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Limitation of the “Freedom Principle” in the Earth’s Orbits – A
Law and Economics Perspective

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Abstract

This dissertation examines the intensifying use of Earth's orbits, with particular focus on low Earth orbit (LEO), where satellite deployments have grown exponentially due to the proliferation of large satellite constellations. Combined with legacy space debris and the inherently limited capacity of orbital space, this growth places LEO under increasing stress, heightening the risk of congestion, collision cascades, and potential inaccessibility of outer space. Against this backdrop, the dissertation analyses the freedom principle enshrined in Article I of the Outer Space Treaty and the limits governing its exercise in the orbital environment. It further examines the role of the International Telecommunication Union regime, alongside relevant principles of international environmental law. In doing so, it identifies the structural legal and economic features that contribute to the overexploitation of LEO. Accordingly, interdisciplinary Law and Economics, complemented with critical approaches, are employed to provide new analytical lenses for addressing the sustainability of the orbital space environment, particularly in LEO. The dissertation argues that sustainable orbital governance requires a paradigm shift toward precautionary, limits-based regulation grounded in ecological constraints, equity, and long-term system integrity, and advances *de lege ferenda* proposals to operationalise such an approach within international space law and governance.

Kurzfassung

Diese Dissertation untersucht die sich zunehmend intensivierende Nutzung der Erdborbits, mit besonderem Fokus auf den niedrigen Erdborbit (Low Earth Orbit, LEO), in dem die Zahl der Satelliteneinsätze infolge der Verbreitung großer Satellitenkonstellationen exponentiell angestiegen ist. In Verbindung mit bereits bestehendem Weltraummüll und der inhärent begrenzten Kapazität des orbitalen Raums, setzt dieses Wachstum den LEO zunehmend unter Druck und erhöht das Risiko von Überlastung, Kollisionskaskaden sowie einer potenziellen Unzugänglichkeit des Weltraums. Vor diesem Hintergrund analysiert die Dissertation das in Artikel I des Weltraumvertrags verankerte Freiheitsprinzip sowie die Grenzen seiner Ausübung im orbitalen Raum. Darüber hinaus untersucht sie die Rolle des Regimes der Internationalen Fernmeldeunion (International Telecommunication Union) sowie relevante Grundsätze des internationalen Umweltrechts. Dabei werden die strukturellen, rechtlichen und ökonomischen Faktoren, die zur Übernutzung des LEO beitragen. Infolgedessen werden interdisziplinäre Ansätze der Law and Economics, ergänzt durch kritische Perspektiven, herangezogen, um neue analytische Zugänge zur Nachhaltigkeit der orbitalen Umwelt, insbesondere des LEO, zu entwickeln. Die Dissertation vertritt die These, dass eine nachhaltige Governance des orbitalen Raums einen Paradigmenwechsel hin zu einer vorsorgeorientierten, grenzbasierten Regulierung erfordert, die auf ökologischen Grenzen, Gerechtigkeit und langfristiger Systemintegrität beruht, und entwickelt de lege ferenda Vorschläge zur Operationalisierung eines solchen Ansatzes im internationalen Weltraumrecht und der Weltraumgovernance.

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“Inescapably we reach the conclusion that the very possibility of freedom is in question. If regulation is the only means of spreading and strengthening freedom in a complex society, and yet to make use of this means is contrary to freedom per se, then such a society cannot be free”.¹

CHAPTER I. Current tendencies in the Earth’s orbits

A. Introduction

Humanity is witnessing an exponential growth of objects which set course on our finite usable trajectories. Only in 2022 the United Nations Office for Outer Space Affairs (UNOOSA) registered a record number of launches, delivering more than 2470 objects into orbit.² Out of the launched objects, in the last years, there has been an enormous increase in the number of commercial satellites launched in our trajectories, adding to the diversity of space actors and challenges of the long-term sustainability of outer space activities. Nevertheless, many of the newly launched satellites are being placed into large constellations, implying the placement of thousands of small satellites in the orbits.

Society remains unaware of their irreversible reliance on access to the global space infrastructure for their daily lives. While small satellites and large constellations bring great socio-economic benefits, they may induce space debris accidents, accelerating the overpopulation of the limited orbital space environment. Space debris scientists have projected for many years that the uncontrolled proliferation of debris appears to be inescapable (at least

¹ Karl Polanyi, *The Great Transformation – The Political and Economic Origins of Our Times* (3rd edn, Beacon Press, 2001) (first published 1944) 266.

² United Nations, ‘For All Humanity – the Future of Outer Space Governance – Our Common Agenda Policy Brief 7’ (May 2023) 4.

in LEO regions) no matter what degree of prevention is applied.³ At the same time, besides the application of crucial mitigation measures, actors may find themselves depending on non-existing remediation technologies (such as active debris removal), that can be viewed as a form of techno-optimism, a seemingly failing paradigm that dominates the global efforts in mitigating ecological damage caused on the surface of the Earth.

Nonetheless, no space actor acts against international law when it invests in the continuous placement of satellites in low Earth orbit (LEO) without considering the actual carrying capacity of the orbit. In fact, international space law (with the drafting of the Outer Space Treaty in 1967) was formed on the concept of the freedom principle, which promotes the rapid growth of the space economy with its costs externalized onto both the orbital and surface environment of the Earth. Although important *limitations on the freedom principle* appear in various hard and soft law instruments, there remains a striking absence of mechanisms capable of addressing the accelerating trend of launching massive numbers of (small) satellites into low Earth orbit. Left unaddressed, this development could ultimately jeopardize humanity's future access to space.

As a reflection to the above tendencies and arguments, the main questions to be answered in the framework of this dissertation can be summarized as follows:

1. Is there a legal lacunae regarding the limitation of the freedom principle in international space law with respect to the use of Earth orbits, especially to LEO?
2. If there is a legal lacunae, how can it best be addressed in accordance with international law in order to protect the Earth orbits and associated space activities?

While keeping the two research questions in mind, this chapter introduces the current tendencies and challenges in the Earth's orbits – especially in LEO – with the aim of highlighting the seriousness of the emerging risks. Chapter II then examines the Earth's orbits and relevant radio-frequency spectrum as natural resources, providing a broader contextual

³ J.-C. Liou and A.K. Anil Kumar, et al., 'Stability of the Future LEO Environment – An IADC comparison study' (April 2013) 1, 7.
<https://www.researchgate.net/publication/266584674_STABILITY_OF_THE_FUTURE_LEO_ENVIRONMENT_-_AN_IADC_COMPARISON_STUDY> accessed 20 October 2025; or Moriba Jah, 'Space Debris Will Block Space Exploration Unless We Start Acting Sustainably', *Scientific American* (August 1, 2023) <<https://www.scientificamerican.com/article/space-debris-will-block-space-exploration-unless-we-start-acting-sustainably/>> accessed 20 September 2025.

foundation for the analysis. Chapter III considers the existing legal mechanisms (de lege lata) that determines the extent of the freedom principle and its limitations as applied to orbital space. Chapter V subsequently approaches the issue from a law-and-economics perspective, advancing proposals shaped by complementary critical insights.

B. Understanding Earth's orbits – a scientific perspective

Despite the universe' unfathomable scale, Earth's orbital space is subject to concrete physical and operational limitations. This comparatively minuscule region of the Solar System, extending from the Kármán line, roughly 80-100 km above sea level,⁴ to the Geosynchronous Orbit at approximately 36 000 km, is broadly recognized as the orbital space surrounding the Earth.⁵ Unlike the theoretical boundlessness of cosmic space, the near-Earth orbital environment is constrained by orbital mechanics, radiation exposure threshold, and the exponential growth of human-made objects.⁶ These physical and operational constraints emerge from fundamental astrodynamics principles.⁷ Earth's gravitational pull generates stable orbital pathways – curved paths or trajectories along which both natural celestial bodies and

⁴ No formal boundary between airspace and outer space has been internationally agreed upon so far. UNCOPUOS has been debating the definition and delimitation of outer space for many decades and has issued several reports but without reaching a decision. A widely, though unofficially, accepted approach to defining between airspace and outer space is the designation of the so-called Kármán line, typically placed between 80 and 100 kilometres above sea level, serving as a practical reference point. To find relevant documents on the discussions taking place at the Working Group on the Definition and Delimitation of Outer Space of the Legal Subcommittee, see: <https://www.unoosa.org/oosa/en/ourwork/copuos/lsc/ddos/index.html> To learn more on the topic, see for example: Tanja Masson-Zwaan and Mahulena Hofmann, *Introduction to Space Law* (5th edn, Wolters Kluwer 2024) 13-15; Gyula Gál, *Space law* (A. W. Stijhoff and Akadémiai Kiadó 1969) 59-105.

