https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

Satellite Ownership and Sustainable Space Exploration: Responsibility- Embedded Polycentric Governance Model (RE-PGM)

Zeljana Zmire[1]

[1]Graduate School of International Studies, Pusan National University, Pusan, South Korea

Correspondence to: zeljana@pusan.ac.kr

Abstract. The accelerated development and increased reliance on satellite infrastructure have spurred concerns related to orbital congestion, space debris, and the long-term sustainability of outer space. Although previous studies have approached the problem of space sustainability from a technological, economic, or international law point of view, they tend to isolate a specific dimension of the problem and lack exploratory capacity in proposing solutions. In particular, there has been a significant gap in research focusing on the problem of satellite ownership in relation to space sustainability. This study posits that satellite ownership structure is a key variable for space sustainability as the increased number of commercial players present a challenge for accountability, monitoring and transparency. The study contributes to the scholarship in two ways. Empirically, it conducts an extensive quantitative and qualitative analysis to understand who owns the satellites (state/ companies), what is their purpose and technological design. Theoretically, the study advances the scholarship by proposing the Responsibility-Embedded Polycentric Governance Model, grounded in 7 adapted principles, 2 space science communication mechanisms, and 2 economics principles; the Precautionary Principle and the Polluter Pays Principles. The study further highlights the crucial role of science communications along with transparent, open-access data and participation of wide range of stakeholders.

1. Introduction

With the rapid expansion of satellite infrastructures, outer space has been undergoing an unprecedented and irreversible transformation. Less than a decade ago, the space race was a domain of primarily state actors. Government organizations such as NASA carried out most space activities including satellite launches, human spaceflights, participation on the International Space Station (ISS), space exploration etc. However, in recent years, the world witnessed the advent of commercial space exploration, private companies such as Starlink launched satellite mega constellations. Starlink's success urged other commercial players to enter the space race and claim their share of the market in the global space economy. The global space economy has been growing at 7.8% yearly rate, reaching more than $600 billion in 2024 (Space Foundation 2026b). All these developments, even though welcomed by futurists, technology enthusiasts, public and private sectors, produced also some unintended consequences. These primarily include congestion risks for the growing presence of mega constellations in the Low Earth Orbit (LEO), collision risks, and space debris (space "junk").

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

Space sustainability has, therefore, emerged as a key challenge for governance and academic research. The existing scholarship has primarily emphasized technological, legal, and economic challenges related to possible debris mitigation strategies, and international law scholars have highlighted problems including transparency and compliance. This study focuses on the issue of satellite ownership structures and their implications for sustainability. Moving beyond problem-identification, the study proposes a Responsibility-Embedded Polycentric Governance Model (RE-PGM) including 7 adapted principles, 2 space science communication mechanisms and 2 economic norms: the Precautionary Principle and the Polluter Pays Principle (PPP) that ensure the model's effectiveness in practice. The model conceptualizes outer space as a global common resource that gets depleted with excessive usage, and as such, it requires coordinated action on all polycentric levels, including international, national, and corporate levels. The seven adapted principles, along with two space science communication mechanisms (on national and international levels), emphasise the role of science communication that informs a wide range of public and private stakeholders and empowers them to participate in decision-making process. In addition, two economic norms ensure that corporate responsibility is not only normative but applicable in practice, i.e. economic instruments are used to mitigate the environmental damage caused by satellites.

At the empirical level, the study advances understanding of satellite ownership through a quantitative analysis of satellite data available at the United Nations Office for Outer Space (UNOOSA) database and the Union of Concerned Scientists (UCS) database. After identifying key states and companies in space, i.e., states/companies with the highest number of satellites, the study moves on to qualitative analysis of the respective companies. The findings reveal not only a high concentration of ownership among major state and commercial actors, but also transparency gaps in satellites' design and purpose. The study contributes to the scholarship by stressing the significance of transparency, open data, and informed participation as key conditions for sustainable governance.

The study is structured in the following way. Section 2 reviews the existing literature and identifies research gaps. Section 3 introduces the responsibility-embedded polycentric model (RE-PGM) along with the seven adapted principles (ADPs), two space science communication mechanisms, and two economic norms; the Precautionary Principle, and the Polluter Pays Principle (PPP). Section 4 presents the empirical analysis (quantitative and qualitative data). Section 5 presents the analysis through the lenses of RE-PGM, while the final section presents the discussion and conclusion.

2. Literature review

The topic of space exploration has gained significant scholarly attention in recent years. While originally this topic was discussed solely in engineering and natural sciences terms, nowadays, scientists from different fields highlight issues such as space sustainability, compliance with international law, benefits/ risks of space technologies, the importance of public and private companies in space, etc. The sustainability of space exploration, along with the related problems, constitutes one of the most frequently addressed research topics in the existing literature (Table 1). Many scholars focus on satellites; for example,

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

Palmroth and Hukkinen (2025) highlight the reliance on satellite technology and its fragility when faced with extreme space weather, including space storms. Buitrago-Leiva et al. (2025) emphasize the problem of space debris and the necessity to improve satellite recycling. Some studies offer a more comprehensive view of space sustainability by highlighting Earth-space connections (Maiwald 2023), or by developing a more comprehensive theoretical framework (Mo et al. 2024), while Kipanga and Hassan (2025) emphasize the significance of national space agencies in voicing their concerns in front of the UN and, thereby, creating a new international space law.

Table 1. How space sustainability is discussed in previous literature

Author/ Work	Main idea	Details
(Palmroth and Hukkinen 2025)	The connection between space weather and the sustainability of space technologies (primarily satellites)	The study elaborates that the world has become increasingly more reliant on space technologies. Ensuring sustainable exploitation of space is a priority for nations and the international community. However; sustainability of space is fragile and dependent on space weather. Space storm events may damage satellites and jeopardize industries such as internet communications, navigation, etc.
(Buitrago-Leiva et al. 2025)	Satellites, space debris, and satellite recycling.	The study highlights the problem of abandoned satellites (zombie satellites), which still have some operational capacity. The study suggests methods for recycling those satellites or extending their operational lifetime.
(Maiwald 2023)	Identification of 3 main fields related to sustainability: Earth to Earth, Earth to space, and space to Earth.	Through a systematic literature review, the study identifies the main topics related to the sustainability of space. The author highlights the relevance of the original definition of sustainability, i.e., meeting current needs without jeopardizing the needs of future generations, and three dimensions: ecological, economic, and social.
(Mo et al. 2024)	Comprehensive view of space sustainability.	The study highlights that leveraging space resources should be done in a sustainable way. They offered a comprehensive sustainability framework encompassing pollution, resource depletion, landscape alternation and space environmental justice.
(Kipanga and Hassan 2025)	National agencies and sustainability.	The study highlights the importance of National Space Agencies. They are important because they have the power to regulate, supervise, and implement space-related issues in domestic law. Developing countries without national

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

		space agencies are important as well since their voice counts in UN discussions.

Source: Author's work based on the above-mentioned literature

Another common approach to space sustainability is international law (Table 2). Di Pippo (2016) elaborated on the significance of space objects' registration and the problems of two different registries maintained by the UN. Freeland and Ireland-Piper (2022) underscored the need to incorporate human rights and corporate accountability as integral parts of the international space law. There is also a vast body of scholarship highlighting the issue of state debris and the related problems in international law. For example, Cirkovic, Rathnasabapathy, and Wood (2021) suggested that Corporate Social Responsibility (CSR) and Space Sustainability Rating (SSR) should be considered together with international law. In the same vein, Campodonico (2023) highlighted the importance of CSR, while Poonuganti (2023) suggested more concrete measures, including the Polluter Pays Principle (PPP) and the Precautionary Principle.

