sector has emerged as the dominant player in orbital space. While governments continue to set national plans and strategies, the private sector continues to drive private finance and entrepreneurship, leading to innovation and diversity. The private sector is likely to spend on, and innovate in, the sustainability sector. Hence, a careful combination of government-regulated space traffic management, and innovation for Active Debris Removal (ADR) and Space Situational Awareness (SSA) through the private sector would be ideal in the case of space debris.

In the second half of 2022, the US Office of Science and Technology Policy published its implementation plan for orbital debris.[22] The European Commission also released a report in the same year that outlined the European Union's approach to space traffic management and its plans to increase capabilities in tracking space objects. The European Commission has called for an initiative to develop international regulations for safe and responsible operations in space.[23] Japan too, in 2022, proposed a set of efforts to help establish international orbital rules, through its Cabinet Office, which includes space operations, rules for de-orbiting, planning, and design requirements.

### *Orbital Crowding*

Orbital crowding is the growing concern of the combination of space debris, active satellites, proposed constellations, and mismanagement of space objects/lack of situational awareness, and reduced life-cycles of

22. R. Zisk, "Senate Introduces ORBITS Act. Payload", at https://payloadspace.com/senate-introduces-orbits-act/. Accessed on September 15, 2022.
23. EU Space Traffic Management System, European Commission, at https://ec.europa.eu/commission/presscorner/detail/en/IP_22_921. Accessed on February 2022.

satellites. Crowding of orbits may be observed in two ways: one is physical crowding with the increasing number of space objects; the second is the problem of radio frequency interference that emerges due to the proximity between satellites/space objects. While space debris remains the primary concern of crowding, the growth rate in the number of satellites being launched, the constellations, and proposed ideas of mega-constellations, with sparse regulations of management practices regarding dead and defunct satellites add to the crowding problem in the Earth orbits.

**Since 1957, approximately 11,000 satellites have been launched. In the coming decades, based on the proposed plans, an estimated 70,000 satellites could enter the orbital space. Unless there are active decommissioning regulations, many of these satellites are likely to remain in space for hundreds of years.**

The problem of orbital clutter has been discussed often but the active removal of debris or its efficient regulation/monitoring has yet to take form. The risks of orbital crowding are higher as the orbits get crowded. LEOs have observed many close encounters, also called 'conjunctions' between active satellites. There have been ideas to develop automated systems that would help operators carry out "collision avoidance manoeuvres" using Artificial Intelligence (AI). Commercial initiatives are investing heavily on the Low Earth Orbits (LEOs) and Medium Earth Orbits (MEOs) reducing the demand for communications satellites in the Geostationary Earth Orbits (GEOs), areas like hyper spectral remote sensing, energy generation, mining, manufacturing, tourism and expanding broadband services. While the systems have broadened among the civilian, military and commercial sectors, there are also many systems that launch satellites of smaller sizes with low life cycles. Since 1957, approximately 11,000 satellites have been launched. In the coming decades, based on the proposed plans, an estimated 70,000 satellites could enter the orbital space. Unless there are active decommissioning regulations, many of these satellites are likely to remain in space for hundreds of years. There are two problems of crowding: one is the crowding of the orbits themselves which would make services and activities challenging; and the second is the crowding of the orbital space with space junk floating around in the area. Objectively, crowding would bring the world closer to a Kessler's Syndrome and make the orbits impossible to use. Effective governance tools are essential to ensure compliance, common principles, and traffic control.[24, 25]

*Active Debris Removal*

Space junk removal is an emerging market, which includes scenarios and technologies that have been investing in the problem of debris removal from the orbits. While it has to be a global priority to remove this junk, the world is yet to see large scale removal capabilities. The debris problem has reached a tipping point, thus, making the space environment prone to danger even when new space debris is not added to the orbits. There have been worrisome close encounters and small scale collisions taking place in the orbits, but the 2009 Iridium-Cosmos-type of collision brings attention to the issue. Many plans/scenarios of debris removal have been proposed. Prominent among them are the use of nets, laser blasts, harpoons, tethers, and garbage-gathering tentacles or robotic arms as methods to remove the space debris.