⁵ Andy Lawrence, Moriba Jah, et al., 'The Case for Space Environmentalism' (2022) 6 *Nature Astronomy* 428, 428.

⁶ The issue of radiation exposure to space systems, human space flight and the ground- and space-based infrastructure is predominantly addressed within space policy frameworks through space weather monitoring and mitigation strategies. The item of Space Weather has been on the agenda of the Scientific and Technical Subcommittee of the Committee on the Peaceful Uses of Outer Space since 2013. To see current topics on the issue of Space Weather, see for example: UNCOPUOS, STSC 'Draft Report, VI. Space weather' (7 February 2025) Un Doc. A/AC.15/C.1/L.420/Add.5.

⁷ To learn more about the Earth's orbits, see: Gérard Maral, Michel Bousquet and Zhili Sun, *Satellite Communications Systems: Systems, Techniques and Technology* (6th edn, John Wiley & Sons Ltd, 2020) 11-16 and 29-110.

artificial satellites revolve.⁸ Orbits are distinctive physical phenomena that emerge from the balance between the gravitational pull of a celestial body and the velocity of an object placed in motion. The trajectory lies in a single plane and follows an elliptical shape, reaching its farthest point from Earth, called apogee and its closest point, named the perigee.⁹ While cosmic space may appear infinite, the delicate equilibrium between gravitational attraction and inertial motion renders near-Earth orbital space a finite and carefully balanced system. In basic terms, an orbit constitutes a state of continuous freefall relative to the Earth's surface. An object in orbit travels forward along a trajectory parallel to the Earth's surface, while simultaneously being pulled downward by gravity. However, as the object "falls" the curvature of the Earth causes the surface to recede beneath it, enabling sustained orbital motion. This gravitational mechanism not only maintains orbital stability but also defines the spatial parameters within which all Earth-orbiting objects must operate. Velocity is a key determinant of orbital stability. The required speed varies with altitude due to changes in both the Earth-satellite geometry and the strength of gravitational force at different distances from Earth. Beyond velocity and altitude, orbits are further characterized by several additional parameters, including their shape (circular or elliptical), inclination (the angle between the orbital plane and the Earth's equatorial plane), and orbital period (the duration required for a complete revolution around the Earth).¹⁰

For an object to be placed into orbit, it must be accelerated beyond the Earth's atmosphere and then reach a sufficient velocity to achieve stable orbital motion. The forward velocity of an orbiting object ensures that Earth's gravitational force continuously redirects, but does not overcome its motion, resulting in a stable path around the planet. This distinction marks the fundamental difference between the V-2 rocket launch in 1944, which resulted only

⁸ While artificial satellites are human-made objects deliberately positioned in orbit around celestial bodies, natural satellites – astronomically known as moons (a term derived from the Earth's Moon) – are celestial bodies that naturally orbit planets, dwarf planets, or Solar System objects. See: Ian Ridpath, *A Dictionary of Astronomy* (2nd ed. Oxford University Press, 2012)

<https://www.oxfordreference.com/display/10.1093/acref/9780199609055.001.0001/acref-9780199609055?btog=chap&hide=true&page=29&pageSize=20&skipEditions=true&sort=titlesort&source=%2F10.1093%2F9780199609055.001.0001%2F9780199609055> accessed 20 September 2025.

⁹ Gérard Maral, Michel Bousquet and Zhili Sun, *Satellite Communications Systems: Systems, Techniques and Technology* (6th edn, John Wiley & Sons Ltd, 2020) 11.

¹⁰ David Wright, Laura Grego, and Lisbeth Gronlund, *The physics of space security* (American Academy of Arts and Sciences, 2005) 19-28.

in a suborbital trajectory, and the 1957 launch of Sputnik I, which attained true orbital flight.¹¹ There are theoretically infinite orbital trajectories, but particular characteristics – such as altitude, inclination, shape, and orbital period – make certain orbits better suited to specific applications. As a result, certain orbital regions are more intensively used and increasingly subject to congestion, raising both practical and legal concerns around equitable access and sustainable use.¹²

Accordingly, the most favourable orbits can be listed as (1) elliptical orbits, (2) circular low Earth orbits (LEO), (3) circular medium Earth orbits (MEO), (4) circular orbits with zero inclination equatorial orbits (most popular is the geostationary satellite orbit – GEO), (5) and hybrid orbit systems. Each of these orbital zones represents a distinct balance between gravitational forces and operational utility, with altitude and inclination determining their unique characteristics and applications.¹³ Important to note for later reference, specific to LEO that a LEO shell is defined by two orbital parameters, inclination (the tilt of the orbit relative to the Earth's equator) and orbital altitude (the average height of the satellites above Earth's surface).¹⁴ Due to the focused and limited scope of this dissertation, attention will be directed to the two most commonly used orbits (LEO and GEO), and the regulatory frameworks that apply to them.

Among the equatorial orbits, the most popular is the geostationary orbit (GEO). In GEO, satellites circle the Earth in the equatorial plane at an altitude of approximately 35 786 km, matching the planet's 24-hour rotational period.¹⁵ This synchronisation allows a GEO satellite to remain fixed over a single point on the Earth's surface. As a result, GEO constitutes a vital orbital region for telecommunications, weather monitoring, and military applications,

¹¹ See: P.J. Blount, 'Legal Issues Related to Satellite Orbits' (December 2022) *Oxford Research Encyclopedia of Planetary Science* 1, 3 <<https://doi.org/10.1093/acrefore/9780190647926.013.78>>.

¹² Ibid., 3.

¹³ Gérard Maral, Michel Bousquet and Zhili Sun, *Satellite Communications Systems: Systems, Techniques and Technology* (6th edn, John Wiley & Sons Ltd, 2020) 11.

¹⁴ See for example: Cees Bassa, Olivier Hainaut and David Galadí-Enríquez, 'Analytical simulations of the effect of satellite constellations on optical and near-infrared observation' (2022) 657, *Astronomy and Astrophysics* A75 5.

¹⁵ Ibid., 13. Geostationary orbit (GEO) is a specific subset of geosynchronous (GSO) orbit. Both share an orbital period equal to the Earth's rotation (24 hours) and operate at an altitude of approximately 35 786 km. However, while GEO lies in the equatorial plane and thus remains fixed over a single point on Earth's surface, GSO satellites may have various orbital inclination and therefore do not remain stationary, tracing a figure-eight pattern in the Earth's sky. See: Christy Collis, 'The geostationary orbit: a critical legal geography of space's most valuable real estate' (May 2009) 57, S1 *The Sociological Review* 47, 62

offering constant coverage of designated regions. This unique attribute enables continuous coverage over approximately one-third of the planet's visible hemisphere, allowing complete global coverage with just three optimally positioned satellites – a stark contrast to LEO, which requires hundreds of satellites to achieve comparable coverage continuity, as well as ground antennas that can track satellites as they pass overhead. (Conversely, circular MEOs can ensure continuous coverage with constellations consisting of approximately 10 to 15 satellites).¹⁶ However, this comes with significant trade-offs: the high altitude of 35,786 km results in substantially greater launch costs, noticeable signal latency, making real-time applications challenging, and reduced image resolution for Earth observation. Additionally, the availability of optimal GEO slots is physically constrained by the regulatory requirement to maintain a 2-3° separation between satellites to avoid signal interference. This constraint intensifies competition for prime orbital positions, a topic further examined in Chapter III under the regulatory framework of the International Telecommunication Union.

A different, currently highly popular orbital position is called circular low Earth orbit or LEO. Although most operational LEO satellites maintain altitudes between 200-1000 km, the region technically extends up to 2,000 km. The higher reaches of LEO see minimal satellite activity due to radiation hazards, with most missions preferring lower altitudes where orbital periods (the time a satellite takes to complete one full orbit around Earth) average 90 minutes.¹⁷ LEO's close proximity to Earth enables low-latency communications, ideal for real-time services and high-resolution imaging, along with easier and cheaper satellite deployment.¹⁸ However, comprehensive coverage requires more satellites, and atmospheric drag necessitates frequent orbital manoeuvring and periodic boost to maintain orbit. If the network incorporates

¹⁶ Gérard Maral, Michel Bousquet and Zhili Sun, *Satellite Communications Systems: Systems, Techniques and Technology* (6th edn, John Wiley & Sons Ltd, 2020) 13.

¹⁷ The choice of orbit determines the amount of shielding a satellite needs, based on whether and what part of the so-called Van Allen belts they will encounter. Van Allen belts are zones of energetic charged particles, most of which originate from the solar wind, that are captured by the Earth's magnetosphere. At altitudes of less than 500 to 1,000 km, the density of charged particles is low and little shielding is required for satellites. See: David Wright, Laura Grego, and Lisbeth Gronlund, *The physics of space security* (American Academy of Arts and Sciences, 2005) 39-40.