Table 2. How space sustainability is approached through the international law

Author/ Work	Main idea	Details
(Di Pippo 2016)	Voluntary and obligatory registration of objects launched into space.	The study examined the problem of registration. UN maintains two separate but complementary registers, the United Nations Office for Outer Space Affairs (UNOOSA) registry, i.e. the Registry, and the registry set by the Convention on Registration of Objects Launched into Outerspace i.e. the Convention. The author highlights the problem of transparency, double –registration and incoherent information.
(Freeland and Ireland-Piper 2022)	The relation between the space law, human rights, and corporate accountability.	The study posits that a human rights perspective should be included in the international space law, and given the increasing involvement of the private sector in space the study calls for greater corporate accountability.
(Cirkovic, Rathnasabapathy, and Wood 2021)	Space debris in relation to corporate responsibility as set by the international law.	The author posits that space is a common good and space debris presents a significant environmental risk. States (and companies) should be held accountable, in this respect the author proposes the concept of Corporate Social Responsibility

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

		(CSR) and the Space Sustainability Rating (SSR).
(Campodonico 2023)	The relevance of the Guidelines on the Long-term Sustainability and the Space Debris Mitigation Guidelines.	The study elaborates that space as "global commons" cannot be a source of national exploitation. States/ companies should respect the Guidelines for the Long –term Sustainability and the Space Debris Mitigation; however, the guidelines itself should be complemented with the concept of Corporate Social Responsibility (CSR).
(Poonuganti 2023)	States liability for space pollution, Polluter Pays Principle and the Precautionary Principle.	International law is insufficient to facilitate state's responsibility for space pollution. The author suggests that economics concepts including the Polluter Pays Principle (PPP) and the Precautionary Principle are more adequate to facilitate their liability in practice.

Source: Author's own work based on the sources above

In-depth analysis of the existing literature revealed the following key findings; a substantial body of literature analyses space exploration from the international law perspective (i.e. global perspective). Numerous studies, also, highlight the problem of space debris and states/companies accountability (i.e. state or company perspective). However, a sustainable space exploration cannot be facilitated by relying only on one of these perspectives, all three perspectives should be considered together. Furthermore, the existing literature underscores that satellites are the most numerous space objects, and as such they present the biggest danger to space sustainability though space debris. At the same time, they highlight the inadequacy of the international law to deal with this problem since most satellite-owning companies are in private ownership.

Based on these observations, this study advances the analysis by examining satellite ownership structures, their purpose/ mission, along with satellite technology and design. Departing from studies that highlight the insufficiency of the existing international law, this study proposes a governance-based model along with economic instruments that can enforce accountability for space activities and the related environmental damage. Accordingly, the study will be guided by the following research questions;

RQ1: Who owns the satellites in the outer space (states/ companies) and what is the ownership structure (i.e. public/ private/ public-private partnership)? What are satellites' purpose and technological design?

RQ2: How does the issue of satellite ownership structure (together with their purpose and design) relate to space sustainability and, consequently, how sustainability may be improved?

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

3. Theoretical Framework

3.1 From International Law towards Polycentric Governance of Space as Global Commons

Space is widely considered a global common good, i.e. “global commons” (Lambach and Wesel 2021; Hasin 2023). This economic concept pertains to a shared ownership concept, where benefits/resources are non-excludable, i.e., they can be enjoyed by everyone. However, they are also finite, meaning that the increased usage of one actor (individual or company) diminishes the possibility of use for other actors. This often causes the “tragedy of the commons,” a situation where the resources are damaged or depleted. Countries may adopt measures such as prohibitions or economic instruments such as taxes or licensing in order to prevent excessive damage/ depletion. Outer space, same as a clean environment on the Earth, are considered a “global commons,” and international law treaties are widely cited as hard/ soft law instruments dealing with space as a global common good (Cirkovic, Rathnasabapathy, and Wood 2021; Freeland and Ireland-Piper 2022). The Outer Space Treaty (OST), adopted by all major space nations in 1967, is considered Magna Carta of Space,” a binding treaty that obliges states to obey key principles (freedom of use, non-appropriation, peaceful uses, benefit to mankind, and liability) and, thereby, respect obligations including space objects registration, responsibility for space activities carried by public and private entities, avoiding harmful contamination, etc. (Cirkovic, Rathnasabapathy, and Wood 2021; Di Pippo 2016).

OST established foundations for space exploration; however, it also revealed major flaws. It assumes that states (i.e. national governments) are major space actors, a fact that changed with the ascent of private companies in space. Furthermore, international law is frequently disregarded. This is primarily because it lacks enforceability mechanisms. Therefore, this study proposes “polycentric governance” as a model that tackles the situation more adequately and offers practical solutions towards the sustainable use of outer space. “Polycentric governance” contrasts to hierarchical model of governance and “refers to a network of independent nodes that can make decisions independently and coordinate among themselves to produce a joint output (Lambach and Wesel 2021).” A study by Ostrom (2010), which dealt with problems of climate change, stated that polycentricity is a useful tool for understanding global climate change and improving its effects. According to Ostrom, polycentric nodes exercise considerable independence and set norms/rules “within a specific domain (such as a family, a firm, a local government, a network of local governments, a state or province, a region, a national government, or an international regime) (Ostrom 2010).” Polycentric models possess considerable advantages over centralistic/ hierarchical systems because of mechanisms for mutual monitoring, learning and adaptation. Therefore, they tend to stimulate innovation, learning, adaptation, trust and cooperation among the participants.

Ostrom’s polycentric governance model was developed for smaller scale communities. In order to make it suitable for large scale environments such as space, Lambach and Wasel (2021) developed seven “adapted design principles (ADP)” (Table 3)

Table 3. Adapted Design Principles

ADP number and name	Description

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

ADP 1: Invest in science to understand the resource and its interactions with users and those affected by its use.	A comprehensive understanding of space as resource is important prerequisite for the sustainable use.
ADP 2: Establish independent monitoring of the resource and its use that is accountable to the range of interested and affected parties.	Monitoring of space and making it independent and accountable to all stakeholders-space situational awareness (SSA). Importance of open and reliable data. Counties have different SSA systems.
ADP 3: Ensure meaningful participation of the parties in framing questions for analysis, defining the import of scientific results, and developing rules	Initiating a consultative process with all stakeholders to create consensus on space debris. Establishing "watchdog" NGOs to monitor states' accountability. Provide counterweight to states' dominance through transnational public sphere (businesses, science and civil society).
ADP 4: Integrate scientific analysis with broad-based deliberation	Science – based decision making process.
ADP 5: Higher-level actors should facilitate participation of lower-level actors	Encouraging pluralistic participation of new space actors, including private sector.
ADP 6: Engage and connect a variety of institutional forms from local to global in developing rules, monitoring, and sanctioning.	Multi-level nature of space as polycentric system. Suggested decentralization while strengthening the interconnections.
ADP 7: Plan for institutional adaptation and change	Complement UN institutional design with the inclusion of other actors, including low-level actors (ADP 3, 5 and 6).

Source: Content modified from (Lambach and Wesel 2021) and Stern (2011)

According to Lambach and Wasel (2021), ADP1 (*Invest in science to understand the resource and its interactions with users and those affected by its use*) pertains to the necessity of understanding not only space properties, but the problem of space pollution i.e. space debris as well. ADP2 (*Establish independent monitoring of the resource and its use that is accountable to the range of interested and affected parties*) refers to the domain of monitoring and space situational awareness (SSA), which are defined as the information about the space and activities that are safe and efficient. Different countries have different SSA systems. These systems are deemed important for space sustainability; however, there are limitations as many countries' do not share data openly, and there is a lack on interoperability between different SSA systems. ADP 3 (*Ensure meaningful participation of the parties in framing questions for analysis, defining the import of scientific results, and developing rules*) pertains to the flaws in the existing international law and suggests the following; "1) set in motion a consultative process including all stakeholders to generate consensus about the shape of the space debris problem, likely scenarios and policy options, 2) support the emergence of and strengthen "watchdog" non-governmental organizations to hold governments and

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

space agencies accountable, 3) encourage the growth of a transnational public sphere among business, science and civil society to provide a counterweight to the state-dominated system of outer space governance."

