



WHITE PAPER: THE HIDDEN COSTS OF THE SPACE ECONOMY — SPACE DEBRIS, ENVIRONMENTAL DEGRADATION, AND THE GLOBAL RESOURCE CHAIN

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Executive Summary

The global space economy, which underpins communications, navigation, defense, and environmental observation, has grown exponentially in recent years. Yet beneath its technological success lies a complex web of costs extending from Earth's ecosystems to orbit itself.

The extraction of rare and strategic minerals in the **rainforests of West Africa**, the **salt flats of Bolivia**, and the **coastal dunes of South Africa's iSimangaliso Wetland Park**, to name just a few examples, has become crucial to sustaining satellite production. These activities are destroying biodiversity hotspots and intensifying climate disruption. Meanwhile, the accumulation of **space debris**—a cloud of metallic fragments circling Earth—has created a new frontier of environmental risk.

This white paper explores how these challenges are intertwined, showing that the unsustainable material practices behind orbiting technologies carry planetary consequences. It concludes that the transition to a truly sustainable space era requires integrating environmental accountability, circular design principles, and global cooperation at every level of the space value chain.



1. Introduction:

The Expanding Satellite Economy civilization has never been more dependent on satellites. More than ten thousand orbit the planet, supporting communications, data networks, navigation, trade, and defense. Within the next decade, tens of thousands more are expected to join them.

However, behind every launch lies a material story. Satellites and rockets rely on energy-intensive metals and minerals that are mined, processed, and transported across the world. The benefits of connectivity, data access, and security are inextricably linked to the depletion of natural reserves and the degradation of ecosystems that are fundamental to life on Earth.

For a detailed trend of countries in space activity please refer to **ANNEXURE A – GLOBAL SPACE ACTIVITY AND DEBRIS PRODUCTION** and for an overview of regulation and governance related to space debris, please refer to **ANNEXURE B – KEY LEGAL FRAMEWORKS APPLICABLE TO SPACE DEBRIS**.

2. The Terrestrial Cost of Space Infrastructure

2.1. Mining in the Rainforests of West Africa

In the tropical rainforests of Guinea, Liberia, and Ghana, the push to supply global demand for aluminum, tantalum, and rare earth metals has accelerated in step with the growth of the aerospace and electronics industries. These forests—among the most biologically diverse on the planet—are being cleared for open-pit mines whose waste is altering river courses and contaminating waterways. The loss of tree cover has disrupted regional rainfall patterns and weakened the forests' ability to absorb carbon, contributing to higher local temperatures and more frequent droughts. The consequences are not confined to West Africa; the loss of these carbon sinks alters global atmospheric balances, linking satellite production to planetary heating.

2.2. Lithium Extraction in the Bolivian Salt Flats

The world's appetite for lithium, a cornerstone of battery production, has positioned Bolivia's **Salar de Uyuni** as a focal point of extraction. Beneath its shimmering surface lies a reserve thought to contain one-fifth of global supply. Extracting this lithium requires massive quantities of brine—nearly two million liters per ton—drained from an already arid landscape. Wetlands dry, flamingo populations decline, and surrounding Indigenous communities find their freshwater tables diminishing. This cycle of exploitation underscores a troubling irony: in pursuit of technologies hailed as the backbone of a cleaner, more connected world, humanity is depleting essential water resources in one of Earth's most fragile ecosystems.



2.3. Titanium Mining in South Africa's iSimangaliso Wetland Park

Further south, South Africa's iSimangaliso Wetland Park—a UNESCO World Heritage Site—faces potential disruption from titanium sand dune mining. The park is internationally recognized for its mosaic of wetlands, forests, and lagoons, home to species found nowhere else on Earth. Titanium extracted from nearby coastal dunes is a vital input for satellites and rocket systems due to its strength and heat resistance. Yet mining these dunes could permanently alter coastal defenses, increase vulnerability to storm surges, and damage the marine ecosystems that sequester significant quantities of “blue carbon.” The disturbance of such a valuable natural system represents a direct contradiction to global commitments under the Paris Agreement and the Convention on Biological Diversity.

These are merely three examples, but there are several more that could be brought to the surface as use cases and evidence.