¹⁸ Real-time services refer to applications or systems that require immediate data processing and delivery with minimal latency where delays are measured in milliseconds and any lag would disrupt functionality. Some of the applications that use real-time services are, video conferencing, cloud gaming, autonomous vehicles, remote surgery, etc. For more, see: Gérard Maral, Michel Bousquet and Zhili Sun, *Satellite Communications Systems: Systems, Techniques and Technology* (6th edn, John Wiley & Sons Ltd, 2020) 376.

polar or near-polar orbits, it can extend coverage to polar and high-latitude regions – areas that GEO satellites are unable to effectively reach.¹⁹

To better contextualize the significance of orbital space and its associated risks, it is useful to develop a clearer understanding of the relative severity of the challenges it represents. In 2019, Williams Nordhaus, the 2018 Nobel prize winner in economic sciences shared with Paul Romer, proposed a helpful framing by posing two essential questions: “Is the problem real? and, “How serious is it in relative terms [to other global risks]?”²⁰ In response, he affirms that terrestrial climate change represents a major threat, marked by unpredictable, potentially dangerous consequences – thereby inviting comparison to similarly underappreciated risks, such as those posed by the growing congestion of orbital space. The following section reflects on these questions in the context of orbital over-exploitation and space debris proliferation.

C. Current tendencies in the Earth’s orbits

1. The role of satellites in modern society

The number of active satellites in space continues to rise rapidly, mostly due to the interest in the socio-economic benefits. At the beginnings of the Space Age, only two nations dominated this new frontier – the United States and the Soviet Union. By 2023, more than ninety countries have conducted space activities,²¹ and ten have reached space rocket launching capabilities.²²

According to the well-known geostrategist Nayef Al-Rodhan we can differentiate between seven state capacities, which define state power and legitimacy, that are: social and health issues; domestic politics; economics; the environment; science and human potential;

¹⁹ David Wright, Laura Grego, and Lisbeth Gronlund, *The physics of space security* (American Academy of Arts and Sciences, 2005) 40.

²⁰ William Nordhaus, ‘Climate Change: The Ultimate Challenge for Economics’ (2019) 109(6) *American Economic Review* 1991, 1991-2014.

²¹ UNOOSA, ‘Online Index of Launched Objects Launched into Outer Space’ (https://www.unoosa.org/oosa/osoindex/search-ng.jsp?lf_id=> accessed 20 October 2025).

²² Katharina Buchholz, ‘The Countries Capable of Launching Space Rockets’ (Statista, 18 July 2022) (<https://www.statista.com/chart/27792/countries-capable-of-launching-space-rockets/sdfsdf>) Accessed 20 September 2025.

military and security issues; and international diplomacy.²³ Al-Rodhan convincingly stipulates that outer space is critical for all seven state capacities.²⁴ Satellites play a pivotal role in the social and health sector, enabling remote delivery and communications, monitoring diseases, providing remote training for medical personnel, and integrating populations from remote areas into healthcare systems.²⁵ The positive impacts of space applications on health care has been especially proven globally in the context of the COVID-19 pandemic.²⁶ Within domestic politics, space assets contribute to border control and surveillance. Additionally, space activities have a historical association with national prestige, exemplified by the launch of the Apollo Program, which sent the first person to the Moon in 1969 and was celebrated globally as a triumph of the United States technological power and political leadership. The economic significance of space is also undeniable. In 2022, global government expenditure for space activities hit a record of approximately 103 billion US dollars,²⁷ which means a 19% boost since that year.²⁸ Moreover, the value of the global space economy is exponentially expanding and has reached 464 billion USD in 2022. Various industries heavily depend on space assets for daily operations, influencing sectors such as banking, aviation, global transportation.

In terms of the environment on the surface of the Earth, space assets – especially satellites that provide Earth observation (EO) applications – are crucial for early warning systems, urban and rural planning, and climate change monitoring. Within the realms of science and human potential, space supports strategic and high-technology industries, research and development, and military planning and operations. Space activities also foster collaboration between private and public entities. In the military and security domain, space assets or satellites are indispensable for providing critical support to air, sea and land force operation,

²³ Nayef Al-Rodhan, 'Implications of New Space Forces for Sustainable Space Terrestrial Security' (2021) Global Policy Journal <<https://www.globalpolicyjournal.com/blog/19/02/2021/implications-new-space-forces-sustainable-space-and-terrestrial-security>> accessed 20 September 2025.

²⁴ Ibid.

²⁵ United Nations, 'For All Humanity – the Future of Outer Space Governance – Our Common Agenda Policy Brief 7' (May 2023) UN Doc A/77/CRP.1/Add.6.

²⁶ See for example: Andrew de Naray, 'How Satellites are Fighting Coronavirus from Space' (June 2020) Space Foundation <<https://www.spacefoundation.org/2020/06/25/how-satellites-are-fighting-coronavirus-from-space/>> accessed 20 October 2025.

²⁷ Statista Research Department, 'Government expenditure on space programs worldwide from 2014 to 2022' (Statista, December 2023) <<https://www.statista.com/statistics/745731/global-governmental-spending-on-space-programs/>> accessed 20 September 2025.

²⁸ Space Foundation Editorial Team, 'Space Report 2022' (Space Foundation, 27 July 2022) <<https://www.spacefoundation.org/2022/07/27/the-space-report-2022-q2/>> accessed 20 October 2025.

particularly through facilitating navigation and observation. Military space endeavours, however, include the militarization of space itself and the development of anti-satellite and other counter-space capabilities. Last but not least, international diplomacy is influenced by space in terms of national prestige and has tangible impacts through information-gathering for compliance with international treaties. As Al-Rodhan argues, the strategic importance of space across all the seven state capacities justifies the allocation of financial (and military) resources for its protection and development of governments. In fact, satellite activities have proven to be so integral to modern society, that a report by the United Nations Office for Outer Space Affairs (UNOOSA) – the United Nations office, responsible for promoting international cooperation in the peaceful uses of outer space –²⁹ has called for the protection of the orbital space environment, given humanity’s growing and irreversible dependence on orbital infrastructure.³⁰ Moreover, it has become primary to ensure that both government and private investments in space activities are conducted in a manner that does not compromise the sustainable use of orbital space as a global commons.³¹

Viewed from a broader global perspective, the United Nations primarily justifies the need for the expansion of orbital space activities due to their role in promoting the sustainable development on Earth.³² Under the United Nations’ umbrella, sustainable development is measured and monitored through the achievement of the Sustainable Development Goals

²⁹ The United Nations Office for Outer Space Affairs (UNOOSA) works to promote international cooperation in the peaceful use and exploration of space, and in the utilization of space science and technology for sustainable economic and social development. The Office assists any United Nations Member States to establish legal and regulatory frameworks to govern space activities and strengthens the capacity of developing countries to use space science technology and applications for development by helping to integrate space capabilities into national development programmes.

³⁰ UNOOSA, ‘Space Sustainability: Stakeholder Engagement Study – Outcome Report’ (May 2021) 31 <<https://www.unoosa.org/documents/pdf/studies/Space-Sustainability-Stakeholder-Engagment-Study-Outcome-Report.pdf>> accessed 20 October 2025.

³¹ Nayef Al-Rodhan, ‘Implications of New Space Forces for Sustainable Space Terrestrial Security’ (2021) *Global Policy Journal* <<https://www.globalpolicyjournal.com/blog/19/02/2021/implications-new-space-forces-sustainable-space-and-terrestrial-security>>.

³² The term, “sustainable development” was coined in the so-called Brundtland Report, published in 1987 by the United Nations World Commission on Development, chaired by former Prime Minister of Norway, Gro Harlem Brundtland. The Brundtland Report defined sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. According to the Brundtland Report, sustainable development rests on three independent pillars: environmental protection, economic growth and social development. While interpretations of the individual pillars vary, together the three pillars are meant to work in connection to one another with true sustainability occurring when the three pillars are balanced. See: World Commission on Environment and Development, *Our Common Future* (Oxford University Press, 1987) [hereinafter: Brundtland Report].