ADP 4 (*Integrate scientific analysis with broad-based deliberation*) refers to the significance of scientific knowledge as a base for decision making. This can be further stimulated thorough investments in science (ADP1), information sharing (ADP2) and stimulated inclusiveness (ADP3). ADP 5 (*Higher-level actors should facilitate participation of lower-level actors*) suggests that space is a matter of pluralistic interests. Higher level actors i.e. international organizations (UN) and national governments should include low level actors i.e. private companies, NGOs, individuals into the discussion.
ADP 6 (*Engage and connect a variety of institutional forms from local to global in developing rules, monitoring, and sanctioning*) pertains to multi-level nature of polycentric governance for the governance of space debris. It encompasses organizations on various levels including international organizations such as the UN, The Inter-Agency Space Debris Coordination Committee (IADC), the International Organization for Standardization (ISO), the International Astronautical Federation (IAF) and others. It includes national organizations (governments, space agencies) and private actors (private companies). It suggests encouraging decentralization while strengthening the interconnections. The recommendations include; " 1) encourage forms of private governance, e.g. in the coordination of space assets, 2) empower lower-level decision making through national space laws that define appropriate roles for non-state actors, 3) reform the IADC to facilitate participation by non-state actors or create a parallel forum for public-private deliberation, and 4) leverage existing norms of cooperation and collaboration in space activities to argue for more cooperative, cross-cutting ways of decision-making."
ADP 7 (*Plan for institutional adaptation and change*). Sustainability of space is endangered not only by the number of actors in space but also by the growing number of purposes of space. Space economy is expanding to include new industries such as telecommunications, navigation, medicine, biotechnology and other industries, signifying that economic interests might further endanger space sustainability. The authors highlight that the UN proved to be flawed when it comes to coping with this changes, which is evident by the inability to adopt new binding laws. ADP 7 recommends combining UN institutional design with the polycentric approach, especially by including other actors (ADP 3, ADP 5 and ADP 6).

The study additionally proposes two *space science communication mechanisms* and pathways that complement the adapted principles and enable the general public to participate in the decision-making process in a more direct and deliberate manner. The first - *national level mechanism* – deals with the obligation of space regulatory agencies to perform *"public consultations,"* as a mandatory process before adopting licencing of new satellite constellations or a new space policy. "Public consultations" are envisioned as open discussions online, where experts and general public can share their opinion of the proposed policy. Once public consultation period is closed, the related space regulation agency has an obligation to inform the public of the results, elaborate decision as accepted/ non accepted or requiring modifications according to the results of the consultation process. "Public consultations" are also combined with "*public voting*" on how to utilize taxpayers' funds. During this process the general public votes on space projects (public, private or public-private) they want to finance.

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

For these, national level mechanisms, to function properly, *space science education* is a necessary pre-condition. Scholars researching about space should move away from teaching solely university courses towards presenting their research through science communication channels (science news or science related social media). Furthermore, they should translate open source data published by space agencies to reports and presentations easily understandable by the general public. In this way, the general public would be equipped with a reliable information in a right time, i.e. before "public consultations" and "public voting" period. .

The second space science communication mechanism is on an international level. International space agencies such as UNOOSA have the obligation to publish data in a transparent, open-access format. This data should be presented to the general public and NGOs in a format that adequately demonstrate benefits and risks related to satellites' technology, design, and ownership. Especially, data on national space agencies and their compliance with the international space law should be made publicly available. Based on these information, NGOs and general public would be equipped with information to perform informed oversight of national agencies and advocate for changes in space policy through the mechanisms presented above "pubic consultations" and "public voting." In this way, national-level and international level mechanisms are connected and interoperable.

3.2. Responsibility-Embedded Polycentric Governance Model (RE-PGM); Integrating the Polluter Pays Principle and the Precautionary Principle

The polycentric governance model combined with the ADPs and space science communication mechanisms provide useful tools that extend beyond the international law and provide actionable solutions; however, to make private space companies accountable the model should be strengthened with the instruments of economic policy. This primarily refers to the fact that private companies grow more dominant in space, i.e. they explore the space for the private benefit while depleting a common resource. In order to prevent "the tragedy of commons" from occurring, international law and economic theory suggest instruments such as the Precautionary Principle and the Polluter Pays Principle (PPP) (Poonuganti 2023)

The Precautionary Principle is widely mentioned in the environmental sciences. It was included in the 1992 Rio Declaration on Environment and Development, and it stands for the obligation of causing no harm to the environment and human health. This obligation exists even when there are no fully established scientific evidences of the harm caused. The Precautionary Principle obliges the states, as well as decision makers on industry levels, including medicine, biotechnology, genetic science, etc., to prevent or refrain from activities that may cause harm. In contrast, the Polluter Pays Principle (PPP) is an economic instrument that requires actors responsible for environmental damage, commonly private corporations, to internalize the costs. PPP is often operationalized through the externality tax or so-called Pigouvian tax. Chowdhury (2022) suggests that PPP, which already exists in the Rio Declaration, should be extended to space by making launching states responsible and financially liable (Chowdhury 2022).

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

This study extends Chowdhury's conclusions by drawing attention to both public and private companies. National governments should collect externality costs (Pigouvian tax) from both, public and private, satellite launching companies. Once collected those taxes should be deposited in an international climate fund, established under the UN and responsible for space debris. It has been widely acknowledged that companies lack incentives to remove the debris for it is deemed expensive and technologically demanding (Kipanga and Hassan 2025; Buitrago-Leiva et al. 2025). Establishing funds to finance such activity would provide financial incentives for private/public companies to engage in debris removal business and consequently it would initiate a new sector of space economy. Furthermore, the imposition of the tax itself would stimulate companies to develop satellite recycling technologies or extend their life cycles though repairs or re-purposing (Buitrago-Leiva et al. 2025).

4. Research Methodology and Satellite Data

In order to answer the research question on who owns the satellites, what is their ownership structure and the related purpose/ technology design, the study undertakes the following analysis of the United Nations Office for Outer Space Affairs (UNOOSA) satellite database. The database provides information on the year (date) of launch, launching state and company/operator. Firstly the study provides a background launch data from 2019 to 2025 on the main state-actors in space. From dominant state actors the study moves on to explore details on ownership structures, satellite purpose and design. To complement UNOOSA dataset the study utilizes also the database of the Union of Concerned Scientists (UCS) and later it conducts a qualitative analysis of dominant companies in space (private and public). This analysis is done through the examination of digital resources, primarily company official web sites and public communication documents.

According to UN Nations Office for Outer Space Affairs (UNOOSA) there were 16.263 objects, i.e. satellites in Earth's orbit as of January 20th, 2026 (UNOOSA 2026). As visible in the Table 4 below there were 3923 satellites launched in 2025, 2679 satellites in 2024, 2586 in 2023, 1971 in 2022, 1215 in 2021, whereas the number of satellites launched in 2020 amount to 663 and 184 in 2020. These numbers reveal a significant increase of satellite launches each year, ranging from 31% to 260%, with the exception of the year - 2024. Prior to 2021, the number of launches were calculated in hundreds, whereas nowadays the calculations are made in thousands, revealing an intensified global interest in space exploration.

Table 4. Satellite launch data from 2019 to 2025

Year	Total Number of satellites	Increase compared to the year before (%)	Countries/ satellite launches							
			USA	CHI	RUS	FRA	GER	ITA	UK	ESA

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

2025	3923	46%	USA (3416)	CHI (258)	RUS (42)	FRA (27)	GER (18)	ITA (24)	UK (7)	ESA (4)
2024	2679	3.5%	USA (2167)	CHI (243)	RUS (77)	FRA (21)	GER (7)	ITA (7)	UK (27)	ESA (5)
2023	2586	31%	USA (2024)	CHI (201),	RUS (49)	FRA (9)	GER (5)	ITA (18)	UK (143)	ESA (1)
2022	1971	62%	USA (1591)	CHI (162)	RUS (19	FRA (6)	GER (8)	ITA (8),	UK (112)	ESA (0)
2021	1215	83%	USA (757)	CHI (87)	RUS (6)	FRA (6)	GER (5)	ITA (6)	UK (284),	ESA (0)
2020	663	260%	USA (461)	CHI (47)	RUS (15)	FRA (1)	GER (5)	ITA (1)	UK (104)	ESA (1)
2019	184		USA (67)	CHI (62)	RUS (11)	FRA (3)	GER (5)	ITA (2)	UK (10)	ESA (1)

Source: Adapted according to data available on UNOOSA (2026)

The United States is convincingly the most dominant actor in space exploration. It has been rapidly increasing the number of launches from only 67 in 2019 to 3416 in 2025. The second leading actor is China, with annual launches rising from 62 in 2019 to 258 in 2025. Russia, often cited as the third most dominant power in the space (World Forum 2026), improved its launches from 11 annual launches in 2019 to 42 in 2025, with a brief surge of launches to 77 in 2024. The European Union (EU) is also a space actor. Its members; France, Germany and Italy, launch roughly 10 to 20 satellites yearly. Their number of launches are relatively modest as they act separately. The EU also acts collectively with European Space Agency (ESA); however, it launches only around 4-5 satellites yearly. The United Kingdom (UK) could be considered as one of leading actors in space; however, its number of launches has been largely inconsistent. Based on these considerations, combined with other sources underscoring the importance of the USA and China as two most dominant space exploring nations, this study focuses only on their space activities, i.e. their companies/operators in space (World Forum 2026; Al-Rodhan 2019).