3. Orbital Pollution: The Expanding Threat of Space Debris

Space debris—commonly referred to as orbital junk—has become one of the fastest-growing forms of environmental pollution. **Yet, countries collect little to no systematic data on this issue, and it remains outside any established UN statistical frameworks or national statistical office (NSO) reporting requirements.** Earth's orbit is now densely populated with obsolete hardware: defunct satellites, spent rocket stages, discarded tools, and countless fragments from past collisions. These objects travel at tremendous speeds, colliding and shattering into still smaller pieces, thereby accelerating a self-perpetuating cascade of debris known as the *Kessler Syndrome*.

The metallic composition of this debris reveals the technological legacy of the space age. The bulk of it—around sixty percent—is made up of aluminum alloys, used for lightweight structural panels and fuel tanks. Roughly twenty percent consists of titanium and steel, sourced primarily from engine casings and fasteners, while another ten percent is composed of copper and specialty alloys critical for electrical systems. The remainder includes high-performance metals such as tungsten and molybdenum, along with nonmetallic materials like carbon fiber composites and heat-resistant foils.

These fragments do not merely float harmlessly in space. They pose an increasing collision hazard to operational spacecraft, including those monitoring Earth's climate and biodiversity. Moreover, some larger pieces eventually re-enter Earth's atmosphere, occasionally landing in populated areas. The line between orbital safety and public safety is now alarmingly thin.



4. Global Circularity and Resource Inefficiency

The space industry has developed largely within a linear model of production: materials are extracted, engineered, launched, and ultimately discarded. Once in orbit, few satellites are designed with retrieval or reusability in mind. Less than ten percent of spacecraft material ever returns to Earth, and almost none is recycled. The enormous energy invested in producing these components—and the environmental cost of the mining that supplies them—remains permanently locked in orbit or burns during atmospheric re-entry.

Circular design principles are virtually absent. Components are not standardized for reuse, and there are no universal regulations requiring manufacturers to recover or repurpose materials after a mission ends. This inefficiency extends beyond orbit: new mineral frontiers continue to expand across tropical forests, wetlands, and deserts to meet demand for metals that could otherwise be reused.

The result is a broken material loop in which the benefits of advanced technology are purchased at the expense of finite planetary resources. **Unless data is collected on these issues and circularity principles becomes a central criterion in satellite design and mineral governance,** space activity will remain an **extractive process that intensifies global inequality and environmental decline.**

5. Shared Planetary Risk: Why This Matters to All Nations

The consequences of these trends extend well beyond countries with space programs, as outlined in **ANNEXURE B**. Every nation, regardless of its technological capacity, depends on the same interconnected environmental systems. When forests are cleared for bauxite and copper, when salt flats are drained for lithium, and when wetlands and coastal dune forests are stripped for titanium, the global atmosphere and biosphere lose their capacity to regulate temperature, store carbon, and shelter diverse forms of life.

As deforestation and ecosystem loss accelerate, the Earth's climate systems become increasingly unstable. Heatwaves grow longer and more intense, droughts deepen, and hurricanes and cyclones strike with greater force. The disappearance of natural buffers such as mangroves, coral reefs, floodplains, and wetlands removes vital protections, leaving coastal and riverine communities more vulnerable to flooding, storm surges, and erosion. At the same time, ecological disruption alters the distribution of pathogens and their carriers, driving the spread of vector-borne, tropical, water-borne, and zoonotic diseases into new regions and populations. What were once localized health risks are now emerging as global public health challenges intertwined with environmental decline.

These changes drive economic instability and human insecurity everywhere. The degradation tied to space resource extraction and orbital waste is therefore a planetary issue. The benefits of space must be weighed not only in strategic terms but in planetary sustainability terms—because no nation is sheltered from an unstable Earth system.



6. Toward Planetary Stewardship

The future of the space economy depends on reframing its relationship with Earth's material and ecological boundaries. **International** and **UN frameworks** must evolve to ensure that space technologies are both **sustainable** and **circular**.

