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Orbital Debris and Sustainability of Space Environment: Analysis of Issues and Challenges Under Space Law

Mr. Namit Kumar Srivastava[1], Dr. Saurabh Kishor[2]

[1]Research Scholar, Sharda School of Law, Sharda University
[2]Assistant Professor, Sharda School of Law, Sharda University

ABSTRACT

The present paper is an attempt to emphasize the role of space resources in achieving the sustainable development goals (SDGs), in the light of Space4SDG programme. The paper shall also outline the orbital debris problem as a threat to the sustainability of space for further exploration and use. It shall further analyze the wider framework of the International Space Law and whether there exist certain principles or provisions that would help in the mitigation of orbital debris. Finally, the paper would provide some suggestions and way forward in addressing the issues relating to orbital debris and ensuring environmental sustainability in outer space.

Keywords*: Orbital Debris, SDGs, Space4SDGs, Space Law, Environmental Sustainability*

1. INTRODUCTION:

Space technologies and tools play a vital role in areas such as telecommunications, weather forecasting, security purposes, navigation and other scientific explorations etc. In 2015, the United Nations Office for Outer Space Affairs (UNOOSA, 2015) introduced a framework called Space4SDGs. This serves as a practical roadmap for using space technology and resources to achieve all 17 'Sustainable Development Goals'. Today, there is no real debate: human survival now hinges on the satellites we've placed in orbit. We rely on a massive network of these machines for everything from basic navigation to deep-space exploration. Because our daily lives are so tied to these resources, keeping the space environment "healthy" and sustainable isn't just an option - it's a necessity.

The problem is that our own success is creating a "trash" crisis. Every satellite launch and mission leaves behind a trail of orbital debris. This junk is a direct threat to the very spacecraft we depend on. We are also entering a "New Space" era where profit, not just national pride, drives exploration. With private companies now leading the charge, the number of rocket launches has exploded. Naturally, this surge in traffic means more debris and a much higher risk of high-speed collisions.

As Williamson (2003) pointed out, expanding into space for industry, trade, and even tourism is just a natural step for our global economy. Whether we are hunting for life on other planets, mining asteroids, or planning for space hotels, our intentions are clear: we are treating outer space as a functional extension of Earth's own backyard.

The way we use space is changing at a breakneck pace. It used to be a "government-only" club, but now private companies are major power players. Countries are leaning on private partnerships for two main reasons. First, the demand for space data has become so huge that governments can't keep up alone. Second, they need private money to fund these expensive missions. While private firms used to just build the hardware, they are now the ones hitting the "launch" button. Space is no longer just a frontier; it's an industry.

In fact, some estimates suggest the space industry could be worth $1 trillion within just a few decades (Sheetz, 2022). As these missions multiply, the "garbage" problem will only get worse. We haven't seen a massive, catastrophic collision yet, but the danger is real. If we don't take action now, the consequences for our global infrastructure could be devastating. Safety in orbit must become a top priority for the global community. The world needs a plan that doesn't just put out fires but looks at the debris crisis from every angle.

2. Orbital Debris as Threat to Space Sustainability:

Outer Space and more specifically orbits are important resources for the usage and benefit of humans on earth. However, the sustainability of space resources is threatened by the creation of orbital debris by ever-increasing human activities.

2.1. What are Orbital/Space Debris?

'Orbital debris' or 'space debris' is 'junk' that is circling the Earth. These may be fragments of old satellites, spent stages of rocket launch, parts generated due to fragmentation or collisions of space objects etc. The UN Committee on the Peaceful Uses of Outer Space (Space Debris Mitigation Guidelines 2010) defines 'space debris' as:

"All man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional."

This is perhaps the first definition of space debris or orbital debris that is internationally accepted and which is being gradually adopted by many nations in their domestic legislations. The key ingredient of the definition is 'non-functional and man-made objects' which is capable of handling the threat posed by both fully intact large space objects and small pieces of debris (Munoz-Patchen 2018).

