Ethical Pathways to Integrate Earth and Space Economies 2025

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Abstract

As the global space economy accelerates, its potential benefits remain out of reach for many, reinforcing economic and technological disparities and mirroring long-standing geographic inequalities. Despite the increasing involvement of private firms and emerging technologies lowering the cost of space access, fundamental barriers still exist for developing nations and non-STEM communities. These inequalities reflect not only a lack of technical infrastructure but also disparities in legal recognition, access to radio frequency spectrums, and resource control rights.

This paper will argue that integrating ethical governance, equitable access, and public-private collaboration into space economic development is critical for shaping a sustainable Earth-Space economy. In particular, this research explores how hybrid frameworks–such as Decentralized Autonomous Organizations (DAOs) and public-private research and development partnerships (PPRDPs)- can allow small companies and emerging nations to meaningfully contribute to and benefit from the space economy. It will also propose international agreements for dynamic spectrum management to alleviate congestion in the radio frequency (RF) system, one of the unexpectedly great technological bottlenecks of space exploration.

Through a multidisciplinary lens, this paper evaluates the gaps in current international space law–particularly the Outer Space Treaty of 1967–and analyzes the risk of monopolization in the absence of enforceable equity standards. Acknowledging that the proposed frameworks are idealistic and cannot fully solve ethical and logistical challenges, this paper aims to propose a practical yet aspirational roadmap toward a more inclusive, globally cooperative space economy. At its core, it argues that an ethical and circular approach to the space economy is not a matter of justice but a necessity for long-term economic resilience and environmental stewardship.

Introduction

The rapid expansion of commercial space activity has transformed space from a domain of national prestige to a frontier of global economic opportunity. With launch costs plummeting and the number of private actors growing, the space economy is now valued at over $546 billion and is projected to exceed $1 trillion by 2040 (New Space Economy, 2024) (See Figure 1). Yet, access to this expanding domain remains uneven. Technological, economic, and legal barriers disproportionately exclude non-STEM communities, developing nations, and smaller enterprises from meaningful participation in space ventures. The result is a concentration of benefits among a narrow group of corporations and governments, risking the creation of a "space divide" analogous to the digital divide that emerged in the early internet era.

This paper addresses a central challenge: How can the economic and technological growth associated with space exploration be integrated into global systems in a way that reflects ethical values, promotes inclusivity, and ensures long-term sustainability? In response, it presents a framework that combines circular economic principles with public-private research and development partnerships (PPRDPs) to create a more accessible, balanced, and accountable space economy. This dual approach aims not only to mitigate emerging inequities but also to foster innovation, distribute value for equitably, and enhance international collaboration.

The following sections will examine the historical context of the space economy, analyze current obstacles to equitable access, evaluate existing legal and ethical frameworks, and propose a circular economic model supported by collaborative research and transparent government mechanisms. Counterarguments and limitations of this approach will also be discussed, acknowledging that no angle model can address all concerns in such a complex and evolving field. Nevertheless, the proposed framework offers a forward-looking foundation for policymakers, researchers, and entrepreneurs to consider as they shape the future of space resource development and integration with Earth-based economies.

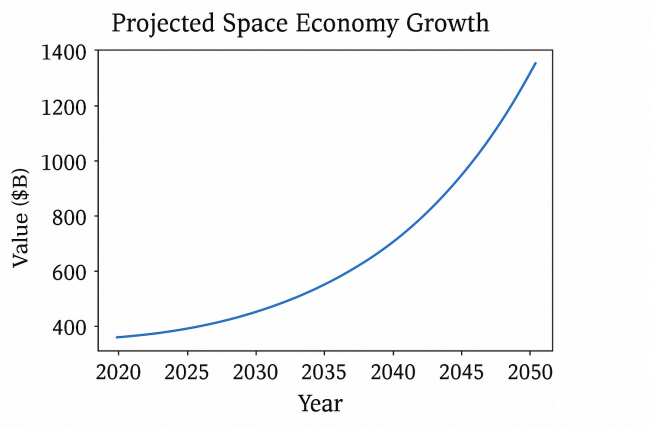


Figure 1-Projected Space Economy Growth Chart, 2020-2040 (Source: The New Space Economy, 2024)

The Rise of the Space Economy

The evolution of space activity from Cold War-drivel national prestige projects to commercialized ventures reflects a shift in both technological capability and economic motivation. During the mid-20th century, space exploration was largely dominated by state-funded programs, such as NASA and the Soviet space agency, which prioritized scientific discovery and geopolitical dominance. These programs, while symbolically powerful, were often disconnected from broader economic structures and lacked mechanisms for distributing their benefits beyond elite institutions and national interests.