(SDGs). The SDGs were incorporated in the so-called, “2030 Agenda: for Sustainable Development”, which was part of four milestone multilateral instruments adopted in 2015.³³ Out of the four instruments, the SDGs consist of a series of 17 goals and 169 targets identified by the United Nations and adopted by all (193) Member States of the United Nations in 2015.³⁴ Indeed, space-based technologies support all 17 SDGs by offering essential tools for tackling global challenges – ranging from natural disasters and food security to climate change and environmental degradation – while enabling informed decision-making that improves everyday life worldwide.³⁵ An important and growing element that further connects the United Nations, satellite services, and the space economy, most relevant to the topic of this dissertation, is internet access. Accordingly, the United Nations is determined in stating that “by 2030, every person should have safe and affordable access to the Internet, including meaningful use of digitally enabled services in line with the Sustainable Development Goals”.³⁶ Such purpose is often coupled with the incentive of many human rights activists and UN officials that today, in a connected global society, internet access should be a human right, emphasizing the active duty of governments to ensure its people’s connectivity. The use of internet has become a fundamental part of modern life, prompting governments – both in developed and developing countries – to seek resilient, affordable, and globally accessible coverage. Satellite broadband services are increasingly viewed as a means to achieve these objectives. Small satellites, in particular, can be deployed in constellations capable of providing

³³ The 5 five treaties are the Sendai Framework for Disaster Risk Reduction 2015-2030 (UNGA, Sendai Framework for Disaster Risk Reduction 2015-2030, UN Doc. A/RES/69/283 (LXIX) of 3 June 2015); the 2030 Agenda for Sustainable Development (UNGA, Transforming Our World: the 2030 Agenda for Sustainable Development, UN Doc. A/RES/70/1 (LXX) of 25 September 2015); and the Addis Ababa Action Agenda on Financing for Development (UNGA, Addis Ababa Action Agenda of the Third International Conference on Financing for Development (Addis Ababa Action Agenda), UN Doc. A/RES/69/313 (LXIX) of 27 July 2015); and the Paris Agreement to the United Nations Framework Convention on Climate Change, Dec. 12, 2015, TIAS. No. 16-1104 [hereinafter: Paris Agreement].

³⁴ For more information on the Sustainable Development Goals, see United Nations Department of Economic and Social Affairs, ‘Transforming our world: the 2030 Agenda for Sustainable Development’ <<https://sdgs.un.org/2030agenda>> accessed 20 October 2025.

³⁵ Danielle Wood, Minoo Rathnasabapathy, Keith Javier Stober, and Pranav Menon, ‘Challenges and progress in applying space technology in support of the sustainable development goals’ (2024) 219 *Acta Astronautica* 678, 678-681. See also: André Baumgart, Eirini Ioanna Vlachopoulou, Jorge Del Rio Vera and Simonetta Di Pippo, ‘Space for the Sustainable Development Goals: mapping the contributions of space-based projects and technologies to the achievement of the 2030 Agenda for Sustainable Development’ (2021) 4:6 *Sustainable Earth Reviews* <<https://doi.org/10.1186/s42055-021-00045-6>> accessed 20 October 2025.

³⁶ United Nations, ‘Achieving universal connectivity by 2030’, United Nations Office of the Secretary-General’s Envoy on Technology (2022) <<https://www.un.org/techenvoy/content/global-connectivity>> accessed 20 October 2025.

wide-area internet services. This technology will be explored in a greater detail later in this chapter, in the section addressing large satellite constellations.

While it is undeniable that satellites bring substantial socio-economic benefits to humanity,³⁷ the uncertainty remains about the threshold at which the deployment of such satellites could detrimentally impact the Earth's surrounding orbital space, resulting in counterproductive consequences in the long term. While there is a remarkable increase in the launch of LEO satellites and a corresponding surge in sector investment, our understanding of the orbit's carrying capacity remains incomplete. Simultaneously, there is a lack of consensus regarding the legal implications of the preservation of LEO, with a preference given to the freedom principle (and the first-come, first-served principle) outlined in the Outer Space Treaty. Consequently, conflicting realities and interests surround orbital space, especially LEO, and this dissertation contends that time and technology alone will not resolve the escalating conflict. Instead, active mitigation measures, particularly concerning new launches, are deemed necessary.

2. Trends in the scale and complexity of space operations

a. Miniaturization of satellite manufacturing

As of today, there is no consensus or universally accepted standard on the definition of a small satellite. In fact, there is a difficulty to define what differentiates a small satellite from a conventional spacecraft.³⁸ For example, a small satellite is not necessarily physically small, as it may have deployable structures. It is generally argued that small satellites have a mass

³⁷ See for example: Alessandra Tasa, 'The socio-economic value of satellite earth observations: huge, yet to be measured' (07 May 2019) 23(1) *Journal of Economic Policy Reform* 34; or Yarnaphat Shaengchart and Tanpat Kraiwanit, 'Starlink satellite project impact on the Internet provider service in emerging economies' (June 2023) 6 *Research in Globalization* <<https://doi.org/10.1016/j.resglo.2023.100132>> accessed 20 October 2025.

³⁸ Two examples illustrate the issue of small satellites qualifying as space objects under space law are, first Swarm Technologies' satellites (one-fourth the size of a standard CubeSat) were denied an FCC license due to tracking concerns, while KickSat's (2014) deployment, and the unregistered femto-satellite, 'Sprites'—mere computer chips—raised questions about their legal status as space objects. The sprite femto satellites were not registered, highlighting ambiguities in applying space law to small or unconventional satellites. See: Tanja Masson-Zwaan and Mahulena Hofmann, *Introduction to Space Law* (5th edn, Wolters Kluwer 2024) 175-176.

smaller than one tonne.³⁹ This does not constitute a rigid scientific definition, as some resource define small satellites as those weighing less than 500 kilograms.⁴⁰

According to a joint handout by UNOOSA and the International Telecommunication Union (ITU), which provides guidance for small satellite developers and operators on space object registration and frequency management, small satellite missions are typically characterized by features such as, a) reasonably short development times; b) relatively small development teams; c) modest development and testing infrastructure requirements; and d) affordable development and operation costs for the developers, in other terms “faster, cheaper and smaller”.⁴¹ Furthermore, as noted by the UNOOSA - ITU report, satellites are commonly classified into several categories based on their mass (mini satellites < 100 kg, nano satellites < 10 kg, pico satellites < 1 kg, femto satellites < 0,1 kg).⁴²

For small (nano) satellites, the CubeSat has become the most common standard platform, with its dimension of 10x10x10 cm with a mass of up to 2 kg (one unit CubeSat).⁴³ These CubeSats have transformed traditional approaches to satellite development and launch. Unlike conventional satellites – which are costly, custom-built, affordable, and built using standardized components that can often be sources online. This modularity has significantly reduced production time and costs. As a result, CubeSats have opened access to space for a broader range of actors, including non-spacefaring nations, universities, and nonprofit organization. The affordability and accessibility of CubeSats have made them a key entry point into space technology, leading many commercial companies to integrate them into their business models.⁴⁴ A crucial development is the emergence of small-satellite constellations, which take advantage of their compact size and low mass to launch as secondary payloads alongside larger primary missions. This “piggyback” approach maximizes launch capacity while reducing costs, as small satellites fill excess space originally financed by the primary

³⁹ Ibid., 172.

⁴⁰ Otto Koudelka, ‘Micro/Nano/Picosatellite-Activities: Challenges Towards Space Education and Utilisation’ in Irmgard Marboe (ed.) *Small Satellites: Regulatory Challenges and Chances* (Brill 2016) 7, 7.

⁴¹ UNOOSA & ITU, *Guidance on Space Object Registration and Frequency Management for Small and Very Small Satellites* (2015) 2 <https://www.unoosa.org/documents/pdf/psa/bsti/2015_Handout-on-Small-SatellitesE.pdf>.

⁴² Ibid., 2.

⁴³ California Polytechnic State University, ‘CubeSat Design Specification’, Rev.14.1 (2022) <https://static1.squarespace.com/static/5418c831e4b0fa4ecac1bacd/t/62193b7fc9e72e0053f00910/1645820809779/CDS+REV14_1+2022-02-09.pdf> accessed 20 October 2025.

⁴⁴ Tanja Masson-Zwaan and Mahulena Hofmann, *Introduction to Space Law* (5th edn, Wolters Kluwer 2024) 172

payload customer.⁴⁵ The growing demand for small satellite launches has spurred innovation in dedicated small launch vehicles, offering alternatives to traditional rideshare methods. Beyond transforming satellite design, this shift has revolutionized launch logistics – making space more affordable and accessible, thereby driving the “democratization of space activities”.⁴⁶

Examples of common advantages of small satellites compared to traditional satellites include, reduced price per satellite, reduced cost and size of the required launch vehicle, the ability to function as hosted payloads, catching a ride-share to orbit, and shorter life cycle.⁴⁷ On the contrary, a crucial disadvantage of small satellites from an environmental point of view is that small satellites typically have shorter life cycle, which means that operators must replace satellites more frequently. This, again, compels us to consider additional benefits and drawbacks of satellite miniaturization from an environmental point of view. Such factors may include weighing against each other the environmental impacts of launching and the fast natural decay of small satellites from LEO.⁴⁸

Manoeuvrability of a small satellite alleviates the need to deal with an uncontrolled object in orbit. Operators of large LEO constellations, thus, are encouraged to ensure that their satellites are manoeuvrable and capable of avoiding collisions with non-manoevrable objects. Without this capability, the presence of tens of thousands of small, non-manoevrable satellites substantially increase the risk of collisions and the generation of space debris.⁴⁹ However, small satellites most of the time remain non-manoevrable, as carrying extra propulsion units – even electric, without fuel – adds to the price and weight of the spacecraft, which makes it impossible to carry out a collision avoidance manoeuvre. Space surveillance and tracking organizations such as the United States Space Surveillance Network, and other relevant entities, typically do not directly provide detailed information about the manoeuvrability of specific spacecraft,

⁴⁵ Ibid.,173-174.