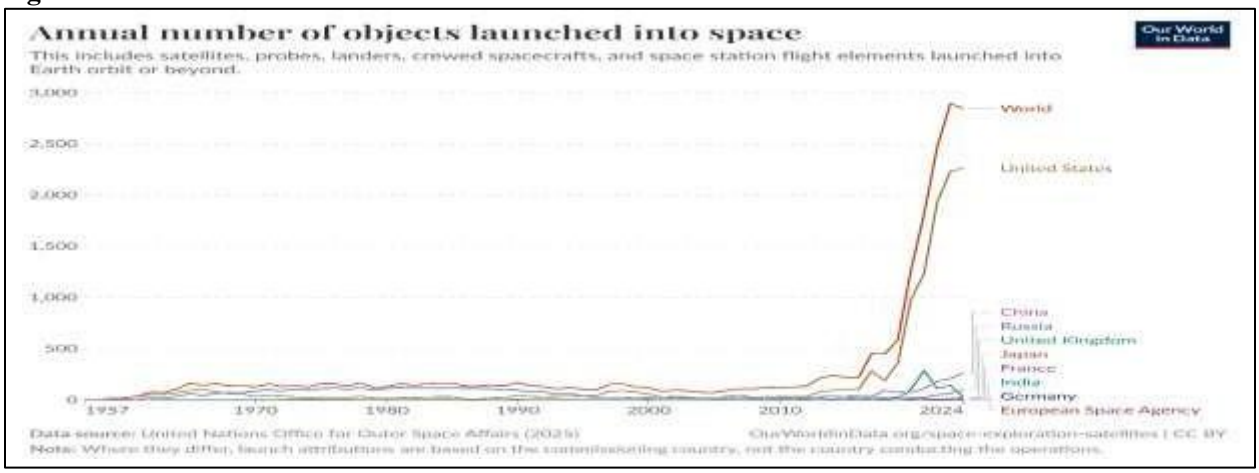
According to UNCOPUS, the 'primary sources' of orbital debris in Earth's orbits have been "(a) accidental and intentional break-ups which produce long-lived debris, and (b) debris released intentionally during the operation of launch vehicle orbital stages and spacecraft" (UNCOPUS, 2010). However, in future it is feared that the fragments generated by collisions in the orbits may form a significant source of debris. Orbital debris poses several risks which may vary from just littering in outer space to triggering Kesseler Syndrome (Kessler & Cour-Palais, 1978). This phenomenon occurs when it is expected that the density of objects in Low Earth Orbit (LEO) would reach a critical point, where a single collision triggers a self-sustaining "cascade" of further impacts. This could render entire orbital shells unusable for generations. The individual fragments, such as 'paint flakes' may seem like minor pollutants, their extreme kinetic energy transforms every such piece of junk into a potential shrapnel capable of destroying the multi-billion-dollar infrastructure we rely on for various purposes. Now that we are moving toward a trillion-dollar space economy, the risk is no longer just a technical nuisance but a fundamental threat to the humanity's survival (Popova & Schaus, 2018).

The recent focus on the exploitation of space resources for financial gains has led to the increase in the number of satellites being launched in the Outer Space. This has fairly increased the probability of collisions (Popova & Schaus, 2018; Williamson, 2003).

2.2. Orbital Debris Scenario in Outer Space:

It's certain that every launching activity in space creates orbital/space debris. In the early days of space exploration various launch elements- spent boosters, cones, explosive bolts- were simply abandoned to go where they might (Lyall & Larsen 2020). The first space object was launched in the year 1957, and since then, more than 17000 space launches have been done till 2024 (UNOOSA 2024- major processing in Our World in Data). (Fig. 1)