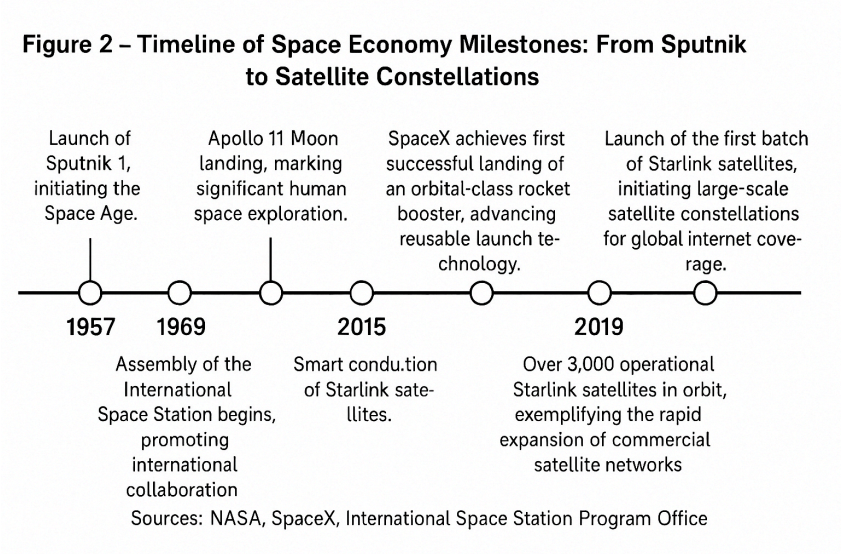
Today, the space economy has entered a new phase. Declining launch costs, advancements in reusable rocket technology, and the influx of private investment have made space more economically viable than ever before. Companies such as SpaceX, Blue Origin, and Planet Labs exemplify this transformation, developing everything from satellite constellations to lunar landers. SpaceX alone has reduced the cost per kilogram to low-Earth orbit by over 90% compared to the Space Shuttle era, enabling greater frequency of missions and broader applications for satellite technology (PNAS, 2023).

However, lower costs have not translated into universal access. The ability ti participate in and benefit from the space economy remains concentrated among a small set of actors with the capital, infrastructure, and legal frameworks necessary to operate in this domain. While commercialization has introduced new efficiencies and accelerated innovation, it has also amplified existing inequalities. For example, the radio frequency (RF) spectrum–a finite resource essential for satellite communication–is becoming increasingly congested. Private companies often gain preferential access, sidelining smaller firms and nations that lack comparable technological leverage or legal representation. Moreover, infrastructure challenges continue to limit participation. Many resource-rich but technologically underdeveloped countries are excluded from meaningful roles in space activity despite having much to gain. This mirrors historical patterns of extractive economic models on Earth, where access to capital and infrastructure determined who could exploit resources and who remained dependent on external

actors. Without intentional efforts to include emerging economies and smaller enterprises, space risks becoming yet another arena in which global disparities are reinforced rather than reduced.

While some argue that market-driven expansion allows for rapid development and innovation, others highlight the necessity of public oversight and ethical governance to ensure that space remains a shared domain. As one study notes, public-private coordination is essential for guiding investment toward projects that generate long-term economic activity rather than only short-term profits (New Space Economy, 2024). (See Figure 2)

Figure 2 - Timeline of Space Economy Milestones: From Sputnik to Satellite Constellations (Source: Stanford Emerging Technology Review, 2024)