Commercial initiatives in Japan and the UK have had successful tests of space debris removal. Astroscale Inc., a private company from Japan, is set to deliver the world's first initiative named ELSA (End-of-Life Services by Astroscale) with the ability to remove defunct satellites through a garbage truck. This is expected in the year 2024. In March 2021, the company launched ELSA-d to test its technology. The model is designed to drag down satellites using a magnetic plate from high altitudes towards the Earth's atmosphere where the objects, including the cleaner, would burn up before they hit the surface of the Earth. In September 2022, Astroscale Inc. and Switzerland-based ClearSpace were offered contracts by the UK Space Agency for the

24. H. Madhusudan, "Explained: The Need for Space Sustainability", *The Hindu*, at https://www.thehindu.com/sci-tech/explained-the-need-for-space-sustainability/article65599294.ece. Accessed on July 4, 2022.
25. "Global Risks Report 2022", (n.d.), n. 20.

removal of two spacecraft from the LEO in the year 2026.[26] In the year 2018, the UK deployed a satellite, RemoveDEBRIS, from the International Space Station (ISS) and tested the debris removal capabilities through two methods: capture with a harpoon and capture with a net.[27] However, the tested methods are unlikely to be applicable to all kinds of space debris, and the probability of the dual use of such technology, making it a potential threat to satellites, looms large. Hence, space environment management guidelines would have to be able to address these concerns of ADR.

***Space Weather and Monitoring***

Space weather refers to the irregularities and varying conditions of the sun and in space that have the potential to influence the performance of space assets, satellites and technology. A major part of the space weather occurs within the Earth's magnetosphere and the upper atmosphere. Environmental disturbances related to space weather are measured on three types: solar radiation storms, geomagnetic storms, and radio blackouts.[28] The impact of these phenomena are often felt on the Earth's upper atmosphere and they affect the systems of satellite-based positioning and navigation, high-frequency radio communications, and when they affect the Earth, they impact the electric power grid.[29]

To the airline industry, the impact of space weather will be on high-flying airplanes and those flying over the North Pole. These are exposed to more radiation. Geomagnetic storms are known to alter the shape of the Earth's protective magnetosphere which allows more high-energy particles to the upper levels of the atmosphere. Space weather also poses a great risk

26. M. Lockhart, "ADR and Space", Australian Disputes Centre, at https://disputescentre.com.au/adr-and-space/. Accessed on May 9, 2022.
27. "Active Debris Removal" (n.d.), at https://www.esa.int/Space_Safety/Space_Debris/Active_debris_removal. Accessed on July 20, 2022.
28. "Space weather" (n.d.), "National Oceanic and Atmospheric Administration," at https://www.noaa.gov/education/resource-collections/weather-atmosphere/space-weather. Accessed on September 10, 2022.
29. National Research Council (n.d.), Space Weather: A Research Perspective. The National Academies Press, at https://nap.nationalacademies.org/catalog/12272/space-weather-a-research-perspective?record_id=12272. Accessed on September 14, 2022.

**Space weather impacts operations of satellites that are in Earth orbit. Most spacecraft are partly or entirely within the radiation belts, and the likelihood of a charged particle hitting a sensitive electronic device is high.**

to the health of satellites and orbits. Surface charging from the surface of the sun causes electrical discharges that are harmful to on-orbit electronics. In altitudes below 1,000 km, the atmospheric drag increases during solar storms which, in turn, would increase the altitude of the spacecraft. Changes in the magnetic field on the Earth's surface which are associated with geomagnetic storms are said to induce currents that flow through man-made structures. These structures could be power transmission lines, pipelines, or railroad systems, causing minor disruptions in services, or large incidents like blackouts on ground systems.[30] For example, in the year 1989, a power grid failure in Quebec, Ontario, was caused by a geomagnetic storm which impacted electricity access to six million people. In 2003, a similar power failure was seen in Sweden.