This means holding companies and countries accountable for tracing the metals used in spacecraft to their environmental origins and requiring every satellite project to include a robust end-of-life plan. Launch licensing should consider not only safety and trajectory but also the full environmental footprint of materials extraction, manufacturing, and disposal. Technologies for active debris removal must be accelerated through public-private partnerships and global incentives, and may require updates to existing treaties (refer to **ANNEXURE B**).

Equally vital is the development of global standards for responsible mineral sourcing, building on the work of the United Nations Environment Programme, the International Energy Agency, and the Ellen MacArthur Foundation. Integrating these efforts into existing frameworks under the **Committee on the Peaceful Uses of Outer Space (COPUOS)** and the **UN Framework Convention on Climate Change (UNFCCC)** can ensure that managing orbital debris and protecting Earth's ecosystems are recognized as complementary elements of planetary governance.

7. Conclusion

The achievements of the space age represent some of humanity's greatest technical triumphs, yet their foundations rest on a material footprint that threatens the stability of the planet they aim to observe and protect. **The chain linking mineral extraction, ecological loss, orbital pollution, and climate instability is undeniable and urgent.**

A sustainable space future demands new forms of responsibility — a commitment to circular design, ethical resource governance, and active remediation both on Earth and in orbit. Only by aligning technological innovation with ecological integrity can we ensure that the expansion of civilization into space does not compromise the survival of life on the planet that made it possible.

The mission to protect Earth must begin by cleaning our skies—and by recognizing that the sustainability of space and Earth are one and the same.

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ANNEXURE A –

GLOBAL SPACE ACTIVITY AND DEBRIS PRODUCTION

As of **2025**, about **80–90 countries** are formally engaged in some form of **space activity or program**, though the scale and capability vary dramatically — from full-fledged launch nations to emerging participants focused on research, education, or satellite data use.

Below is a structured summary, ranked by **level of capability and program scale** (from largest and most advanced to smallest/emerging).

1. Major Comprehensive Space Powers

These countries have full-spectrum capabilities — launch vehicles, human spaceflight, planetary missions, and manufacturing industries.

Rank	Country	Key Capabilities
1	United States	Full launch capability, human spaceflight (NASA, SpaceX), interplanetary missions, global satellite network.
2	China	Human spaceflight, independent space station, lunar and Mars missions, multiple domestic launch sites.
3	Russia	Long-standing launch and human spaceflight legacy, major provider of launch services, planetary missions.
4	European Union / ESA Member States	Joint capabilities through the European Space Agency (ESA); launch vehicles (Ariane, Vega), Earth observation and planetary missions.
5	India	Independent launch capacity, lunar and Mars missions, growing commercial sector (ISRO, NSIL).
6	Japan	Advanced launch vehicles, asteroid return missions, lunar programs, and large satellite industry.

2. Intermediate and Regional Launch Nations

These countries have developed **independent launch vehicles** or extensive orbital program infrastructure.

Rank	Country	Capabilities
7	Iran	Indigenous satellite launches, expanding rocket technology.
8	Israel	Independent launch capability (Shavit rocket), advanced satellite technology.
9	South Korea	Domestic launch vehicle (KSLV-II), lunar orbiter program.
10	North Korea	Limited but demonstrated orbital launch capability.

3. Established but Non-Launch Space Agencies

These nations operate **national space agencies or space programs**, often relying on foreign launch partners.

Includes about **30–35 countries**, of which the most active are: **Canada, Australia, Brazil, United Kingdom, United Arab Emirates, Saudi Arabia, Pakistan, Turkey, Italy, Germany, France** (individually within ESA), **Argentina, Mexico, Nigeria, Egypt, South Africa, Indonesia, Malaysia, Vietnam, Thailand.**

These states design and operate satellites, host ground infrastructure, and fund research but typically launch via the U.S., Europe, or India.

4. Emerging and Developing Space Programs

Roughly **40 additional countries** have **nascent or emerging space programs**, often established within the past decade. These focus on remote sensing, telecommunications, or capacity building through collaboration with the UN Office for Outer Space Affairs (UNOOSA).

Examples include: **Kenya, Ghana, Angola, Ethiopia, Rwanda, Sudan, Bangladesh, Nepal, Laos, Colombia, Peru, Chile, New Zealand, Luxembourg, Norway, Finland, Poland, Czech Republic, Romania, Hungary**, and several **Pacific Island nations** via regional constellations.