Fig. 1

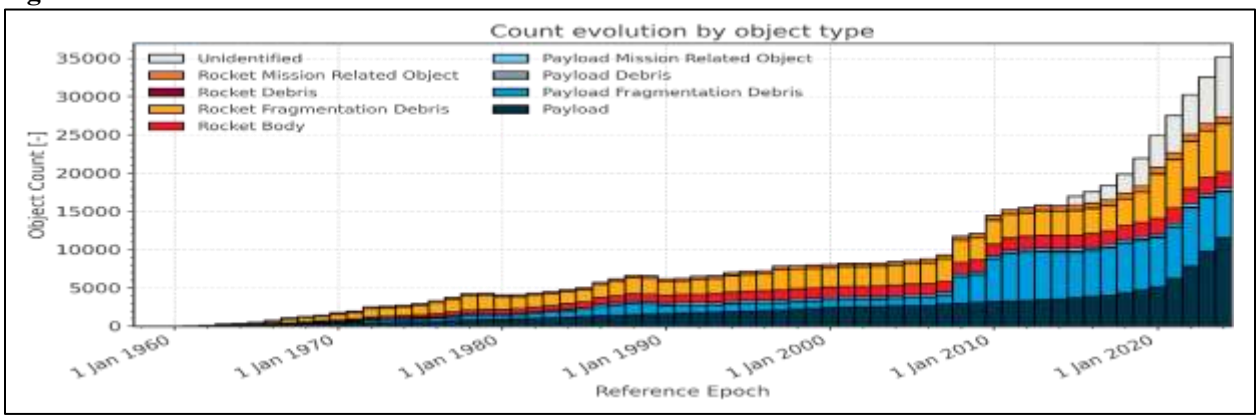


As a result, during the past six decades, near-Earth orbits have been filled with functional and non-functional objects, the overwhelming majority of which are debris of all sizes from less than 1 mm to more than 10 cm and even larger than that also (Popova & Schaus 2018). It is of concern that pieces of debris larger than 1 cm are particularly dangerous as no protection or shielding against them is possible. But, even the smallest objects

of 1 mm size has the potential to cause damage to functional satellites due to extreme orbital velocity and impact thereof.

It is not possible to track and catalog all objects in space. However, one estimate made by the statistical model of the European Space Agency (ESA) has provided the following data: i) there are more than 40500 orbital debris greater than 10 cm; ii) 11 million debris in the range of 1 cm to 10 cm, and iii) 130 million debris of 1 mm to 1 cm range (MASTER-8-Future Population 2024). It's a fact that the number of debris in the orbits are ever increasing (Fig.2).

Fig. 2



Sometimes an irresponsible conduct by a nation may create amount of debris in the outer space, for example in 2007 China experimented an Anti-Satellite Test (ASAT) by destroying its own weather satellite (Fengyun-1C) that created thousands of trackable debris and lakhs of tiny and untraceable debris pieces (Johnson et al., 2008). Most of these debris are circling as debris clouds in orbits around the Earth (David 2021). It was in the news recently, that in Kemya, a large metallic ring dropped from the space causing wide spread concerns. It was found by Kenyan Space Agency (KSA) during the investigation of the event that the ring was a debris which was a left-over rocket part that fell from the space during a launching activity. It is true that no harm to human life and property was caused due to the incident, but the event showed that even on earth there are dangers associated with space debris. Thus, making the space debris an imminent threat not only to the functional satellites but as environmental hazards on earth as well.

2.3. Sustainability of Outer Space for Human Needs

It is to be noted that that most important outer space resources are the 'Near-Earth Orbits' that consist of: i) Low-earth orbit (LEO), ii) Medium-earth orbit (MEO), and iii) Geo-synchronous orbit (GEO) (Popova & Schaus, 2018). Most of the human activities take place in the orbital region of the space, making it vulnerable for debris and associated risks. All kinds of man-made satellites such as for the purpose of communication, weather monitoring, surveillance, spying, navigation, earth imaging, etc. are orbiting in these orbits. Presently, there are 7560 operational satellites in the Earth's Orbits, of which 6768 are in LEO, 143 in MEO, 590 in GEO, and 59 are in elliptical orbits (Ustin & Middleton, 2024). It is to be noted that Debris in orbital space presents specific danger to active satellites. Thus, it poses an urgent challenge to the scientific and legal community and stakeholders of outer space exploration to come up with a sustainable solution. We know that most of the major functions of humans on Earth are now dependent on the manmade satellites navigating in outer space, and especially in the orbital space. Also, it has to be realized that orbits are limited resources in the sense that only a handful of orbits are accessible to humans. It is, therefore, necessary that debris created by human activities does not make the orbits unfit for navigation and use. Thus, orbital space must remain sustainable for future usage.

The debris is the real threat to the sustainability of orbital resources in particular and outer space as a whole in general. More debris means a greater threat of collision with operational satellites that will further trigger sustainability issues. Thus, an immediate long-term solution is needed for controlling as well as mitigating debris-related issues in outer space.