Detailed analysis of the UNOOSA data with the selection criteria of country (USA/ CHI), year (2025/ 2024), satellites launched and in orbit (Table 5) reveals the following information. Both, the USA and China, conducted their space activities through various public and private entities. On the USA side, Starlink, a privately-owned company operated by SpaceX, is convincingly a dominant player with around 3150 satellites launched in 2025 and 1907 in 2024. It is followed by Kuiper and Flock, privately-owned companies, which launched 79 and 71 satellites, respectively. USA launched satellites owned by public companies as well – 91 in 2025 and 110 in 2024.
On China's side, 120 satellites were launched by Hulianwang Digui in 2025, operated by China Satellite Network Group. Compared to this, other companies have significantly less launches Qianfan, owned by Shanghai Spacecom Satellite

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

Technology (SSST) and backed by Shanghai municipal government and Chinese Academy of Sciences (CAS) launched 54 satellites in 2024 and 34 in 2025, whereas all other companies had from 10 to 30 launches (CircleID 2026; Satnogs DB 2026).

Table 5. Satellites launched in 2025 and 2024 by country and ownership

2025			
USA/ company	Number	CHI/company	Number
Starlink	3150	Hulianwang Digui	120
Kuiper	79	China	11
Flock	71	Yunyao	10
USA	91	Qianfan	34
Praetorian	21	Centispace	10
2024			
USA/ company	Number	CHI/company	Number
Starlink	1907	Qianfan	54
USA	110	Tianqi	24
Flock	35	Geesat	22
Hawk	12	Yaogan	11
Tomorrow	4	Huliangwang Digui	10

Source: Author's work based on data available on UNOOSA (2026)

UNOOSA database (Table 4 and Table 5) reveals which states/ companies launch and own satellites; however, less in known about satellite types and purposes. More detailed analysis was done by the Union of Concerned Scientists (UCS), whose database shows the cumulative number of operational satellites in orbit. The database was last updated on May 1, 2023, and it allows the analysis according to the purpose (commercial/civil, military and government), type of orbit (LEO, MEO, GEO), etc. The UCS database shows (Table 6) that cumulative number of USA commercial/civil satellites (4680), significantly outnumbers cumulative number of military (250) and government (160) satellites. Starlink with its 3996 satellites outnumbers any other commercial, military or government entity, and therefore it deserves special scholarly and regulatory attention. All Starlink satellites are classified as commercial satellites with communication as their main purpose and they are all launched into the LEO. Other main players from the USA side are National Reconnaissance Office with 75 military satellites and Iridium Communications with 76 satellites deployed in a collaboration with the government.

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

Table 6. USA satellites according to their purpose and operator/owner (Cumulative number until 2023)

Commercial /Civil		Military		Government	
Owner	Number	Owner	Number	Owner	Number
SpaceX (Starlink)	3996	National Reconnaissance Office	75	Iridium Communications, Inc.	76
Planet Labs, Inc.	220	Department of Defense / US Air Force	49	National Aeronautics and Space Administration (NASA)	47
Spire Global Inc.	130	US Air Force	48	National Oceanographic and Atmospheric Administration (NOAA)	10
Swarm Technologies	90	Air Force Research Laboratory	11	Universities	10
Intelsat S.A.	36	Defense Advanced Research Projects Agency (DARPA)	10		
ORBCOMM Inc.	35	Space Development Agency	10		
Globalstar	33	US Army Space and Missile Defense Command	7		
HawkEye 360	18	US Navy	7		
Other	90	Other	23	Other	17
Total	4680	Total	250	Total	160

Source: Author's work based on UCS Satellite Database (UCS 2026)

On the Chinese side, UCS database (Table 7) revealed that Chang Guang Satellite Technology is the main commercial player with 59 satellites with communication as their main purpose, Chinese Ministry of National Defense with 141 satellites launched for military purposes and China Academy of Space Technology (CAST) with 47 satellites deployed in a collaboration with the government mainly for technology development purposes.

Table 7. China's satellites according to their purpose and operator/owner (Cumulative number until 2023)

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

Commercial/ Civil		Military		Government	
Owner	Number	Owner	Number	Owner	Number
Chang Guang Satellite Technology Co. Ltd.	59	Chinese Ministry of National Defense	141	China Academy of Space Technology (CAST)	47
Guodian Gaoke	16	People's Liberation Army (C41)	8	China Aerospace Science and Technology Corporation (CASC)	27
Zhuhai Orbita Control Engineering Co. Ltd.	12	China Academy of Space Technology (CAST)	5	Chinese Academy of Sciences	23
Ningxia Jingui Information Technology Co. Ltd.	10	Academy of Military Science	2	Shanghai Academy of Spaceflight Technology	18
Geespace	9	National University of Defense Technology	1	China Satellite Communication Corp. (China Satcom)	10
HEAD Aerospace	7			China Meteorological Administration	9
Beijing Commsat Technology Development Co., Ltd	7			China’s Ministry of Land and Resources, Ministry of Environmental Protection, and Ministry of Agriculture	8
GalaxySpace	7			China National Academy of Sciences (CNSAS)	7
Spacety Aerospace Company	7			Chinese Ministry of National Defense	7
Xiyong Microelectrics Park	6			State Oceanic Administration (SOA)	5
APT Satellite Holdings Ltd.	5			China Centre for Resources Satellite Data and Application (CRESDA)	5
Other	96	Other	0	Other	46
Total	241	Total	158	Total	222

Source: Author’s work based on UCS Satellite Database (UCS 2026)

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

Based on the above-presented quantitative data, the study understands that the most dominant USA companies in space are Starlink for the largest amount of commercial satellites, National Reconnaissance Office for military satellites and Iridium Communications for government satellites. On China's side, integrated analysis of Table 7 and Table 5 shows that the most dominant companies include; Chang Guang Satellite Technology and Hulianwang Digui for commercial satellites, Chinese Ministry of National Defense for military satellites and China Academy of Space Technology (CAST) for government satellites. From now on, the study moves on to qualitative analysis of the above mentioned companies. The data was acquired primarily through companies' web sites, official company communication materials and supported with a literature review.