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Summary by Tier (Approximate Numbers, 2025)

Capability Tier	Description	Number of Countries
Full Launch & Human Spaceflight	Advanced, independent, global programs	~6
Independent Launch without Human Spaceflight	Regional or strategic launch capacity	~4–5
Operational National Space Agencies	Satellite operators, ESA members, active research	~30–35
Emerging / Developing Programs	Early-stage, academic, or cooperative programs	~40–45
Total		≈ 85–90 nations

Key Insight

The rapid growth in national space programs—rising from fewer than 20 in the 1980s to nearly 90 by 2025—means **orbital traffic and debris are no longer dominated by a handful of powers**.

Space governance, therefore, must evolve from a “superpower framework” into a **truly multilateral system** where both large and emerging nations share accountability for sustainable orbital practices.

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ANNEXURE B –

KEY LEGAL FRAMEWORKS APPLICABLE TO SPACE DEBRIS

1. The Outer Space Treaty (1967)

The **Outer Space Treaty of 1967**, formally known as the *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies*, is the foundational framework for international space law. Adopted by the United Nations, it establishes space as the **province of all humankind**, prohibiting any nation from claiming sovereignty over outer space or celestial bodies. The treaty also bans the placement of **nuclear weapons or other weapons of mass destruction in orbit**, limits the use of the Moon and other celestial bodies to peaceful purposes, and holds states **responsible for national space activities**, including those of private entities. With over 110 signatories, it remains the cornerstone of global governance for the peaceful, cooperative, and responsible use of outer space.

While it predates the modern debris crisis, several of its articles are directly relevant:

- **Article VI:** States are internationally responsible for national space activities, whether conducted by government or private entities. This establishes clear state accountability for debris created by domestic operators.
- **Article VII:** States are **liable for damage** caused by their space objects. If debris re-enters Earth's atmosphere and causes harm or damage, the launching state bears responsibility.
- **Article IX:** Requires states to conduct activities "with due regard to the corresponding interests of all other States Parties," implying a duty to minimize harmful contamination of outer space — a principle now interpreted to include debris mitigation.

Although the OST does not explicitly mention *space debris*, it forms the normative bedrock upon which later guidelines are built.

2. The Liability Convention (1972)

Formally known as the **Convention on International Liability for Damage Caused by Space Objects**, this treaty operationalizes Article VII of the OST. It establishes two regimes of liability:

- **Absolute liability** for damage caused on Earth or to aircraft in flight — meaning a launching state must pay compensation regardless of fault.
- **Fault-based liability** for damage to another state's property or personnel in outer space.



This framework is crucial for debris that falls from orbit and causes harm on Earth. However, proving *fault* for debris-on-debris collisions in orbit remains extremely difficult, revealing the limits of the Convention in modern contexts.

3. The Registration Convention (1976)

The **Convention on Registration of Objects Launched into Outer Space** requires states to **maintain national registries of all space objects and report them to the United Nations**. This is critical for tracking ownership and attribution when debris causes damage or collision risks. It helps establish which state is the "launching state" responsible under liability principles.

4. The UN Space Debris Mitigation Guidelines (2007)

Adopted by the **United Nations Committee on the Peaceful Uses of Outer Space (COPUOS)**, these **non-binding** guidelines represent the international consensus on debris prevention. They include measures such as:

- Post-mission disposal of satellites and rocket stages.
- Re-entry design guidelines to minimize ground harm.
- Avoidance of intentional breakups or explosions in orbit.

While not legally binding, many states have incorporated these principles into **national space legislation** (for example, the U.S. Orbital Debris Mitigation Standard Practices and the EU Space Surveillance and Tracking Framework).

5. The Long-Term Sustainability (LTS) Guidelines (2019)

Developed under **COPUOS**, these guidelines extend beyond mitigation to governance — urging transparency, sharing of orbital data, and cooperation to reduce collision risk.

They emphasize **sustainability of space operations** as part of the global commons, reinforcing state responsibility and "due regard" principles under the OST.