3. Framework of International Space Law to Address Orbital Debris Issue:

The UNOOSA is the primary UN body that has been tasked with promoting cooperation between and amongst various stakeholders for the peaceful usage of outer space. The Committee on the Peaceful Uses of Outer Space (UNCOPUOS) is the only General Assembly committee dedicated to outer space. It has developed a structured governance model divided into two specialized bodies: i) 'Scientific and Technical Subcommittee', and ii) 'Legal Subcommittee' (United Nations Office for Outer Space Affairs [UNOOSA], 2023). Beyond administrative oversight, UNOOSA is instrumental in helping nations bridge the technological gap through targeted training and capacity-building initiatives. Increasingly, the office has pivoted toward addressing existential orbital threats, actively coordinating global efforts to develop policy solutions for the escalating crisis of debris in the orbits.

Orbital Debris is one of the most crucial and urgent issues where the UNCOPUOS (with the help of UNOOSA) has been focusing its attention, especially in coordinating and framing space debris mitigation and minimization mechanisms.

3.1. Principles and Treaties under the 'International Space Law':

UN Resolution No. 1962 (XVIII) as adopted by the General Assembly in 1963 includes the fundamental principles on which the present International Space Law framework is based (United Nations, 1963). Some of the relevant principles are:

1. The 'use and application of outer space resources will be for the advantage of whole of the mankind'.
2. 'Outer space in general and celestial bodies in particular cannot be appropriated by claiming sovereignty, or by means of use or occupation, or by any other means'.
3. International law will be the 'guiding principle for the actions of States in the exploration outer space resources so as to maintain international peace and security, and also for building cooperation and trust'.
4. For 'both governmental and non-governmental entities actions in the outer space, the concern States shall bear the responsibility internationally'. The concerned 'State must authorize and supervise the activities by non-governmental entities so as to ensure the compliance of the principles enshrined in the Declaration'.
5. The 'jurisdiction and supervision' over any object that has been launched in the outer space will be of that State in whose registry the said object has been registered. It's the same for any personnel who is in the outer space for the time being.

The later structure of International Space Law was built on the premise of above-mentioned principles. The major part of the existing 'International Space Law' framework includes the set of Five International Treaties and Conventions formulated and adopted between the 1960s and 1980s, viz.:

i) 'Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, 1967' ('Outer Space Treaty');
ii) 'Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space, 1968' ('Rescue Agreement');
iii) 'Convention on International Liability for Damage Caused by Space Objects, 1972' ('Liability Convention');
iv) 'Convention on Registration of Objects Launched into Outer Space, 1976' ('Registration Convention');
v) 'Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, 1984' ('Moon Agreement').

These 'Treaties' along with the 'UN Resolutions' relating to outer space (such as the 'International Co-operation in the Peaceful Uses of Outer Space, 1961' and the 'Recommendations on national legislation relevant to the peaceful exploration and use of outer space, 2013'), and some other important Guidelines (such as 'Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, 2010') form the existing 'International Space Law (ISL) framework'.

Certain principles occurring in the ISL framework do have the potential to regulate activities of humans in outer space but the question is whether these are adequate to also govern the legal and technical issues arising out of the problem of 'Orbital debris'. It is suggested that their applicability to space sustainability issues needs further clarification and strengthening.

3.2. International Treaties and Space Debris Mitigation:

International Space Law designates outer space and celestial bodies the status of a global commons-a domain beyond national jurisdiction that is not subject to national sovereignty (Popova & Schaus 2018). The Preamble to the Outer Space Treaty (OST) governing the Law of Space aims that the "exploration and use of outer space" are to be "for the benefit of all peoples". Thereafter, Article I reiterates the intentions stated in the Preamble by stating that "the exploration and use of outer space shall be carried out *for the benefit and in the interests of all countries*, irrespective of their degree of economic or scientific development, and shall be the *province of all mankind* (OST, 1967).

The expression 'province of mankind' is one of the most significant principles of space exploration. It is difficult to ascertain the entire scope of the 'expression'. But it's not in doubt that one of the meanings of this is that all states, without the consideration of their economic or technological advancement, are equally free to explore and use the resources of outer space. This freedom includes accessibility to outer space resources including in the Earth's orbits.

Therefore, it is argued that the access to space resources must be secured not just in the short term but also for the long term. It is more so as human dependence on outer space is set to grow in the near future. As a result, space operations are required to be sustainable for their usage and exploration.