4.1. Dominant USA companies in space; Case study of Starlink, National Reconnaissance Office and Iridium Communications

4.1.1.Starlink

Starlink, subdivision of SpaceX, owns large-scale satellite constellations with a purpose of providing low-latency, high-speed broadband internet with a global coverage. Starlink satellites are deployed to LEO, around 500 km from the Earth's surface. Because of their relative proximity to the Earth they offer greater power and wider bandwidth compared to GEO satellites (Humphreys et al. 2023). They use a bent-pipe strategy, where LEO satellite connects to the traffic on a Ground Station (GS) and gets further routed. As such, Starlink offers internet connectivity to remote areas, including Amazon, albeit, there are some limitations especially on cross-ocean routes (Ma et. al 2023). Furthermore, user's experience is heavily affected by space weather, including solar storm, rain, cloud, and temperature.
To overcome these challenges, Starlink announced a gradual shift from bent-pipe technology towards laser intersatellite links (LISLs) technology. It enables direct communication between LEO satellites without relying on ground stations. This technology is deemed critical for 6G internet, next generation of internet systems, with significant empowered performance, resilience and extended connectivity to the most remote places on Earth including oceans (Chaudhry and Yanikomeroglu 2021). Starlink satellites are already considered to be revolutionizing communication technology, including global positioning, navigation and timing (PNT), and "they offer higher power, wider bandwidth, more rapid multipath decorrelation, and the possibility of stronger authentication and zero age of ephemeris, all of which, will enable greater accuracy and greater resilience against jamming and spoofing." (Humphreys et al. 2023)"

Despite these technological advancements and benefits they produce, there are concerns as well. These pertain primarily to the environment, most notably decaying satellites that no longer serve their purpose and eventually create "space debris," or so-called "space junk." Some decaying satellites re-enter the atmosphere, and create rising concentrations of metal particles and gasses that eventually harm the ozone (Clery 2026). Another concerns relate to the light pollution and the reflection of light from the satellites that reduce the visibility for the ground astronomers when observing the stars and planets. With Starlink's plan to launch more numerous constellations in the future, the issue of pollution and related responsibility becomes more

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

pronounced. Starlink actually operates for its own profit and pays taxes to the respective countries where Starlink services have been provided; however, it does not pay any environmental tax or compensation for the pollution that is expected only to grow in the future (Clery 2026). At the same time, Starlink made progress to reduce light pollution by improving its design. Originally it had installed "sun visors" a material that was supposed to block the sunlight towards dielectric mirror film that scatters the sunlight away from the Earth. Furthermore, every satellite component was painted in black color to reduce brightness (SpaceX 2026).

4.1.2. National Reconnaissance Office

National Reconnaissance Office (NRO), is a USA intelligence agency under the Department of Defense (DoD) with a central purpose of providing intelligence and reconnaissance data to DoD, military, and other intelligence agencies. NRO highlights potential security threats from other space actors; therefore, enhancing technological innovation and resilience remain its main goals. To achieve this purpose, NRO has been launching larger numbers of smaller satellites, so-called proliferated constellation. In this way it achieves increased coverage, faster delivery of information, while eliminating single failure points (NRO 2026a). NRO introduced partnerships with commercial companies at the core of its strategy. It incorporated commercial imaginary in two programs; the first includes commercial remote-sensing capabilities, including commercial radar, hyperspectral imagery, radiofrequency sensing and electro optical capabilities. The second includes Electro Optical Commercial Layer (EOCL) in partnership with small satellite constellation operators. EOCL is expected to deliver next generation of commercial imaginary (Atlantic Council 2026). Furthermore, it has been partnering with SpaceX and utilized its Falcon rockets for launching. In this way NRO offsets launch costs and invests more financial means into new technology development (NRO 2026a).

Since NRO is a public intelligence company, its budget has been fully provided by the USA government. The amount of budget remains classified; however, its commercial part amounts to 400 million USD. NRO is a non-profit company, therefore it is not subjected to taxes neither.

4.1.3. Iridium Communications, Inc.

Iridium Communications is a publicly traded company with a headquarters in the USA. Its major investors include; institutional investors (75.3%), individuals (12.8%) and others (7.8%) (Market Screener 2026). It has around 2.5 million subscribers and its commercial part amounts to around 62% of its total revenue or 59.6 million USD. Another part of its business is providing voice and digital solutions for the USA government through contracts with U.S. Space Force. Iridium satellites are deployed in LEO on the altitude of 781km with inclination angle of 86.4 (Calian 2026). They utilize Inter-Satellite Links to route signals from satellite to satellite. Each satellite is connected to neighbouring satellites. This boosts robustness of the system, reduces reliance on ground stations, and provides a global coverage (Iridium 2026; Gunter's Space Page 2026). Iridium is subjected to USA state and federal tax.

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

4.2. Dominant Chinese companies; Case study of Chang Guang Satellite Technology, Hulianwang Digui , Chinese Ministry of National Defense and China Academy of Space Technology (CAST)

4.2.1. Chang Guang Satellite Technology

In the case of China, private and public ownership have been interconnected. This is visible in the case of Chang Gung Satellite Technology (CGST). It is one of the earliest China's commercial satellite companies; however, as a company based in Jilin, it is connected with Jilin's Provincial Government, PRC government and People's Liberation Army (PLA). Its key business are space-based imaging and remote sensing. Its Jilin satellite constellation "is intended for use in disaster response, environmental protection, agriculture, and resource management, as well as in providing remote sensing capabilities to the PRC military (China Aerospace Studies Institute 2026)." It was established as a joint venture of Chinese Academy of Sciences' (CAS), Changchun Institute of Optics, Fine Mechanics and Physics (CIOMP) and the Jilin provincial government. Although CGST is labeled as a commercial company, it is still closely linked with the government and reliant on financial support (China Aerospace Studies Institute 2026). Due to its participation in military projects, many details related to satellite design and detailed missions remain concealed. There are some general information related to satellite weight and launch sites, as well as information on ground stations located in Changchun, Sanya and Kashgar. The company currently works on implementing space-based laser communications and intelligent remote sensing (China Aerospace Studies Institute 2026; Chang Guang Satelite Technology Co., Ltd. 2026).

4.2.2. Hulianwang Digui

Hulianwang Digui refers to satellites operated by China Satellite Network Group, i.e. China Satellite Communication Ltd (China Satcom). It is the main subsidiary of China Aerospace and Technology Cooperation (CASC). The satellites were manufactured in cooperation with CAST, and there are some general information available on satellite design (mass around 800kg) and energy source (solar arrays, and battery power). The company provides secure and stable satellite communications to various customers including broadcasting, telecom, corporate and government companies (KeepTrack 2026). Its main mission is an independent satellite-based broadband network for China, as well as other regions in the world. Hulianwang Digui are classified as small/ medium size satellites in LEO, at the same time the company own 19 geostationary satellites covering China, Southeast Asia, South Asia, the Middle East, Africa, Europe and Pacific (China Satellite Communications 2026).

4.2.3. Chinese Ministry of National Defense and China Academy of Space Technology (CAST)

China Academy of Space Technology (CAST) is a leading government agency and institute for research and development of China's space industry. It was established in 1968 as a subordinate affiliation of China Aerospace Science and Technology

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

Corporation (CASC). Both CASC and CAST are state-owned companies. While CASC encompasses wide range of activities including rocket and propulsion systems, and electronics, CAST functions as the main manufacturer of satellites and spacecraft. CAST produces satellites with a purpose of communication, earth observation and remote sensing, navigation satellites, and encryption systems (CAST 2026). CAST is a major supplier of satellites to the Ministry of Defense and PLA.

Ministry of Defense revealed some information related to satellite usage and design. For example, China started to launch its experimental satellites at the beginning of 1970s with a purpose of tracking vessels and any other potential military threats in the region. Over the years it had deployed ELINT satellites with a purpose of tracking military vessels and defense systems. Later, ELINT satellites were upgraded to form a full reconnaissance satellite network. At the beginning of 2010s China developed remote sensing satellites, which were used primarily for Earth observation. Nowadays, satellites owned/ operated by the Ministry of Defense are classified in several groups; 1) Yaogan reconnaissance satellite program, 2) Tongxin Jishu Shiyan (TJS), 3) Tianhui and 4) Ziyuan satellites.

Yaogan satellites are the largest fleet, launched with the purpose of observing Earth's surface and to cover military and weather phenomena. This group of satellites supports the ground command with the intelligence and reconnaissance information. It is estimate that Yaogan satellites provide intelligence related to one third of the Earth's surface (Manohar Parrikar Institute for Defense Studies and Analysis 2026) . TJS satellites are launched into GEO orbit, and they are utilized to provide high-speed satellite communication. Furthermore, TJS satellites are considered to be engaged in acquiring intelligence information, early warning missions and satellite inspection activities (Space News 2026b). Tianhui are satellites with a dual use, i.e. military and civilian. These are stereo-topographic mapping satellites that operate on a 500 km circular sun synchronous orbit. They are equipped with three-dimensional survey camera and a CCD camera that provide information for different civil and military observation include remote sensing programs. Tianhui are considered also a part of Ziyuan program with a similar purpose. Ziyuan program is used for military and civilian observation as well, including aerial surveillance, and stereo mapping (Gunter's Space Page 2026c).