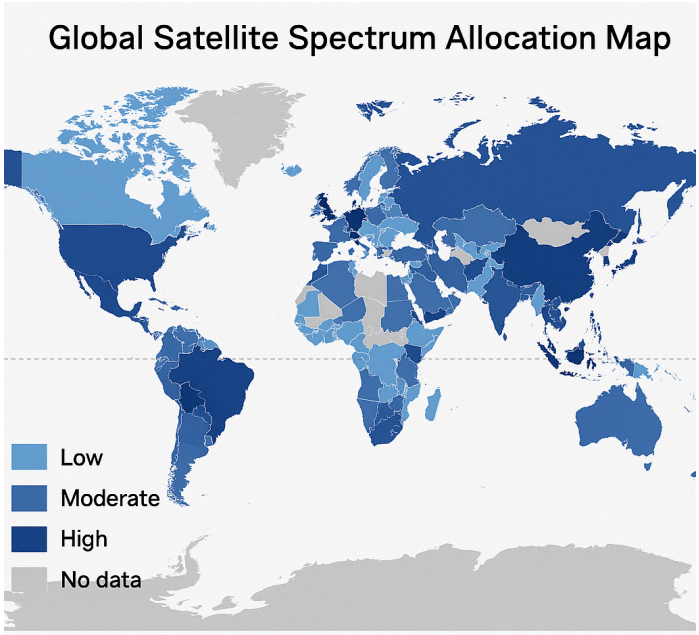
Barriers to Access

While the momentum of space commercialization presents new opportunities, structural and systematic barriers continue to hinder equitable participation and must be examined comprehensively to understand the full scope of exclusion within the current space economy.

At the legal level, space remains governed by a patchwork of outdated and incomplete treaties, most notably the Outer Space Treaty of 1967. While the treaty emphasizes non-appropriation and peaceful use, it lacks clear enforcement mechanisms or pathways for equitable benefit-sharing. Ambiguities around property rights, resource extraction, and liability make it difficult for emerging nations and small enterprises to engage confidently in long-term planning or investment. Furthermore, newer commercial entrants often operate in legal gray zones, exploiting regulatory gaps that favor wealthier, technically advanced actors.

Technological barriers include access to launch services, satellite manufacturing capabilities, ground station networks, and digital infrastructure. Countries with limited access to high-speed internist, advanced computing resources, or skilled labor in aerospace engineering are functionally excluded from meaningful space participation. The cost of acquiring, licensing, and coordinating use of RF spectrum licenses to launch domestic systems (International Telecommunications Union, 2022) (See Figure 3).

Politically, power dynamics shape the rules of access. Global North countries, often aligned through multilateral agreements like the Artemis Accords, are positioned to define standards and norms in the absence of universal governance. Meanwhile, many resource-rich but economically marginalized nations are left without representation in critical decision-making bodies such as the International Telecommunication Union or the UN Committee on the Peaceful Uses of Outer Space (COPUOS). This discrepancy perpetuates a cycle where access to space is mediated through pre-existing geopolitical hierarchies.



Private capital also plays a gatekeeping role. Much of the venture capital and government funding flows toward firms already located in the United States, European Union, or China. As smaller firms attempt to innovate in areas such as orbital debris cleanup, small-satellite constellations, or lunar payload delivery, they encounter difficulties in securing long-term investment or technology-sharing partnerships.

Figure 3 - Global Satellite Spectrum Allocation (Source: ITU Policy Brief, 2022)

These overlapping barriers create a feedback loop: Without inclusion, there is limited visibility; without visibility, there is limited support; without support, participation remains inaccessible. Addressing these issues requires more than technical fixes–it demands a

reevaluation of how participation, innovation, and governance are defined within the space economy.

Existing Legal and Ethical Frameworks

The foundational legal structure for governing outer space, the Outer Space Treaty (OST) of 1967, was crafted in an era of geopolitical tension, intended primarily to prevent militarization and assert the principle that space belongs to all humankind. While it established key norms such as non-appropriation, peaceful use, and state responsibility, the OST falls short in addressing the commercial realities and distributive justice concerns of today's space economy. Notably, it does not offer clear guidelines for resource sharing, dispute resolution, or equitable participation for emerging economies and private actors (Jakhu and Pelton, 2017).

In particular, Article II of the OST, which prohibits national appropriation of celestial bodies, creates ambiguity when juxtaposed with the growing interest in space mining. The legal gray area between sovereign claims and corporate extraction rights has enabled countries like the United States and Luxembourg to pass domestic legislation permitting private entities to extract resources–arguably undermining the treaty's intent (Williamson, 2016). This has led to concerns among non-spacefaring nations that early actors may establish de facto control over lucrative regions of the Moon, asteroids, or Mars.