Space weather impacts operations of satellites that are in Earth orbit. Most spacecraft are partly or entirely within the radiation belts, and the likelihood of a charged particle hitting a sensitive electronic device, is high. These ions that strike satellites could potentially damage solar cells, degrade wiring and other equipment or could overwhelm the sensors. Geomagnetic storms would disrupt radio frequency signals impacting the positioning technologies, car radios or even satellite televisions. In the atmosphere, plasma bubbles which are regions of dense ionised gas are formed in the atmosphere, potentially disrupting signals passing through them. These geomagnetic storms would also cause electric charges to build up inside a spacecraft and when they discharge, they would overwhelm the systems.[31]

With the investments in human spaceflight increasing at great levels, it is also essential to assess the damage of space weather phenomena on space-

30. B. B. Poppe, and K. P. Jorden, "Sentinels of the Sun: Forecasting Space Weather," Bower House, 2006.
31. W. B. Cade and C. Chan-Park, "The Origin of 'Space Weather'," *Space Weather*, 13(2), 2015, pp. 99-103, at https://doi.org/10.1002/2014sw001141. Accessed on November 25, 2022.

farers' health. During geomagnetic storms, the energy of particles trapped in the radiation belts and the increased density would mean that there is a greater possibility of a damaging particle causing harm to an astronaut. Radiation exposures are likely to cause damage to the DNA within the cells. The International Space Station, hence, focusses on increasing the shields around crew quarters. The astronauts' radiation exposures are carefully monitored throughout their careers, due to the possible cancer-causing tendencies. All these factors of space weather could degrade the performance across the spacecraft's lifetime, exposing the spacecraft for further mission/systems failures.

**In India, the Indian Institute of Science Education and Research (IISER) in Kolkata has a space weather monitoring system in place. India also has the Indian Network for Space Weather Impact and Monitoring (INSWIM) to monitor the impact of space weather phenomena on the Indian space systems.**

The US National Oceanic and Atmospheric Administration has a Space Weather Prediction Centre (SWPC) in the US that works on space weather forecasting. The National Oceanic and Atmospheric Administration (NOAA) has a national weather service that has a computerised model that provides improved forecasts on space weather.[32] Many space programmes like those of Russia, China, Brazil, Australia, UK, European Commission, Germany, Japan, Korea, Canada, Belgium, South Africa have space weather services that are internationally available. In India, the Indian Institute of Science Education and Research (IISER) in Kolkata has a space weather monitoring system in place.[33] India also has the Indian Network for Space Weather Impact and Monitoring

32. NOAA (n.d.), Space Weather Prediction Centre, Space Weather Live, at https://www.spaceweatherlive.com/en/reports/noaa-swpc-alerts-watches-and-warnings.html. Accessed on July 10, 2022.
33. Space Weather, World Meteorological Organisation (n.d.), at https://community.wmo.int/activity-areas/wmo-space-programme-wsp/space-weather-introduction. Accessed on June 10, 2022.

(INSWIM) to monitor the impact of space weather phenomena on the Indian space systems.[34]

The European Space Agency has discussed the concept of an SSA Space Weather Network that also emphasises on observing space weather trends from ground and satellites. Efforts need to be made to ensure a collective initiative towards studying the space weather and creating sufficient databases that are continuously available for prediction and early warning mechanisms to take timely action.[35, 36, 37]

***Terrestrial Resource Demands and Climate Impact***

The global space economy value was at $424 billion in the year 2020, according to the Space Foundation. This value shows an expansion of 70 per cent since 2010, with the space industry currently looking at 1,700+ private companies.[38] While the growth has been phenomenonal, its impact on terrestrial systems would need to be evaluated. In terms of investments, the interest rates have worsened in recent years and despite the fall in the launch costs of missions, the time to show output by private companies is large, from technological developments to approvals and regulatory systems.[39] There are often discussions on the usage of extraterrestrial resources (in-situ space utilisation) for missions. However, most space initiatives depend on Earth-based resources for their activities. Primary resources for a space