5. Analysis

Departing from existing scholarship that emphasize problems related to sustainability including decaying satellites, space debris and related technological and accountability concerns, alongside international law-based studies highlighting primarily legal problems, this study shifts the analytical focus to satellite ownership as a critical variable affecting space sustainability. This is justified not only by the rapid expansion of satellite launches but also by the debris generated and comparatively underexplored role of ownership structures in the existing scholarship. Furthermore, the purpose of the study extends beyond problem identification towards proposing a solution based on RE-PGM model, including adapted principles, space science communication mechanisms and economics norms.

To evaluate the implications of satellite ownership structures the study conducted an extensive analysis of UNOOSA and UCS databases, which led to the following conclusions; the USA and China are the most dominant state actors in space. Contrary to the early beginnings in 1960s, when all major actors were public companies, nowadays, the main actors in space are both

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

public and private companies. Besides departments of defense, national intelligence agencies, academic/ government development agencies, the world has witnessed the growth of commercial companies including Starlink, Planet Labs, Chang Guang Satellite Technology, Hulianwang Digui, etc. The expanding plurality and heterogeneity of space stakeholders are consistent with the premises of the polycentric governance model that interprets the relations between the space stakeholders as a network of independent nodes rather than a hierarchical system. Both government and commercial companies have the ability to make their decisions with some degree of independence, and in coordination with other actors. The UN serves as an international forum to discuss and create international space law; however, it lacks enforcing mechanisms to compel the states to obey the law. At national level, states exercise regulatory authority over private companies through providing/ denying launch licenses, taxation and the obligation to register satellites in domestic registries. However, many of these companies are multinational companies, providing their services globally, and therefore, reducing the capability of a national government to regulate their operations.

This further raises the issue of transparency and communication. The international law obliges states to register satellites within the UN. The database is publicly accessible, an open-data source providing launch information, including launching state and company and launch date. This rule was originally created on a premise that transparency in launch data would decrease the risk of incidents and prevent possible collisions. However, companies are not obliged to register satellites with the UN, they are obliged to register them at national registries, after which states are responsible for transmitting information to the UN. However, the investigation of UNOOSA database showed that satellites launched by private companies in 2025, including Starlink, are still not registered with the UN at the time of writing this study. At the same time, the USA national registry is not publicly accessible. This limited transparency undermines the role of the international law, and potentially increases the risks of incidents. One of those incidents was a close approach, almost causing a collision, between a Starlink and CAS satellite in December 2025 (Space News 2025).

The purpose of this study extends beyond problem identification and advances the scholarship by proposing responsibility-embedded polycentric governance model (RE-PGM) aimed at improving sustainability in space. For this reason, the study conducted an in-depth examination of the UCS satellite database, which provides detailed information on satellite operators (private, public ownership) and their purpose. This data was combined with a qualitative review of company-level information, including the analysis of satellite design, technology, core business and services provided.

To systematically assess the governance implications of the above-mentioned data, the empirical findings are evaluated under the responsibility-embedded polycentric governance model, analytical design principles (ADPs) and space science communication mechanisms. These principles provide a framework for enhancing transparency, participation, monitoring communication and adaptive governance. ADP 1 (*Invest in science to understand the resource and its interactions with users and those affected by its use*) pertain to knowledge condition, ADP 2 (*Establish independent monitoring of the resource and its use that is accountable to the range of interested and affected parties*) pertain to monitoring ADP 3~5 pertain to participation, i.e. increasing participation of various stakeholders, while ADP 6~7 pertain to adaptive governance (Table 8). .

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

The empirical findings are consistent with ADP1 as both the USA and China possess satellites with purpose of space research and technological development. However, scientific understanding (ADP1) is dependent also on openly-shared data, and interoperable SSA systems (ADP2). At this point, both sides, including commercial, government and military companies, do not share data in this transparent manner; however, Starlink revealed more data related to technical design and purpose compared to other players.

ADP 3~5 pertain to the increased participation of relevant stakeholders, including scientific community, private sector and media. Scientific findings should be made relevant and serve as a foundation behind policies. However, governments and private companies tend to overlook science for profit. Strengthening the role of science, therefore, requires well-informed and engaged civil society. This can be achieved through engaging the general public through *space science education* offered by space researchers in an accessible and easy to read formats. Their lectures and research findings can be published on science news portals. On the USA side, this is offered by organizations such as the *Space Foundation* and *Space News*; however, their focus is more on sharing the news, while lectures are accessible with a subscription. On the China's side, daily newspapers *South China Morning Post* and *Xinhua* offer space related news while lectures are not presented. On both sides, space agencies NASA and CNSA present space news, along with public reports and some educational materials. However, as both are government space agencies they cannot be understood as independent voice of scientists. In the same vein, their reports aim to engage people by increasing their interest in space; however, they do not equip people with information necessary to be engaged on policy-creation level. For example, there is a lack of information related to licencing of private launch companies, related benefits and concerns. Especially, there is a lack of communication channels that can be equivalent to "public consultation" or "public voting" (space science communication mechanisms – national level).
In contrast, the examination of UNOOSA proved that there are abundant lecture materials for the general public on topics ranging from space law, policy, economy towards sustainability. However, the reports on national compliance with the international law and practical information that can equip general public to participate in "public consultations" and "public voting" on national levels should be enhanced. This can be done by publishing shortened versions of long reports that are easily understood by the general public.

Analysis of qualitative data demonstrated that information on satellites' purpose and technological design is not always publicly accessible, in particular military satellites. Both states, the USA and China, revealed very little data on their design and their purpose/ mission. Contrary to this, data on commercial satellites is publicly available, including details on satellite design and materials used. This is especially true for Starlink satellites. ADP 6 and 7 pertain to governance and institutional design. The study deems essential to enhance science communication in both vertical and horizontal form; vertical pertains to communication from low-level stakeholders such as NGOs and civil society towards national governments and the UN, whereas horizontal communication refers to popularizing science-based public discourse on sustainability. The findings indicate that vertical communication should be enhanced by *space education* so that the general public may be equipped with

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

the necessary information to participate in a dialogue with the respective governments. Furthermore, as mentioned above dialogue might be insufficient, instead mechanisms of "public consultations" and "public voting" should be adopted for the general public to be included in a decision making process. In this way, the respective national governments would be compelled to become more transparent when adopting new space policy or providing new licences.

Table 8. Analysis through RE-PGM and ADP conditions

ADP number and name	Category/ condition	Implication
ADP 1: Invest in science to understand the resource and its interactions with users and those affected by its use.	Knowledge condition.	It is necessary to have openly-shared data, and interoperable SSA systems (Interaction with ADP2).
ADP 2: Establish independent monitoring of the resource and its use that is accountable to the range of interested and affected parties.	Monitoring condition.	Interaction with ADP1, effective monitoring is possible with open and transparent data and interoperable SSA systems.
ADP 3: Ensure meaningful participation of the parties in framing questions for analysis, defining the import of scientific results, and developing rules	Participation condition. (NGOs, businesses, scientific and civic society)	Dissemination of scientific results though media, engaging the civil society.
ADP 4: Integrate scientific analysis with broad-based deliberation	Participation condition. Science – based decision making process.	Well informed and engaged civil society may create pressure to the governments to adopt science-based decision making.
ADP 5: Higher-level actors should facilitate participation of lower-level actors	Participation condition. Encouraging pluralistic participation of new space actors, including private sector.	Well informed and engaged civil society may create pressure to the governments to adopt science-based decision making.
ADP 6: Engage and connect a variety of institutional forms from local to global in developing rules, monitoring, and sanctioning.	Adaptive governance Multi-level nature of space as polycentric system. Suggested decentralization while strengthening the interconnections.	Enhancing horizontal communication in public.
ADP 7: Plan for institutional adaptation and change	Adaptive governance Complement UN institutional design with the inclusion of other actors, including low-level actors (ADP 3, 5 and 6).	Enhancing vertical communication format.