Thus, it is pertinent to note that in order to achieve sustainability in outer space including in the Earth orbit, International Space Law will have to be evolved with respect to two broader legal issues (Popova & Schaus, 2018):

i) Firstly, legal rights and obligations of the states to take 'preventive measures' that will address the risk posed by Orbital debris, and

ii) Secondly, *w*ith regard to 'legal consequences' in case such a risk actually manifests.

The first issue includes legal issues such as the legality of producing Orbital debris and obligations to mitigate and remediate the same. The second one mainly raises questions with respect to responsibility and liability for harm/damage caused by Orbital debris.

'Article IX' of the Outer Space Treaty (1967) provides for the "avoidance of harmful contamination of outer space due to human exploration" and requires "States to conduct activities with due regard to the interests of other States and to prevent harmful interference". It entails the "idea that there shall be protection of space activities from all forms of interference that might harm and pose risks to other States". Similarly, Article II of the Convention on International Liability for Damage Caused by Space Objects (1972) - commonly known as the Liability Convention - provides for absolute liability in cases where a space object causes damage on the Earth's surface or to aircraft, while Article III establishes fault-based liability for damage occurring elsewhere, such as in outer space. However, further examination is required to ascertain whether the term "space object," as used in the Liability Convention (1972), includes orbital debris as well.

Other than the current scientific and legal debates, the 'recovery and return of orbital debris' is a core obligation found in the 'Rescue Agreement' (1968). Under this framework, the States are legally obligated to return any 'foreign' space objects found within their jurisdiction to the original owners. The treaty also mandates that states must officially bring the it to the notice of the 'Secretary-General' of the United Nations whenever such objects are discovered, ensuring a transparent process for the repatriation of space hardware.

3.3. International Space Law Guidelines and Standards with regards to Space Debris:

Though, the UN Guidelines provides for "*a prudent and necessary step towards preserving the outer space environment for future generations",* its effectiveness is debatable because it lacks binding character.

The UNOOSA has been working to strategize ways and means of 'preventing and minimizing the creation of 'space debris'. It is required that every year, all the space faring States and organizations must share information relating to their research on issues of space debris with the UNCOPUS's 'Scientific and Technical Subcommittee'. One of the most significant outcomes of these discussions has been a set of guidelines known as "Space Debris Mitigation Guidelines", which was approved by the UN GA in 2007.

Apart from, scientific research and deliberations, the UNCOPUS's Legal Subcommittee also discusses the 'legal aspects of space debris' mitigation measures regularly. As a result, a 'compendium of space debris mitigation standards' has been prepared by UNOOSA, and the same has been made available through it's website.

3.4. Compendium of space 'debris mitigation' standards

In order to address the growing problems of debris, a few international institutions have come up with certain mitigation guidelines:

1. Committee on the Peaceful Uses of Outer Space (COPUOS): Space Debris Mitigation Guidelines (UNCOPUS, 2010)
2. Inter-Agency Space Debris Coordination Committee (IADC): Space Debris Mitigation Guidelines (IADC, 2020)
3. International Telecommunications Union (ITU): Recommendation ITU-R S.1003.2 (ITU, 2010)

The above-mentioned treaties, resolutions and guidelines only go half ways to creating national and international space legal regimes that will help address 'debris issues' in the coming years. The commercial interests, and also the risks redressals are not directly addressed in these treaties or guidelines (Hurtzfeld 2009).

4. CONCLUSION AND EMERGING WAY FORWARD:

From the above analysis it can be seen that neither the Treaties nor the 'Debris Mitigation Guidelines', expressly prohibit the creation of Orbital debris. Also, these frameworks do not even make it *obligatory* on the states and their space actors to Mitigate or Remediate debris from the Earth orbit. The problem of Orbital debris is so imminent that we urgently need concrete and binding ways of action such as 'Active Debris Removal' (ADR) or 'Remediation' along with the technique of Mitigation.