6. Customary International Law and Environmental Principles

Several environmental law norms are increasingly being applied *by analogy* to orbital debris:



- **The "no harm" principle** — states must prevent activities within their jurisdiction from causing environmental harm to other states or to areas beyond national jurisdiction.
- **The precautionary principle** — a duty to act to prevent potential harm even when scientific certainty is incomplete.
- **The polluter pays principle** — the producer of waste (debris) should bear the cost of mitigation and cleanup.

These principles, rooted in instruments like the **Rio Declaration (1992)**, are gaining traction in space law discourse.

7. National Space Legislation

Because international treaties rely on national implementation, many states have enacted or updated domestic laws to govern debris management.

Examples include:

- **United States:** 51 U.S.C. §50905 (commercial launch licensing) and NASA's **Orbital Debris Mitigation Standard Practices**.
- **European Union:** **EU Space Surveillance and Tracking Framework** and the **European Space Agency's Clean Space Initiative**.
- **Japan, Australia, and the UK** also have licensing regimes requiring compliance with debris mitigation standards.

Summary

Legal Instrument	Status	Relevance to Debris
Outer Space Treaty (1967)	Binding	Foundational obligations and due regard principle.
Liability Convention (1972)	Binding	Defines state liability for damage caused by debris.
Registration Convention (1976)	Binding	Enables assignment of responsibility and tracking.
UN Debris Mitigation Guidelines (2007)	Non-binding	Establishes international best practices.
LTS Guidelines (2019)	Non-binding	Expands to long-term sustainability and cooperation.
Environmental law principles	Customary	Extends "no harm" and "polluter pays" duties to space.



In essence: Space debris law today rests on a **patchwork system** — binding treaties that assign responsibility and liability, supplemented by **soft law guidelines** that define best practices. Because most debris resides in Earth’s orbit (a global commons rather than national territory), enforcement still relies on **good-faith compliance, data sharing, and evolving norms of environmental stewardship** rather than direct legal sanctions.

8. Future Directions: Emerging Legal and Policy Frameworks

While current space law provides a foundation of accountability and cooperation, it remains insufficient to address the accelerating scale of orbital congestion and debris generation. In recent years, policymakers, legal scholars, and international organizations have advanced a range of proposals to strengthen governance and embed sustainability within the legal structure of space operations.

One of the leading ideas is the creation of a **dedicated Space Traffic Management (STM) regime**. This framework would operate much like international civil aviation agreements, establishing shared standards for orbital coordination, collision avoidance, and proximity operations. Under such a system, all spacefaring nations and private actors would adhere to a unified set of guidance norms—potentially administered through an international registry and technical data exchange center. The International Telecommunication Union (ITU), which already coordinates orbital slots for communications satellites, is often cited as a model for implementing STM through multilateral cooperation.

Another proposal gaining traction is the development of an **Orbital Debris Convention**—a new treaty specifically focused on debris mitigation, remediation, and accountability. This instrument could codify duties of prevention, establish financial or insurance mechanisms for debris removal, and formalize the **“polluter pays” principle** within the context of orbital environments. Provisions might include obligations for mission-end disposal, extended producer responsibility for satellite manufacturers, and shared funding of international active-debris-removal (ADR) services.

Some experts have also proposed expanding the **Liability Convention** to address new realities in the commercial space economy. This might involve introducing proportional liability for multi-party launches, no-fault compensation funds for damage from unidentified debris, or arbitration mechanisms to resolve disputes more efficiently.

In parallel, space agencies, private companies, and the United Nations Office for Outer Space Affairs (UNOOSA) are exploring **“rules of the road”** for sustainable operations—voluntary commitments that could evolve into customary international law through consistent state practice and repetition. Such norms may require disclosure of end-of-life plans, environmental impact assessments for launches, and standardized identification markings on all orbital objects.

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Ultimately, the long-term goal is to move beyond mitigation and toward **active environmental management of near-Earth space**—treating Earth’s orbital zones as an integral part of the planetary ecosystem. A binding international agreement that integrates space sustainability into global climate and environmental frameworks, perhaps under the coordination of **COPUOS, UNEP, and the UNFCCC**, would represent the next milestone in ensuring that exploration beyond our atmosphere remains consistent with environmental responsibility on Earth itself.

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