Source: Author's work based on citations above

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

Quantitative findings offer some other implications as well. The most numerous satellites on both sides, the USA and China, are commercial satellites. Companies such as Starlink, Chang Guang Satellite Technology, and Hulianwang Digui operate for own profit while depleting global common good. These companies may be further incentivized by the fact that they do not need to pay the externality tax, which is normally applicable to polluters on the Earth. To make sustainability issue move from normative towards real, practical solutions, this study deems that the Precautionary Principle and Polluter Pays Principle (PPP) should be integrated into governance model. The Precautionary Principle is closely connected to the above-mentioned science communication. Governments and profit-oriented private companies may neglect the risks of space pollution, including the issue of growing space debris. Strengthening science communication, ensuring transparency and public engagement are, thus, essential preconditions to operationalize Precautionary Principle within the governance model.

In contrast, PPP should be operationalized in a form of externality tax. This may be collected in the process of license acquiring or it may be charged per launch. The money collected should be used to finance the removal of space debris. This may further incentivize the development of debris removal related business, as for now this business is deemed unprofitable (Buitrago-Leiva et al. 2025). Another connected condition may be debris in relation to the type of materials used. Most satellites are made out of aluminium, thus satellites eventually dissolve into smaller metal pieces that increase the pollution. PPP may be reduced for satellites made out of biodegradable materials or for satellites made in a way that increases their lifecycle, reducing the need of launching new satellites (Vivatech 2026).

6. Discussion and Conclusion

The study examined and proved the significance of satellite ownership structures (and the pertaining satellites' mission, and technological design) for the sustainability in space. With the increased reliance on space technology across industrial sectors including; communication, navigation, satellite imagery, military intelligence, metrology, disaster management, medicine, biotechnology etc., there has been an expansion of public and private satellites. This situation created the increased risks of collisions and environmental pollution. Satellites commonly have a lifespan of about one year to fifteen years (UCS database), at the end of their lifecycle they effectively become unoperational (zombie satellites) or they decay into pieces of metal (debris) that continues to orbit around the Earth and potentially collide with other satellites or burn as they re-enter Earth's atmosphere (Buitrago-Leiva et al. 2025). Scientists across different disciplines have pointed out to these problems with a limited success as to providing potential solutions.

This study contributed to the scholarship by proposing Responsibility-Embedded Polycentric Governance Model (RE-PGM), including seven adapted principles (ADPs), two space science communication mechanisms , and the Precautionary Principle and the Polluter Pays Principle (PPP) as a practical model to enhance space sustainability. The model identifies the crucial role

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

of science communication across all ADPs and active participation of stakeholders including scientists, NGOs, media, and the general public. The study understands that the international law, even its biding principles, is fragile to national governments' decision-making, i.e. it lacks enforceability mechanisms. For this reason, communication and active participation of the above-mentioned stakeholders is essential to raise awareness of space sustainability and exert pressure on national governments to adopt science-based decision-making process.

The study further stresses the significance of transparent and publically-accessible data. This is essential not only for reducing risks of potential collisions, but also for fostering trust among wide-spectrum of stakeholders. Sustainable space depends on effective governance, which in turn requires meaningful stakeholder participation, which depends on access to reliable, timely and verifiable data.

The study has several limitations. The empirical analysis focused on the USA and China, identified as dominant state actors, together with their private/ public companies in space. The findings reveal a profound disparity in satellite ownership between these powers and other states. Although Russia, the EU and the UK maintain space programs, they have considerably less satellites compared to the USA and China. Such concentration of satellite ownership can cause asymmetries in technological development and economic development, amid growing dependence on space technology and rapid development of space economy. It may also cause ethical problems, even near-monopolistic competition, due to concentration of satellites in hands of few private companies. Furthermore, it may cause greater developmental gaps between Global North and Global South, as Global South countries lack national and corporate resource to rival space programs of developed countries. These implications are related to the subject of this study – satellite ownership, but because of their scope they should be addressed in a future, separate study.

Code and data availability

Author declares that all sources used are listed in the reference list.

Author contributions

ZZ as a sole author is responsible for the whole research paper.

Competing interests

Author declares no competing interests.

Ethical statement

Ethical approval was not required for this study as it is conceptual work that did not include human participants or collection of primary empirical data.

Disclaimer

Copernicus Publications adds a standard disclaimer: "Copernicus Publications remains neutral with regard to jurisdictional claims made in the text, published maps, institutional affiliations, or any other geographical representation in this paper. While Copernicus Publications makes every effort to include appropriate place names, the final responsibility lies with the authors. Views expressed in the text are those of the authors and do not necessarily reflect the views of the publisher."
Please feel free to add disclaimer text at your choice, if applicable.

Acknowledgements

Besides the author's statement of gratitude to and recognition of the people and institutions that helped the author's research and writing, authors are also asked to include relevant research infrastructure they have benefitted from during their research, where research was conducted or data/resources were used. Examples are Field Stations and Marine Laboratories (FSMLs).

Financial support

This work was supported by a 2-year Research Grant of Pusan National University.

Review statement

The review statement will be added by Copernicus Publications listing the handling editor as well as all contributing referees according to their status anonymous or identified.

References

Al-Rodhan, Nayef. 2019. "Meta-Geopolitics of Outer Space, National Power and Global Politics."
Atlantic Council. 2026. "Small Satellites. The Implications for National Security." Accessed February 13, 2026. https://www.atlanticcouncil.org/in-depth-research-reports/report/small-satellites-the-implications-for-national-security/.
Buitrago-Leiva, Jeimmy Nataly, Mohamed El-Khayati-Ramouz, Adriano Camps, and Joan A. Ruiz-de-Azua. 2025. "Operational and Regulatory Assessment for Satellites Recycling." Space Policy. Elsevier Ltd. https://doi.org/10.1016/j.spacepol.2025.101705.

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

Campodonico, Camilla. 2023. “ADVANCING SPACE ENVIRONMENTAL SAFETY.” Journal of Law, Market & Innovation 2 (2): 43–70.

Chowdhury, Ditipriya Dutta. 2022. “The Conundrum of Space Debris and Its Sustainable Remediation by Polluter Pays Principle.” NUJS Journal of Regulatory Studies 7 (3). https://heinonline.org/HOL/Page?handle=hein.journals/nujsjlry7&id=280&div=30&collection=journals.

Cirkovic, Elena, Minoo Rathnasabapathy, and Danielle Wood. 2021. “Sustainable Orbit and the Earth System: Mitigation and Regulation.” Proc. 8th European Conference on Space Debris (Virtual), no. April: 20–23.

China in Space. 2026. “China's mega-constellations mega-article.” Accessed January 28, 2026. https://www.china-in-space.com/p/chinas-mega-constellations-mega-article.

CircleID.2026.”Global Domain Report 2026.” Accessed January 28, 2026. https://circleid.com/posts/chinese-leo-satellite-internet-update-guowang-qianfan-and-honghu-3.

Clery, Daniel. 2026. “Burned-up satellites are polluting the atmosphere; As commercial fleets grow, concerns raised about ozone-destroying effects of metal particles.” Science. Accessed February 11, 2026. https://www.science.org/content/article/burned-satellites-are-polluting-atmosphere.

Chaudhry, A. U. and H. Yanikomeroglu. 2021. "Laser Intersatellite Links in a Starlink Constellation: A Classification and Analysis," in IEEE Vehicular Technology Magazine, vol. 16, no. 2, pp. 48-56, June 2021, doi: 10.1109/MVT.2021.3063706.

Calian. 2026. “Iridium Satellite Communications. Accessed February 13, 2026. https://at.calian.com/gnss__trashed/applications/iridium-satellite-communications/.

China Aerospace Studies Institute. 2026. “Chang Guang Satellite Technology.” Accessed February 14, 2026. /https://www.airuniversity.af.edu/Portals/10/CASI/documents/Research/Space/2024-04-01%20Chang%20Guang%20Satellite%20Company%20overview.pdf

China Satellite Communications. 2026. Accessed February 14, 2026. http://english.csat.spacechina.com/n931656/n931661/index.html.