The frameworks of the 'Space Debris Mitigation Guideline' have no legally binding provisions under the International Space Law (ISL) to ensure obligation with regard to 'non-creation' of orbital debris. Also, the Liability Convention, 1972 as part of the ISL does not provide any specific solution in case debris collides with active satellites and causes destruction of the satellite and in turn creates a large amount of new debris. It is clear that the mass of debris orbiting the Earth poses a very substantial risk to the sustainability of future space explorations. Thus, a long-term strategy is needed to address the problems associated with space debris, especially for making usage of space resources sustainable for SDGs on Earth.

In the recent past several new approaches both technical and legal, have started to take shape, such as the shielding of spacecraft through innovative technologies so as to minimize debris creation, active debris removal technologies, and debris mitigation and remediation guidelines. But the question remains that despite these measures the rate of creation of debris has not reduced, which poses a prominent challenge to the stakeholders of space exploration.

The world is facing new challenges due to large-scale commercialization of space activities. Thus, the problems linked with space debris have to be seen in the larger context of space governance also. In that both public and private players are held equally responsible for maintaining the sustainability of outer space for the benefit of human beings. At present the space debris mitigation is not a clear legal duty but depends on voluntary action albeit that individual space agencies do seek to conform to the Space Debris Mitigation Guidelines (Lyall & Larsen 2020).

As per the opinion of the authors here, the following may be the future course of action to address the issues relating to 'orbital debris':

i) Legally binding Treaty or amendments in the already existing treaties:

From the time of the Moon Treaty, which came in the year- 1984, no other legally binding treaty was brought into force in under the ambit of Space Law. This is, perhaps one of the major issues in the era of commercial space exploration as the space actors do not feel obligated to enforce debris mitigation measures. During the last four decades, one can find only guidelines, regulations or other non-binding instruments being framed by various international institutions. However, these all have been insufficient in controlling and mitigating space debris. It is suggested that a separate Treaty can be framed which shall deal with varied facets of Space Debris problems including the aspects of commercialization as well. In the alternate, it is suggested that changes/amendments can be made to the existing Treaties.

ii) Larger Issue of 'Space Governance':

'Space governance' is a larger issue that includes the problem of 'orbital debris' as well as it concerns the regulation mechanism of outer space. In this wider context, proper governance of the outer space activities can happen only when international space law instruments are ratified and accepted by the states in a uniform manner. As per the present situation it can be seen that a lot of variations are there in ratifications. For

instance, as of January 2024, the OST has been ratified by 114 nations whereas the 'Registration Convention' by 74 nations and the Moon Treaty only by 17 (UN COPUS, 2024). It is to be noted that each Treaty deals with at least one basic principle for space activities as contained in the Resolution No. 1962 (XVIII) and the OST. Thus, for the effective governance of outer space, equal importance to all the principles are necessary and that can be achieved only when all the nations give equal weightage to principal international space law instruments.

iii) Domestic Legislation:

Due to rapid commercialization of space exploration, it is necessary that all the space-faring nations must have corresponded national legislation. The importance of national space legislation cannot be emphasized more as it is primarily the concerned state that grants permission to private players to get involved in space explorations. If the state did not have domestic legislation governing the space activities then it would be difficult to fasten any liability to the private entity in cases of debris creation and collisions, if any. India is one notable example which despite being one of the foremost space powers, does not have national space legislation making it vulnerable to any unforeseen events and consequences thereof.

iv) Applicability of Sustainability Principles in Space Exploration:

It is not yet fully established that principles of environmental sustainability such as 'polluter pays', 'precautionary principle', and 'inter & intra-generational equity' principles are applicable in the domain of ISL as well. It is suggested that these principles have to be adopted as part of space exploration since space is no longer an alien territory and has become very much part of the Earth's environment.

v) Techno-Legal Solutions:

Prevention is better than cure. In the last few decades, scientific and technical advancements have made possible the development of such technologies which are helpful in mitigating the chances of debris creation in space launches. In order to eliminate the challenges which are emanating from space debris coordinated efforts of all stake holders are required. Legal framework in silos cannot provide apt solutions rather syntheses of Law and Technolgy can be a amicable solutions for the same. Thus, debris mitigation technologies must be made mandatory through a legally enforceable instrument.

vi) Environment Impact Assessment:

The principle of 'Environment Impact Assessment' could be made mandatory for all space activities in the outer space. This will have the effect of fastening the liability for harms done to the space environment, and, in-turn, ensure sustainability for the future of mankind.

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