⁴⁶ Ibid.,173-174; The ongoing democratization of space has broadened access beyond superpowers and large corporations, enabling participation by developing nations, start-ups, universities, and even high schools. See: William Welser IV, ‘The Democratization of Space’, (*Inside Sources*, 28 March 2016) <<https://insidesources.com/the-democratization-of-space/>> accessed 20 October 2025.

⁴⁷ Michael Dornik and Milton Smith, ‘Small Satellite Industry and Legal Perspectives in the United States’ in Irmgard Marboe (ed.) *Small Satellites: Regulatory Challenges and Chances* (Brill 2016) 67, 68.

⁴⁸ Otto Koudelka, ‘Micro/Nano/Picosatellite-Activities: Challenges Towards Space Education and Utilisation’ in Irmgard Marboe (ed.) *Small Satellites: Regulatory Challenges and Chances* (Brill 2016) 7, 26.

⁴⁹ See: Hanhui Zha and Jinyuan Su, ‘The “due regard” obligation in the deployment and operation of satellite mega-constellations’ (2025) 73 *Space Policy* 1, 5 <<https://doi.org/10.1016/j.spacepol.2024.101674>>.

including the specifics of their propulsion systems, capabilities, or intended manoeuvres, therefore it is difficult to estimate the percentage of launched small spacecrafts having manoeuvrability units on board. Enclosing such information, however, may be necessary.⁵⁰

It is further important to emphasize that fulfilment of tasks with the help of small satellites neither implies a need to reduce the role of heavy and large satellites nor even a total cancellation of their use. Because of their limitations in mass and capacity to manoeuvre for example, small satellites are unable to replace the large ones in many cases. It can be argued, therefore, that strategic issues of national importance are still suggested to be carried out with the use of large space objects with a long orbital lifetime.⁵¹

The rapid expansion of small satellite operations highlights the need to reassess the legal frameworks governing these activities, ensuring they remain fit for purpose in this evolving landscape. In legal terms, it was also the general observation of UNOOSA and ITU officials that small satellite missions often involve actors new to space activities mainly non-governmental actors; they are often – due to inexperience or unfamiliarity with the national and international regulatory framework –, not conducted in full compliance with international obligations, regulations and relevant voluntary guidelines; and they have raised concerns to worsening the space debris situation.⁵² At the same time, it is important to stress that in legal terms, a small satellite is considered to be no different from any other space object. Small satellites are therefore subject matter to all legal obligations outlined for space objects in international law sources as well as to other relevant legal obligations.

Additionally, when it comes to the protection of orbital space activities, Guideline B.8 of the COPUOS Guidelines for the Long-term Sustainability of Outer Space Activities (LTS Guidelines), specifically offers guidance for small satellite operators.⁵³ The impact of the LTS

⁵⁰ See for example: International Academy of Astronautics (IAA), the International Astronautical Federation (IAF) and the International Institute of Space Law (IISL), ‘Memorandum of Understanding (MoU) of the International on a Cooperative initiative to develop comprehensive approaches and proposals for Space Traffic Management’ (2022) 1 <<https://iaaspace.org/wp-content/uploads/iaa/Communication/stm-mou.pdf>> accessed 20 October 2025.

⁵¹ Olga Volynskaya and Rustan Kasyanov, ‘Launching Numerous Small Satellites – A Flourishing Business? The Case of the Russian Federation’ in Irmgard Marboe (ed.) *Small Satellites: Regulatory Challenges and Chances* (Brill 2016) 83, 89.

⁵² Ibid. 89.

⁵³ United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), ‘Guidelines for the Long-Term Sustainability of Outer Space Activities’ U.N. Doc. A/AC.105/2018/CRP.20 (2018) [hereinafter: LTS Guidelines]

Guidelines – along with the several regulatory limitations of space activities – on the protection of orbital space will be discussed in Chapter III of this dissertation further.

In terms of their usage, small (and very small) satellites have developed from purely educational and research purposes. At the same time, industry and space agencies are embracing this technology to test, demonstrate, and validate new systems, operational procedures, and services in space at low cost and within much shorter timescales.⁵⁴ Moreover, mini- and micro-Earth observation satellites are dramatically improving the applicability of remote sensing by offering new observation opportunities, especially for disaster and environmental monitoring purposes, such as for the detection of fires, survey of areas of natural disasters, ecologic monitoring and meteorological observation, as well as detailed mapping of the Earth surface. Additionally, the increasing number of small satellites and their applications drive developments in the fields of small launchers, small ground station networks, cost-effective data distribution methods, and cost-effective management and quality assurance procedures.⁵⁵ Lastly, low-cost communication constellations consisting of small satellites have become a new breakthrough application especially of commercial services, but also more and more states are finding the meaning of greater autonomy and independence in building such constellation services in LEO.⁵⁶

b. The “New Space” concept

Between 1957 to 2012, the number of satellites launched into outer space remained relatively stable, with an annual average of roughly 150 satellites.⁵⁷ This period encompassed major milestones such as human spaceflight to Earth orbit and the Moon, the establishment of global communication satellite networks, and the construction of the International Space Station. However, since 2013, satellites launch rates have risen exponentially, largely as a result

⁵⁴ Rainer Sandau, Klaus Briß and Marco D’Errico, ‘Marco, Small satellites for global coverage: Potential and limits’ (2010) 65(6) *ISPRS Journal of Photogrammetry and Remote Sensing* 492, 496.

⁵⁵ *Ibid.*, 496.

⁵⁶ *Ibid.*, 493.

⁵⁷ UNOOSA, ‘Online Index of Launched Objects Launched into Outer Space’ <https://www.unoosa.org/oosa/osoindex/search-ng.jsp?lf_id=>> accessed 20 October 2025.

of decreasing barriers to accessing outer space.⁵⁸ Total operational spacecraft increased from roughly 3,371 in 2020 to 11,539 satellites in orbit by the end of 2024 largely driven by commercial mega-constellations.⁵⁹ This shift is largely attributable to accelerated technology innovation and the miniaturization of satellite components, particularly the advent of small and nanosatellites. The miniaturization of satellites has significantly lowered the cost of accessing space, while substantial investment by tech industry billionaires have catalysed a surge in private sector engagement in space ventures.⁶⁰ By 2024, small satellites represented 98% of total spacecraft launches.⁶¹ Furthermore, the convergence of exponential advances in computing power, rapid digital transformation enabling novel space applications and proactive government policies fostering commercial space innovation has given rise to the New Space paradigm.⁶²

According to the Organization for Economic Co-operation and Development (OECD), this transformation – often called, “New Space” – began in around 2007, but it has gained significant momentum in the last couple of years.⁶³ While a clear definition of this dynamic is difficult to acquire, New Space can be described as “a disruptive sectorial dynamic featuring various end-to-end efficiency-driven concepts driving the space sector towards a more business- and service-oriented step”.⁶⁴ The New Space phenomenon is “characterized by new commercial actors who are introducing innovative industrial practices and funding strategies to the space sector”.⁶⁵ One of the most relevant features, amongst a number of other demarcations of this new dynamic and ecosystem is that it “enables the sharing of both costs

⁵⁸ Ibid.,

⁵⁹ Satellite Industry Association (SIA), ‘Historic Number of Launches Powers Commercial Satellite Industry Growth – Satellite Industry Association Releases the 28th Annual State of the Satellite Industry Report’ (May 2025) <<https://sia.org/historic-number-of-launches-powers-commercial-satellite-industry-growth-satellite-industry-association-releases-the-28th-annual-state-of-the-satellite-industry-report/>> accessed 20 October 2025.

⁶⁰ In 2020, the average launch cost was \$10,313 per kg for non-commercial satellites and \$4,092 per kg for commercial satellites. By 2045, some estimates that that the average launch price will fall below \$1000 given expected technological advances in the industry. See: Nodir Adilov, Peter Alexander, Brendan Cunningham and Nikolas Albertson, ‘An Analysis of Launch Cost Reductions for Low Earth Orbit Satellites’ (2024) 42(3) *Economics Bulletin* 1561, 1664; also at 1569.

⁶¹ Bryce Tech, ‘Smallsats by the numbers’ (2025) <<https://brycetek.com/reports/report-documents/smallsats-2025/>> accessed 20 October 2025.