Moreover, the lack of binding enforcement mechanisms within the OST has limited its practical impact. The treaty relies on voluntary compliance and mutual accountability, making it difficult to challenge violations or assert new norms. As a result, ethical considerations, such as environmental protection, benefit-sharing, and cultural respect, are largely unregulated (Boley and Byers, 2021). Complementary agreements, such as the Moon Agreement (1979), attempted to address these gaps by proposing a framework for international oversight and equitable benefit distribution. However, the Moon Agreement has been ratified by only 18 countries, none of which are major space powers, rendering it largely ineffective (United Nations Office for Outer Space Affairs, 2020). More recently, the Artemis Accords, introduced by NASA in 2020 have sought to establish norms around transparency and peaceful exploration. Yet critics argue that these accords reinforce U.S.-centric leadership and do not sufficiently address structural or global inequalities (Johnson, 2022).

International maritime law offers a useful comparative lens. The Unites Nations Convention on the Law of the Sea (UNCLOS) outlines mechanisms for managing global commons like the ocean floor, balancing national interests with international stewardship (UNCLOS, 2022). By contrast, space law lacks a centralized authority akin to the International Seabed Authority, which coordinates resource exploration and revenue-sharing. Incorporating similar governance structures into space policy could help ensure that the benefits of extraterrestrial resources are not monopolized by early actors. To build a more inclusive legal framework, future agreements should prioritize the following (See figure 4 for additional info):

- Clear standards for commercial resource extraction and benefit-sharing
- Provisions for environmental sustainability and intergenerational equity
- Inclusive representation for emerging economies and non-state actors in policy forums
- Binding mechanisms for dispute resolution and regulatory enforcement

While no legal framework will perfectly balance innovation with equity, the goal should be to evolve current treaties to reflect contemporary realities. Without such reform, the legal vacuum risks enabling a space economy shaped more by geopolitical self-interest than by shared global progress.

Governance Aspects	Outer Space Treaty	UNCLOS
Foundational Principles	Common heritage of mankind	Common heritage of mankind
Freedoms	Open access for all states	Rights of coastal nations and open access to high seas
Resource Exploitation	Lacks specific exploitation rules	Partially regulates resource extraction
Regulatory Bodies	No regulatory authority	International Seabed Authority

Figure 4 - Comparison Chart: Outer Space Treaty vs. UNCLOS Governance Mechanisms (Source: Journal of Space Law, 2023)

Circular Economic Models and Public-Private Research and Development Partnerships (PPRDPs)

To counteract exclusionary dynamics in the current space economy, forward-looking frameworks must be designed to foster both resilience and inclusivity. Circular economic models–focused on minimizing waste, maximizing resource efficiency, and ensuring long-term environmental and economic sustainability–present one such opportunity. When combined with public-private research and development partnerships (PPRDPs), these models can serve as both

philosophical guideposts and practical instruments for restructuring the space economy to be more equitable and globally cooperative.

Circular economy principles are particularly suited to space, where resource scarcity and mission longevity necessitate careful planning and closed-loop systems (Lammers, 2023). Technologies just as in-situ resource utilization (ISRU), additive manufacturing using regolish, and energy recycling aboard spacecraft embody this mindset. However, circularity is not just about engineering–it also applies to policy. By aligning incentives for reuce, decentralization, and local innovation, circular models can empower smaller actors who are otherwise marginalized by linear extractive paradigms (NASA Technology Transfer Program, 2022).

PPRDPs represent a critical pathway for operationalizing this framework. These partnerships bring together government institutions, academic research teams, private firms, and international collaborators to jointly fund and manage projects that have long-term benefits but high upfront risks. For example, NASA's partnerships with startups like Astrobotic and Orbit Fab exemplify how state backing can enable smaller firms to tackle ambitions goals–ranging from lunar delivery systems to on-orbit refueling infrastructure (NASA, 2023).

In addition, integrating decent5ralized governance tools, such as smart contracts and decentralized autonomous organziations (DAOs), can further democratize participation. By encoding cooperative rules into blockchain-based systems DAOs can facilitate transparent spectrum management, resource claims, or R&D grant allocation (Zubrin, 2021). This could give smaller companies or nations collective leverage in a system historically dominated by major spacefaring states. They rely on significant coordination, international goodwill, and technical interoperability–conditions that are not always present an increasingly fragmented geopolitical landscape. Still, as a foundation for imagining a more inclusive future, they offer a powerful starting point.