Chang Guang Satelite Technology Co., Ltd. 2026. Accessed February 14, 2026. https://www.jl1global.com/.

Eoportal. 2026. “Yunyao Aerospace Constellation.” Accessed January 28, 2026. https://www.eoportal.org/satellite-missions/yunyao#eop-quick-facts-section

Freeland, S., and D. Ireland-Piper. 2022. “Space Law, Human Rights and Corporate Accountability.” UCLA Journal of International Law and Foreign Affairs 1 (26): 1–34.

Gunter’s Space Page. 2026. “Iridium.” Accessed February 13, 2026. https://space.skyrocket.de/doc_sdat/iridium.htm

Gunter’s Space Page. 2026c. “Tianhui 1-01, 1-02, 1-03, 1-04.” Accessed February 14, 2026. https://space.skyrocket.de/doc_sdat/tianhui-1.htm.

Hasin, Gershon. 2023. “From ‘Space Law’ to ‘Space Governance’: A Policy-Oriented Perspective on International Law and Outer Space Activities.” Harvard International Law Journal 64 (2): 385–430. https://doi.org/10.2139/ssrn.4179934.

Iridium. 2026/ Accessed February 13, 2026. https://www.iridium.com/.

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

Kipanga, Kassim B., and Manzoor Hassan. 2025. “Space Activities for Sustainability and the Role of the National Space Agencies.” Beijing Law Review 16 (02): 1227–59. https://doi.org/10.4236/blr.2025.162063.

KeepTrack. 2026. “Huliangwang Digui-05.” Accessed February 14, 2026. https://www.keeptrack.space/satellite?s=62327

Lambach, Daniel, and Luca Wesel. 2021. “Tackling The Space Debris Problem: A Global Commons Perspective.” Researchgate.Net, no. 1: 1–19. https://www.researchgate.net/profile/Daniel-Lambach-2/publication/351064949_Tackling_the_Space_Debris_Problem_A_Global_Commons_Perspective/links/60826947907dcf667bb9b107/Tackling-the-Space-Debris-Problem-A-Global-Commons-Perspective.pdf%0Ahttps://www.esa.

Humphreys, Todd E., Peter A. Iannucci, Zacharias M. Komodromos, Andrew M. Graff. 2023. “Signal Structure of the Starlink Ku-Band Downlink.” IEEE Transactions on Aerospace and Electronic Systems, Volume 59, Issue 5. https://ieeexplore.ieee.org/document/10107477.

Maiwald, Volker. 2023. “Frameworks of Sustainability and Sustainable Development in a Spaceflight Context: A Systematic Review and Critical Analysis.” Acta Astronautica 204: 455–65. https://doi.org/10.1016/j.actaastro.2023.01.023.

Ma, Sami, Yi Ching Chou, Haoyuan Zhao, Long Chen, Xiaoqiang Ma, Jiangchuan Liu. 2023. “Network Characteristics of LEO Satellite Constellations: A Starlink-Based Measurement from End Users.” EEE INFOCOM 2023 - IEEE Conference on Computer Communications, New York City, NY, USA, 2023, pp. 1-10, doi: 10.1109/INFOCOM53939.2023.10228912.

Market Screener. 2026. Iridium Communications Inc. Accessed February 13, 2026. https://www.marketscreener.com/quote/stock/IRIDIUM-COMMUNICATIONS-IN-5602836/company-shareholders/.

Mo, Weiwei, Brad L Kinsey, John Vickers, and Henry Helvajian. 2024. “Conceptualizing Space Environmental Sustainability.” Npj Adv. Manuf. 1, 2 (2024) 2. https://doi.org/https://doi.org/10.1038/s44334-024-00002-z.

Manohar Parrikar Institute for Defense Studies and Analysis. 2026. “China’s Space-based Surveillance Capabilities. Accessed February 14, 2026. https://idsa.in/publisher/issuebrief/chinas-space-based-surveillance-capabilities.

Nanosats Database. 2026. “CSTP Spacecraft.” Accessed January 28, 2026. https://www.nanosats.eu/sat/cstp.

NRO. 2026a. “Innovation, partnership, and agility key to deterring threats in space, NRO director says at IC summit.” Accessed February, 12, 2026. https://www.nro.gov/news-media-featured-stories/news-media-archive/News-Article/Article/3890394/innovation-partnership-and-agility-key-to-deterring-threats-in-space-nro-direct/.

Ostrom, Elinor. 2010. “Polycentric Systems for Coping with Collective Action and Global Environmental Change.” Global Environmental Change 20 (4): 550–57. https://doi.org/10.1016/j.gloenvcha.2010.07.004.

Palmroth, Minna, and Janne I. Hukkinen. 2025. “Expanding Use of Space Is an Opportunity for Sustainability but a Threat to Resilience.” Ecology and Society 30 (2). https://doi.org/10.5751/ES-16056-300206.

Pippo, Simonetta Di. 2016. “Registration of Space Objects with the Secretary-General.” IISL-ECSL Symposium ``40 Years of Entry into Force of the Registration Convention - Today’s Practical Issues" 55th Legal Subcommittee 364. https://www.unoosa.org/documents/pdf/copuos/lsc/2016/symp-03.pdf.

Poonuganti, Sraavya. 2023. “It ’ s Raining Rockets : Heightening State Liability for Space Pollution Sraavya Poonuganti *.” Chicago Journal of International Law 23 (2): 490–525.

https://doi.org/10.5194/egusphere-2026-1150
Preprint. Discussion started: 20 May 2026

Stern, Paul C. 2011. "Design Principles for Global Commons: Natural Resources and Emerging Technologies." International Journal of the Commons 5 (2): 213–32. https://doi.org/10.18352/ijc.305.

Space news. 2026 b. "Chinese sea launch sends 10 navigation enhancement satellites into orbit." https://spacenews.com/chinese-sea-launch-sends-10-navigation-enhancement-satellites-into-orbit/

Satelitemap Space. 2026. "FSKL5695-14." Accessed January 28, 2026. https://satellitemap.space/sat/64885

Space Foundation 2026b. "The Space Report 2025 Q2 Highlights Record $613 Billion Global Space Economy for 2024, Driven by Strong Commercial Sector Growth." Accessed February 28, 2026. https://www.spacefoundation.org/2025/07/22/the-space-report-2025-q2/.

SpaceX. 2026. "Brightness Mitigation Best Practices for Satellite Operators." Accessed February 11, 2026. https://starlink.com/public-files/BrightnessMitigationBestPracticesSatelliteOperators.pdf.

Space News. 2025. "SpaceX claims close approach to Starlink satellite by payload from Chinese launch." Accessed May 5th, 2026. https://spacenews.com/spacex-claims-close-approach-to-starlink-satellite-by-payload-from-chinese-launch/.

Space News. 2026b. "China expands secretive satellite series with launch of TJS-15." Accessed February 14, 2026. https://spacenews.com/china-expands-secretive-satellite-series-with-launch-of-tjs-15/.

UNOOSA. 2026. "Online Index of Objects Launched into Outer Space." Accessed January 20, 2026. https://www.unoosa.org/oosa/osoindex/search-ng.jspx?lf_id=#?c=%7B%22filters%22:%5B%5D,%22sortings%22:%5B%7B%22fieldName%22:%22object.launch.dateOfLaunch_s1%22,%22dir%22:%22desc%22%7D%5D%7D.

UCS. 2026. UCS Satellite Database. Accessed February 6, 2026. https://www.ucs.org/resources/satellite-database.

Vivatech. 2026. "Orbital Sustainability and the Future of Space Exploration." Accessed February 27, 2026. https://vivatech.com/news/orbital-sustainability-and-the-future-of-space-exploration.

World Forum. 2026. "Who owns our orbit: Just how many satellites are there in space?" Accessed January 27, 2026. https://www.weforum.org/stories/2020/10/visualizing-easrth-satellites-sapce-spacex/.