⁶² OECD, ‘Harnessing “New Space” for Sustainable Growth of the Space Economy’ (July 2023) *OECD Publishing* 1, 3 <https://www.oecd.org/content/dam/oecd/en/publications/reports/2023/07/harnessing-new-space-for-sustainable-growth-of-the-space-economy_72a0cfd9/a67b1a1c-en.pdf> accessed 20 October 2025.

⁶³ Ibid., 3.

⁶⁴ Alessandra Vernile, *The Rise of Private Actors in the Space Sector* (Springer 2018) 34.

⁶⁵ Ibid., 34.

and risks between the private and public sectors, thus possibly reducing the financial burden for the public actor”.⁶⁶ Indeed, with the more cost-effective access to space, focus is turning toward emerging possibilities in fields like hyperspectral remote sensing, energy generation, manufacturing, mining and tourism.⁶⁷ Nevertheless, the most substantial growth has been anticipated in sectors that are already advancing digital connectivity on Earth, such as direct-to-consumer (internet) broadband access.⁶⁸

As a result of the New Space trend, by 2022 the worth of the global space economy was estimated at 613 billion dollars.⁶⁹ Currently, the private space sector represents more than 78% of the global space economy, and 90% of today’s spacecrafts are said to be commercial.⁷⁰ This has led to a more intensive use of orbital resources, with higher launch activity and many more operational satellites in orbit. Indeed, it is widely acknowledged that the space industry has advanced at a pace that outstrips the ability of public awareness and regulatory frameworks to keep up. As UNOOSA highlights, although the rapid expansion of commercial space activities offers opportunities to expand access to the benefits of space applications on Earth, it also poses new challenges to maintaining a safe and sustainable operational environment in orbital space.⁷¹ Thus, as emphasized by many space law scholars, the roles and responsibilities of states in authorization and continuing supervising the orbital activities of their non-governmental entities have proven to be of critical importance.⁷²

⁶⁶ European Space Policy Institute, ‘Evolution of the Role of Space Agencies - Full Report’ (2019) 1, 1 <<https://www.espi.or.at/wp-content/uploads/2022/06/ESPI-Public-Report-70-Evolution-of-the-Role-of-Space-Agencies-Full-Report.pdf>>.

⁶⁷ Morgan Stanley, ‘Space: Investing in the Final Frontier’ (7 July 2018) <<https://www.morganstanley.com/ideas/digital-twin-factories-2019>> accessed 20 October 2025.

⁶⁸ World Economic Forum, ‘The Global Risks Report 17th Edition’ (2022) 1, 72 <https://www3.weforum.org/docs/WEF_The_Global_Risks_Report_2022.pdf> accessed 20 October 2025.

⁶⁹ Novaspaces, ‘Value of Space Economy reaches 464 billion USD in 2022 despite new unforeseen investment concerns’ (January 2023) <<https://nova.space/press-release/value-of-space-economy-reaches-424-billion-in-2022-despite-new-unforeseen-investment-concerns-2/>> accessed 20 October 2025.

⁷⁰ Space Foundation, ‘The Space Report 2025 Q2 Highlights Record \$613 Billion Global Space Economy for 2024, Driven by Strong Commercial Sector Growth’ (July 2025) <<https://www.spacefoundation.org/2025/07/22/the-space-report-2025-q2/>> accessed 20 October 2025.

⁷¹ UN COPUOS, ‘Registration of Large Constellations and Megaconstellations’ (28 March - 8 April 2022) UN Doc. A/AC.105/C.2/L.322.

⁷² See for example: Lesley James Smith and Susan-Gale Wintermuth, ‘Ensuring space sustainability through national space legislation’ in Lesley James Smith and Ingo Baumann & Susan-Gale Wintermuth (eds.) *Routledge Handbook of Commercial Space* (Routledge 2023) 533, 534.

c. Expenditure of the global economic divide

*“Only time will tell,
but if we are on the verge of a significant paradigm shift,
it is clear that it is only the world’s elite
who will be able to participate
in this new networked information economy”.*⁷³

For many years, access to outer space was limited to a small group of spacefaring nations. Space activities were primarily conducted by governments, required substantial resources, and were driven largely by strategic interests. This paradigm is clearly reflected in the UN space treaties, which form the core legal framework of space law.⁷⁴ Over the past two decades, space activities have increasingly transitioned from being state driven involving non-governmental and commercial actors. This shift is particularly evident in satellite operations, alongside the emergence of commercial human spaceflight and space resource utilization.⁷⁵

As satellite technology and launch services become more affordable and accessible, we are witnessing the “democratization of” space exploration and utilization,⁷⁶ especially related to the use of the Earth’s orbits with many governments supporting the development of national space capabilities, better distributing the benefits of space technologies and further improving conditions for innovation. Consequently, emerging countries have entered the space competition and even, in many cases, have begun their own space programmes.⁷⁷ Some examples on the benefits and impacts of implementing small satellite programmes on local space capabilities are, obtaining EO and scientific application data; improvement of technical

⁷³ Negar Mansouri, ‘Money, magic, and machines: International Telecommunication Union and liberalisation of telecommunications networks and services (1970s–1990s)’ (July 2023) 11(2) *London Review of International Law*, 231, 231.

⁷⁴ Tanja Masson-Zwaan and Mahulena Hofmann, *Introduction to Space Law* (5th edn, Wolters Kluwer 2024) 171.

⁷⁵ *Ibid.*, 171.

⁷⁶ See: William Welser IV, ‘The Democratization of Space’, (*Inside Sources*, 28 March 2016) <<https://insidesources.com/the-democratization-of-space/>> accessed 20 October 2025.

⁷⁷ Olga Volynskaya and Rustan Kasyanov, ‘Launching Numerous Small Satellites – A Flourishing Business? The Case of the Russian Federation’ in Irmgard Marboe (ed.) *Small Satellites: Regulatory Challenges and Chances* (Brill 2016) 83, 84.

knowledge of local professionals; infrastructure development; and local space capacity development.⁷⁸

Furthermore, propagators of global broadband connectivity argue that communities that has been lacking access to affordable and reliable broadband connectivity fall more and more behind in an increasingly connected world. Hence, the commercialization of space holds the potential to address the digital divide by granting billions of people worldwide access to broadband internet and unrestricted information, especially through the application of LEO constellations.⁷⁹ At the same time, LEO is a limited environment (both in terms of orbital space and radio-frequency spectrums), and its use is allocated based on a first-come first-served approach. This mentality gives unlimited advantage to existing space powers over newly emerging space actors to occupy limited resources. Nonetheless, this trend is anticipated to widen global economic disparities significantly, with wealthier nations experiencing substantial economic advancements that may elude many other countries.

The equality problem has been addressed relevant to GEO under the International Telecommunication Union's (ITU) framework. The ITU has introduced a specific methodology measuring exploitation of GEO. Accordingly, besides the rational, efficient and economical use, ITU requires equitable access and sharing of spectrum and orbits in a changing orbital space environment.⁸⁰ Although the principle of equitable access is intended to promote opportunities for developing countries to secure positions in the finite GEO and to facilitate wider access to space technologies, studies have shown that the ITU's reservation and coordination procedures are highly complex and, in practice, can even obscure rather than enable the timely implementation of satellite projects by developing states.⁸¹ Furthermore, there is no similar framework currently applied in non-GSO orbits, such as in LEO, to support conversations about equity and other policy concerns in coordination, allocation and assignment of orbital volume. Nevertheless, the characteristics of LEO significantly differ from

⁷⁸ Romina Acevedo and Roberto Becerra, 'Small Satellites as a Chance for Developing Countries' in Irmgard Marboe (ed.) *Small Satellites: Regulatory Challenges and Chances* (Brill 2016) 105, 107.

⁷⁹ Eytan Tepper, 'Space Commercialization is Closing the Digital Divide, but Expanding Global Economic Inequality' (2023) 24(1) *Georgetown Journal of International Affairs* 55, 55.

⁸⁰ Article 44, Constitution of the International Telecommunication Union of 22 December 1992, entered into force 1 July 1994, 1825 U.N.T.S. 31251 (ITU Constitution).