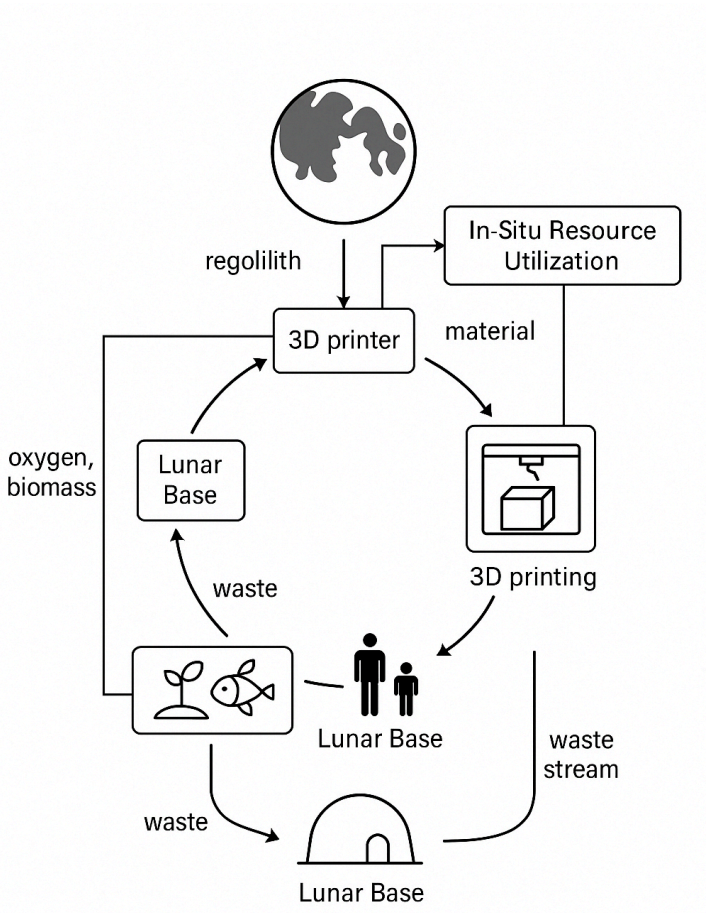
Circular Resource Loops: A Framework for Long-Term Sustainability

An example of a specific circular framework applicable to space development is the closed-loop material cycle model, which has gained traction in both terrestrial and extraterrestrial applications. This model (See Figure 5) emphasizes the reusability of materials, the minimization of waste, and the design of modular systems that allow parts to be repaired, repurposed, or recycled rather than discarded. For the space economy, where resupply is limited and the cost of

launching new materials is extraordinarily high, closed-loop systems present a pragmatic and ethical approach to sustainability (European Space Agency, 2022).

In practice, this model integrates additive manufacturing technologies with in-situ resource utilization (ISRU) techniques to create on-site production ecosystems. For instance, regolith-based 3D printing has been tested as a method for constructing lunar habitats using local materials, drastically reducing reliance on Earth-launch components. A related system is the ESA's MELiSSA (Micro-Ecological Life Support System Alternative), which recycles air, water, and waste in a bioregenerative loop to support long-term crewed missions (ESA, 2022).

On a policy level, the closed-loop model can be mirrored in circular funding mechanisms and open-source engineering databases. These initiatives allow for modular upgrades and shared component libraries among smaller companies, reducing duplication of efforts and enabling distributed innovation. When aligned with international R&D collaborations, these systems empower less-capiatlized actors to contribute meaningfully to space missions through localized fabrication and repair capabilities (Klumpar et al., 2021). Moreover, applying this framework could help address the growing issue of space debris. A closed-loop orbital economy would emphasize the recovery, reuse, and repurposing of defunct satellites and spent rocket stages. Organizations like Astroscale and ClearSpace are already developing technologies to deorbit or reclaim these objects, pointing to a future where orbital sustainability is not only



Closed-Loop Resource Cycle for Lunar Infrastructure
Source: ESA, 2022)

possible but economically viable (Astroscale, 2023).