34. *inswim* (n.d.), Space Physics Laboratory, Vikram Sarabhai Space Centre, https://spl.gov.in/SPL/INSWIM/inswim.html. Accessed on September 10, 2022.
35. R. F. Pfaff, J. E. Borovsky and D. T. Young, "Measurement Techniques in Space Plasmas: Particles (Geophysical Monograph Series) (1st ed.)," American Geophysical Union, 1998.
36. E. Samuel, "Space Station Radiation Shields 'Disappointing'", *New Scientist*, at https://www.newscientist.com/article/dn2956-space-station-radiation-shields-disappointing/. Accessed on October 23, 2002.
37. J. J. Love, "Magnetic Monitoring of Earth and Space", *Physics Today*, 61(2), pp. 31-37, 2008, at https://doi.org/10.1063/1.2883907. Accessed on July 10, 2022.
38. M. Sheetz, "The Space Industry is on its Way to Reach $1 Trillion in Revenue by 2040, Citi says", CNBC, at https://www.cnbc.com/2022/05/21/space-industry-is-on-its-way-to-1-trillion-in-revenue-by-2040-citi.html. Accessed on May 21, 2022.
39. K. M. O'Connell, "Space Sustainability as a Business and Economic Imperative", *Geospatial World*, at https://www.geospatialworld.net/prime/space-sustainability-business-economic-imperative/. Accessed on September 13, 2022.

mission are fuel (100 kg of fuel is required to launch 1kg spacecraft);[40] metal (aluminium alloys, graphite–epoxy composite materials, or other low-density material); small mechanical elements (magnesium or beryllium); composite materials (graphite-epoxy or aramid-epoxy); adhesive fillers (epoxy-polymer mixed with silica micro balloons); phenolic tubing, quantum tubing, aluminium, fibreglass, balsa wood, propellant, water, oxygen, and other life support material are all terrestrial resources that are essential in various combinations for a space mission.[41] While the resource flow has been stable for the past sixty years, the demands are likely to rise with the increase in space activity, making it unsustainable. Space activities are marked as an integral source for terrestrial development and climate goals. Hence, their impact on the environment must also be addressed. Space launches are known to leave a carbon trail on the atmosphere; they also deposit a dangerous amount of alumina on the upper atmosphere. The concepts of mega-constellations pose a direct threat to normal activities in outer space, and to the climate crisis. The possibility of space objects/debris entering the Earth's atmosphere and causing damage to life and property is another threat that comes from unchecked behaviour. The spent stages of multiple Chinese launches falling on locations with active human presence in the recent years is one such example.[42]

Initiatives such as the Active Debris Removal (ADR), the in-orbit servicing could ensure the safety and longevity of the space missions. Industry and innovation would need to be encouraged to undertake environment friendly/ green technologies. Reusable launch vehicles and use of liquid methane are examples in that direction.[43] Careful assessment of the environmental impact of space missions is required.

40. R. A. Meyers (n.d.), *Encyclopedia of Physical Science & Technology*, 3, Academic Press.
41. D. Sang, "Materials for Space Travel", *Catalyst Student*, at https://www.stem.org.uk/system/files/elibrary-resources/2016/01/Catalyst_26_2_632.pdf. Accessed on July 10, 2022.
42. "Clean and Eco-Friendly Space" (n.d.), at https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Clean_and_eco-friendly_space. Accessed on June 10, 2022.
43. "Environmental Impact of Space Debris and How to Solve it", World Economic Forum, at https://www.weforum.org/agenda/2022/07/environmental-impact-space-debris-how-to-solve-it/. Accessed on July 14, 2022.