⁸¹ Camilo Guzman Gomez and Yinet Cordoba, 'The Equitable Access to the GEO for Developing Countries: A Pending Challenge', Proceedings of the International Astronautical Congress, IAC ISSN:0074-1795 (2013) 1, 1 <<https://ssrn.com/abstract=2960223>>.

those of in GEO, rendering it more challenging to precisely determine its carrying capacity, for instance. Due to the absence of obligatory multilateral frameworks for the transfer of technology and equitable distribution of space-related benefits in LEO, the responsibility falls on individual countries to manage access to resources and to seek cooperative arrangements with established spacefaring nations in order to secure meaningful participation in the benefits of orbital activities.⁸²

In order to address the economic divide, a novel suggestion, advocating for the establishment of a universal tax framework for ventures into outer space, has been put forward by Professor Alexander Ezenagu, an expert on international taxation in 2020.⁸³ With his idea, the aim is to guarantee the worldwide distribution of space-related advantages. Additionally, as per this proposal, each country would contribute to the expenses of space exploration, aligning their responsibilities with their individual Gross Domestic Products (GDP). Consequently, nations would be entitled to a fair share of the benefits derived from these exploration efforts. However, it is important to note that, as of now, there is no existing multinational mechanism for the equitable sharing of space-related benefits.⁸⁴

As the frequency of launches into LEO increases, nations possessing established and emerging space capabilities face a crucial decision. They must determine the extent to which they are willing to incorporate environmental damage or negative externalities into the costs of their orbital activities. Additionally, they need to regulate their private space entities to achieve the appropriate balance between safeguarding the orbital space environment and supporting relevant space activities, all while promoting efficiency, innovation, and development.

⁸² The existing capacity and further potential role of the ITU, UNOOSA and other relevant international organizations and regulatory mechanisms relevant to LEO, will be explained in more details in the next parts of this dissertation.

⁸³ Alexander Ezenagu and Eytan Tepper, 'Adopting a Universal Tax Regime for Outer Space Exploration' (July 2020) *Afronomics Law* 1, 1 <<https://www.afronomicslaw.org/2020/07/31/adopting-a-universal-tax-regime-for-outer-space-exploration>> accessed 20 October 2025.

⁸⁴ *Ibid.*, 1.

3. Emergence of large constellations

*“It is (...) fairly certain that, in regard to outer space activities, the era of constellations will be an entirely new and unprecedented era of space activity”.*⁸⁵

The world is becoming ever more connected and digitalized. Continued economic growth has increased the reliance of satellites. In the recent years, entrepreneurs as well as states proposed launching large fleets of satellites, consisting of tens, hundreds, or thousands of satellites, mostly referred to as “constellations”, with their ultimate aim, to provide satellite services to as many users on Earth as possible. Until today, satellite constellations have become the most promising solutions not only used for telecommunication purposes, but also for transportation, agriculture, fisheries, weather forecast, research on space environment, entertainment, military objectives, and many more. Although “satellite constellation” is not defined in international law, both academics and practitioners use this term without specifying its meaning. Satellite constellations are commonly known as a network of identical or similar-type of artificial units of spacecrafts, with the same purpose and shared control, working together as a system.⁸⁶ Unlike a single satellite, a constellation can provide permanent global or near-global coverage, such that at any time everywhere on Earth at least one satellite is visible. Neither the size of the individual satellites, nor the location of the constellation in space or its purpose seem to have much significance for the definition of a constellation.⁸⁷ By 2020, one of the smallest groups of satellites was the Earth observation mission called, RapidEye, which consisted of five satellites.⁸⁸ Specifying a threshold of the number of satellites required to clarify the network as a constellation may be crucial regarding topics, such as insurance, the allocation of orbital slots and radio frequencies, where large fleets may be treated as a single unit.

⁸⁵ Christopher Johnson, ‘The Legal Status of MegaLEO Constellations and Concerns About Appropriation of Large Swaths of Earth Orbit’ in J. Pelton (ed.) *Handbook of Small Satellites* (Springer 2020) 1337, 1349.

⁸⁶ See for example: Damian M. Bielicki, ‘Legal Aspects of Satellite Constellations’ (2020) 45(3) *Air and Space Law* 245, 245.

⁸⁷ *Ibid.*, 246.

⁸⁸ Nicholas Crisp, Katharine Smith and Peter Hollingsworth, ‘Launch and Deployment of Distributed Small Satellite Systems’ (2015) 114 *Acta Astronautica* 65, 66.

The terms, large- and megaconstellations have become prominent in mainstream discussions, describing the substantial quantity of spacecraft that a constellation encompasses. In November 2019, the US Government issued its most recent Orbital Debris Mitigation Standard Practices in which it defines a “large constellation” as ‘a constellation consisting of 100 or more operational spacecraft cumulative’.⁸⁹ In multilateral policy discussions, until now, the term, large constellations and megaconstellations seem to be used interchangeably.⁹⁰ Some have argued that the term mega-constellation is inaccurate and pejorative and should not even be used.⁹¹ In this dissertation, the term “large constellations” is employed in accordance with the US example, referring to constellations comprising 100 or more satellites.

Another element that can be highlighted regarding the tendency of satellite constellations is that, in the last few years, swarms of satellites (as part of constellations) have been mostly placed in LEO – between 200 and 2000 km altitude –, with the advantage of significantly reduced latency for the uplink/downlink operations compared to GEO services – at an altitude of 37 586 km –.⁹² While GEO internet satellites can be used as a single unit, LEO satellites are used in groupings of constellations. This is because GEO satellites can keep pace with the rotation of the Earth, thus a single GEO satellite can maintain constant contact with all the Earth stations in its coverage area. At the same time LEO satellites appear to cross the sky like the sun, “rising” and “setting” at the horizon. Before one satellite sets, another must have risen in the same alignment, or plane, so as to keep a constant link with any users. And in order to cover more than one strip of the Earth, multiple planes are needed, and this entire grouping composes a “constellation”.⁹³

Low latency of LEO satellites provides a competitive edge for internet-dependent markets, especially in supplementing terrestrial 5G infrastructure to increase network coverage

⁸⁹ U.S. Government, ‘Orbital Debris Mitigation Standard Practices’ (November 2019) 1, 7 <https://orbitaldebris.jsc.nasa.gov/library/usg_orbital_debris_mitigation_standard_practices_november_2019.pdf> accessed October 2025.

⁹⁰ See for example: UNCOPUOS, ‘Registration of Large Constellations and Megaconstellations’ (28 March - 8 April 2022) UN Doc. A/AC.105/C.2/L.322.

⁹¹ Ruth Pritchard-Kelly, ‘WRC-23 on the Horizon: Large Satellite Constellations, ITU Issues, and Industry Perspective’ (2023) 48 *Air & Space Law* 179, 181.

⁹² Latency (or signal transmission delay) is the amount of time used by data to reach its destination and come back. A lower latency is particularly crucial for applications like online gaming, video conferencing, and real-time communication, where low latency is essential for a better user experience.

⁹³ Ruth Pritchard-Kelly, ‘WRC-23 on the Horizon: Large Satellite Constellations, ITU Issues, and Industry Perspective’ (2023) 48 *Air & Space Law* 179, 180.

and provide a backup in the event of natural disasters like earthquakes, floods and hurricanes.⁹⁴ Utilizing satellite technology, particularly in LEO presents an opportunity to complement, rather than compete with, ongoing efforts to address the global connectivity gap. The alignment of frequency bands, such as the use of millimetre-wave spectrum in both terrestrial 5G networks and satellite systems, further indicates the potential for closer integration of satellite components within emerging 5G architectures.⁹⁵

There are several other factors that influence the value of LEO satellite constellations over GEO satellites for internet services, such as: avoidance of the Vann Allen radiation belt,⁹⁶ cost,⁹⁷ high throughput,⁹⁸ global coverage,⁹⁹ stability,¹⁰⁰ resilience and redundancy,¹⁰¹ advancements in technology,¹⁰² lower orbit and reusability,¹⁰³ dynamic coverage and flexibility.¹⁰⁴ A crucial drawback, however, of LEO satellites compared to GEO ones is that a

⁹⁴ 5G is about 100 times faster than 4G and is considered to be one of the driving forces behind the Fourth Industrial Revolution – the blurring of the lines between physical, digital and biological spaces. See for example: Sandro Mendonça at al., ‘The rise of 5G technologies and systems: A quantitative analysis of knowledge production’ (2022) 46 *Telecommunications Policy* 1, 1-4.

⁹⁵ For instance, an aircraft connected to an air-to-ground 5G network stands to benefit from this capability, particularly when crossing the oceans.

⁹⁶ An important advantage of using small satellites in LEO of less than 1000km is that in such cases the crossing of the Van Allen radiation belts is prevented. In the Van Allen belt, the spacecraft is subjected to high radiation causing a stronger degradation of the solar panels and the electronics of the spacecraft. Spacecrafts that do not cross the Van Allen belt, therefore, has fewer requirements in terms of electronics shielding from highly charged particle interference.

⁹⁷ LEO satellites have much lower cost to manufacture and to launch due to the shorter trip and their small stature.

⁹⁸ LEO constellations typically offer higher data transfer rates (also known as, throughput) compared to traditional GEO satellites, which can be advantageous for delivering high-speed internet services, especially in areas with high demand or where terrestrial infrastructure is limited.

⁹⁹ LEO constellations with multiple satellites in orbit can provide worldwide coverage, reaching remote and underserved areas – such as at sea and in the air – where deploying traditional infrastructure may be challenging, and no other technology can do. This can contribute to bridging the digital divide and expanding internet access to a broader population.