This model represents not just an engineering solution but a shift in mindset–from extractive and linear growth to regenerative and participatory design. It complements PPRDPs and DAOs by providing a physical and operational infrastructure that embodies the ethical and efficient use of limited resources. As the global community moves toward permanent lunar and Martian installations, this framework will be essential to maintaining ecological balance and minimizing interplanetary externalities.

Figure 6 - Closed-loop resource Cycle for Lunar Infrastructure (Source: ESA, 2022)

Counterarguments and Nuances

While the proposed frameworks of circular economic design and PPRDPs offer innovative strategies for equity and sustainability in space development, they are not without limitations or valid critiques. Many of these concerns center on practical implementation, geopolitical resistance, and the unpredictability of emerging technologies.

One significant critique is the reliance on high levels of international coordination. Circular economies, particularly those extending beyond national jurisdictions into extraterrestrial environments, require consistent regulatory standards and shared enforcement mechanisms. In a fragmented political climate marked by national competition and diverging economic priorities, securing consensus on even basic cooperation can be difficult (Cimono, 2022). The slow ratification of the Moon Agreement and the contested nature of the Artemis Accords illustrate how differing values and priorities can delay or derail the establishment of inclusive governance.

Technological optimism also poses challenges. While circular manufacturing systems, smart contracts, and decentralized organizations present compelling visions, their success depends on stable and accessible infrastructure–not currently guaranteed in many parts of the world. For instance, DAOs rely heavily on blockchain infrastructure, which requires secure internet access, cybersecurity frameworks, and public trust–elements that remain unevenly distributed across global economies (Sims, 2021).

Additionally, the proposed economic models may inadvertently replicate existing inequalities if not designed with equity as a foundational principle. PPRDPs, while beneficial in spreading risk, often skew toward established institutionsand well-networked actors. Without

specific mandates or incentives to include underrepresented communities and nations, such models risk rbecoming tools for reinforcing the status quo under the guise of collaboration (Guston, 2018).

Critics also raise concerns about the balance between regulation and innovation. Overly prescriptive international policies could inhibit experimentation and slow the pace of development in an already challenging environment. Policymakers must walk a fine line: ensuring accountability and ethical standards without stifling creativity or introducing bureaucratic obstacles for emerging space actors (Johnson and Reynolds, 2023).

It is, therefore, crucial to acknowledge that while the proposed solutions are aspirational and grounded in emerging evidence, they do not address every dimension of the problem. They are best viewed as components to a broader strategy–adaptive, evolving, and open to revision as new stakeholders and challenges emerge. By fostering dialogue, piloting regional initiatives, and learning from analogous systems such as international ocean governance, the global community can begin to iterate toward a space economy that reflects both its technical ambitions and ethical responsibilities.

Conclusion

The future of the space economy hinges not merely on technological breakthroughs but on the frameworks we choose to build around access, sustainability, and cooperation. This paper has argued that the prevailing trajectory of space development—dominated by a few powerful states and corporations—must be reimagined through inclusive, ethical, and regenerative lenses. Drawing on the principles of circular economics, the operational potential of public-private research and development partnerships, and the adaptability of decentralized governance structures, a more equitable space future is not only conceivable but essential.

Despite the idealistic nature of the models presented, their value lies in their capacity to inspire tangible structural reform. The closed-loop resource cycle offers a compelling example of how physical, economic, and political systems can align toward shared, long-term goals. PPRDPs and DAOs, while still developing in practice, represent innovative modes of organizing participation and redistributing value.

It is clear that existing legal frameworks, such as the Outer Space Treaty, lack the provisions necessary to manage an increasingly crowded and contested space domain.

Comparisons to UNCLOS highlight viable pathways for governance that are rooted in shared stewardship and accountable oversight. Yet, without deliberate efforts to include the voices and interests of emerging space actors—especially small nations and startups—future governance risks reinforcing the very inequalities it seeks to address.

Ultimately, space is not a blank frontier; it is an extension of Earth-bound politics, economies, and values. The decisions made in the coming decades will shape not only who gets to explore, mine, and settle in space—but also who benefits from these ventures. Ethical imagination must be at the core of space policy, ensuring that progress does not come at the cost of planetary justice.

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