**The technological capabilities of India for satellite fabrication and launch vehicles are known to be among the best in South Asia.**

## A CASE FOR SUSTAINABLE SPACE INITIATIVES IN INDIA

The Indian activities in outer space have always been responsible ones. In the 47 years of its space journey, India has launched up to 129 satellites with over 53 operational satellites in space.[44] India has actively participated in the multiple global fora on discussing responsible behaviour in outer space. The Indian active presence in outer space has primarily been for societal and development applications. The one deviation in Indian activities was the ASAT test in 2019, owing to India's security needs, and while the space debris contribution of India peaked in that year, currently there are less than 114 objects that are categorised as space debris. Hence, the Indian contribution to crowding and debris is minor. However, the technological capabilities of India for satellite fabrication and launch vehicles are known to be among the best in South Asia. As a regional space power, India should be one of the leading countries that drives the discussions at the decision-making levels. It would begin with the strengthening of the IS4OM initiative of India in 2022. The emerging institutional framework of India would need to address sustainability as one of its core concerns.

The security concerns in South Asia, the initiatives for safe practices and defining responsible behaviour in outer space would require norms and principles that have compliance value.[45] India would have to take the lead in representing the issues of slot allotments, equitable access and liabilities, and end-of-life protocols, at an international level. Within the nation, the Indian initiatives must include sustainability standards for all participants in space-related sectors, highlighting the need for responsible space behaviour, investing in renewable/reusable technologies, and in setting up collision assessment and situational awareness/tracking programmes like

44. Indian Union S&T Minister's Statement on Space, PIB, Department of Space, at https://pib.gov.in/PressReleasePage.aspx?PRID=1797196. Accessed on February 10, 2022.
45. Space Brief—Sustainability | The Long-Term Sustainability of Outer Space, Lexology, at https://www.lexology.com/library/detail.aspx?g=3ee6d5ec-77d9-452a-800e-c461b35206fe. Accessed on July 27, 2022.

strengthening Project NETRA,[46] for example. Ensuring access to responsible-commercial players would have to be done by national space strategies. With a medium-scale space programme, India has upheld the need for low-cost launch capabilities, but with the space sector in India expanding, common standards would become extremely essential. At multilateral forums, India could emphasise on the detachment of sustainable practices from security concerns, to initiate dialogues on pressing issues. India, in the coming years, would need to work on a space sustainability strategy to represent the Indian interests on a global scale.[47]

**Sustainability of outer space can be achieved only when safe, responsible, coordinated, continuous, and sustainable practices are adopted at every stage of a space mission.**

## CONCLUSION

Sustainability of outer space can be achieved only when safe, responsible, coordinated, continuous, and sustainable practices are adopted at every stage of a space mission, while ensuring that the terrestrial structures are secure. It would be safe to conclude, in 2023, that the narrative of sustainability in outer space has taken its early steps on being addressed. However, it is yet to ensure that all players—private, non-governmental, civilian, and military—in space are involved in the dialogue. India can ramp-up its engagement and take the lead in its international role at the decision-making level. Domestically, the standards for sustainable practices would have to be defined and incentivised to ensure compliance by all the participants in India's space programme. Collective and timely global efforts are necessary in cases of tracking and tackling space crowding and traffic management with the agenda of debris removal and mitigation. Technological innovation and creative practices must be outlined in order

46. Madhusudan, n. 24.
47. "IS4OM Inaugurated: India Gives Boost to Self-Reliance in Safeguarding Space Assets", *The Economic Times*, at https://economictimes.indiatimes.com/news/science/is4om-inaugurated-india-gives-boost-to-self-reliance-in-safeguarding-space-assets/articleshow/92783668.cms?from=mdr. Accessed on July 10, 2022.

to keep space objects from causing irreversible damage to active space assets and from reaching the Earth's atmosphere. The LTS and the OEWG guidelines would have to introduce enforceable measures for the equitable representation and responsibility of all space-faring entities. All of these sustainability measures would eventually contribute to further growth of the space domain, in terms of both ensuring that outer space remains a peaceful domain and displaying responsible behaviour. While the threats to sustainable space are a natural outcome of the increase in space activities, any threat posed or damage incurred from hereon, would be due to the lack of mechanisms and collective efforts to enforce and comply with the same. The UN has been playing the primary role for over a decade, but the time is right for national and regional discussions on the topic of sustainability, and the active participation of all countries and entities, regardless of the size of their space programmes, or their geopolitical power dynamics, to engage in dialogues of sustainability.