¹⁰⁰ LEO constellations provide more stable connection with less interference as communications must travel shorter distances.

¹⁰¹ The distributed nature of LEO constellations is said to make them more resilient to individual satellite failures or disruptions. If one satellite in the constellation malfunctions, the network can still function with the remaining satellites. This redundancy can enhance the overall reliability of the internet service.

¹⁰² LEO satellite technology has seen significant advancements in recent years, making it more cost-effective and efficient. The use of advanced technologies, such as phased-array antennas and improved propulsion systems contributes to the competitiveness of LEO constellations.

¹⁰³ LEO satellites can be launched into orbit more affordably due to their lower altitude, and some LEO satellite constellations are designed with reusable spacecraft, further reducing launch costs. This economic efficiency can translate into more cost-effective internet services.

¹⁰⁴ In terms of dynamic coverage and flexibility, LEO satellites can be manoeuvred more easily, allowing for dynamic coverage and the ability to redirect resources to areas with high demand. Such flexibility is advantageous for adapting to changing user needs and optimizing network performance.

single satellite in LEO can only cover a portion of the Earth in less than a 20-minute timeframe, implying that a larger number – thousands – of satellites are needed in the constellation to cover the Earth's surface than in GEO. In comparison, due to the size of a GEO satellite and the characteristic of GEO, only 3 equally spaced GEO satellites are needed to provide near-global communication coverage.¹⁰⁵ Regardless of the necessary quantity of satellites that LEO internet service providers require, investors, manufacturers, operators and users focus on the economically profitable aspects of LEO constellations. Indeed, it has been estimated that a third of the world's population (2.7 billion people) has no access to the Internet, thus satellite constellation opens a huge market for such services.¹⁰⁶ Many of the people without Internet access live in least developed countries, landlocked developing countries, and small island developing states. Consequently, a record number of satellites are being deployed and planned to be launched in the upcoming years as part of large constellations in LEO to provide fast, highly available internet services and digital communication infrastructure for real time applications and to access previously isolated areas.¹⁰⁷

Undeniably, since the last decade, more and more countries have started to equip themselves with independent means to guarantee their access to space and to leverage space applications in numerous ways. Aspirations like the establishment of national and regional Global Navigation Satellite Systems – GNSS – or building own launching capabilities are not the only peaceful means anymore to furthering national interest through space capabilities. In fact, there have been both national and private initiatives with increasing interest in placing large constellations in LEO to ensure sovereign capacity for both commercial and governmental communications channels. Countries such as China,¹⁰⁸ the United States,

¹⁰⁵ European Space Agency (ESA), 'Types of Orbits' (30 March 2020) <https://www.esa.int/Enabling_Support/Space_Transportation/Types_of_orbits#:~:text=Satellites%20in%20GEO%20cover%20a,cover%20large%20sections%20at%20once> accessed 20 October 2025.

¹⁰⁶ "As the world is welcoming its 8 billionth inhabitant, 5.3 billion people – or 66 per cent of the total global population – are online, while 2.7 billion are still offline" See: International Telecommunication Union (ITU), 'Measuring digital development: Facts and Figures 2022' (2022) 1, 1 <<https://www.itu.int/itu-d/reports/statistics/facts-figures-2022/>> accessed 20 October 2025.

¹⁰⁷ Michael Dornik and Milton Smith, 'Small Satellite Industry and Legal Perspectives in the United States' in Irmgard Marboe (ed.) *Small Satellites: Regulatory Challenges and Chances* (Brill 2016) 67, 74.

¹⁰⁸ Andrew Jones, 'China establishes company to build satellite broadband megaconstellations' (*SpaceNews*, 26 May 2021) <<https://spacenews.com/china-establishes-company-to-build-satellite-broadband-megaconstellation/>> accessed 20 October 2025; Jason Rainbow, 'China's LEO push looms over Western expansion efforts' (*SpaceNews*, Febr 2023) <<https://spacenews.com/china-establishes-company-to-build-satellite-broadband-megaconstellation/>> accessed 20 October 2025.

Rwanda,¹⁰⁹ Tonga,¹¹⁰ Türkiye,¹¹¹ Papua New Guinea, Germany,¹¹² France,¹¹³ Spain, Norway and the Solomon Islands are planning to establish their independent 5G internet capacity through the set-up of LEO large constellations.¹¹⁴ An interesting element across the filings is that national administrations register their satellite networks at the ITU almost always on behalf of a corporate sponsor, to manufacture and to operate their constellations.¹¹⁵ In fact, in most cases, a constellation company (mostly SpaceX), which enters into contract with a country to roll out their LEO broadband (e.g., Mexico),¹¹⁶ is authorized and supervised by another (appropriate) state (e.g., USA).

Furthermore, no consensus exists on the “ideal” size of a constellation – that is, the number of satellites involved – and proposed systems therefore vary widely. Among the above states, Rwanda’s Cinnamon-937 satellite constellation has been the single biggest constellation filed with the ITU since October 2021, which was made for the French company, E-Space, and projects a total of 337,320 component satellites.¹¹⁷ Although it is unlikely that most of the satellites will be launched at all – due to funding problems, changes in political circumstances and support, or engineering and technology issues –, experts still see the overfilling problem a dire warning that humanity is overstressing the capacity of the limited orbital space environment, and especially of LEO. Overfilings were also popular during the gold rush in

¹⁰⁹ “A RocketLab ‘Electron’ rocket has launched Protosat-1, now confirmed by the US Space Force to be the first satellite from Greg Wyler’s new E-Space so-called ‘sustainable satellite system’ of a promised 300,000-fleet mega-constellation.” See: Chris Forrester, ‘Wyler’s E-Space craft launched’ (*Advanced Television*, 19 Nov 2024) <<https://www.advanced-television.com/2024/11/19/wylers-e-space-craft-launched/>> accessed 20 October 2025.

¹¹⁰ Peter Selding, ‘SpaceX files 29,988-satellite W-band network, using Kingdom of Tonga as regulatory home’ (*Space Intel*, 22 Oct 2023) <<https://www.spaceintelreport.com/spacex-files-29988-satellite-w-band-network-using-kingdom-of-tonga-as-regulatory-home/>> accessed 20 October 2025.

¹¹¹ Rachael Zisk, ‘More countries are building their own constellations to deliver broadband’ (*Fast Company*, 3 June 2023) <<https://fastcompany.com/technology/more-countries-are-building-their-own-constellations-to-deliver-broadband/>> accessed 20 October 2025.

¹¹² Andrew Jones, ‘Germany’s military wants its own Starlink-like satellite constellation’ (*Space.com*, April 2025) <<https://www.space.com/space-exploration/satellites/germanys-military-wants-its-own-starlink-like-satellite-constellation>> accessed 20 October 2025.

¹¹³ Chris Forrester, ‘Wyler now involved with 400,000+ satellites’ (*Advanced Television*, 30 June 2023) <<https://www.advanced-television.com/2023/06/30/wyler-now-involved-with-400000-satellites/>> accessed 20 October 2025.

¹¹⁴ Andrew Falle et al., ‘One million (paper) satellites’, (12 October 2023) 382(6667) *Science* 150, 150.

¹¹⁵ Peter Selding, ‘Signs of a Satellite Internet Gold Rush in Burst of ITU Filings’ (*SpaceNews*, 23 January 2015) <<https://spacenews.com/signs-of-satellite-internet-gold-rush/>> accessed 20 October 2025.

¹¹⁶ Reuters, ‘Musk’s Starlink wins bid roll out Mexico’s rural satellite internet – documents’ *Reuters* (6 November 2023) <<https://www.reuters.com/technology/musks-starlink-wins-bid-roll-out-mexicos-rural-satellite-internet-documents-2023-11-06/>> accessed 20 October 2025.

¹¹⁷ Andrew Falle et al., ‘One million (paper) satellites’, (12 October 2023) 382(6667) *Science* 150, 150.

GEO filings around the 1990s. Over time, the common term for such overfilling practices – essentially the “reservation of capacity without actual use” – became *paper satellites*. These refer to satellite filings submitted to the ITU that exist only on paper, with no genuine intention by the filing party to manufacture or launch the spacecraft.¹¹⁸ The issue of paper satellites will be explored in greater detail in Chapter III of this dissertation.

The most commonly known satellite constellation is provided by the US company SpaceX, which between 2019 and 2025 has deployed nearly 8,100 satellites for its Starlink constellation.¹¹⁹ The company has sought permission to launch up to 42,000 satellites,¹²⁰ a scale that has raised concerns among some observers about potential monopolization of orbital space.¹²¹ Interestingly, about 3% of the Starlink satellites are already out of service, and no longer manoeuvrable, leading to the creation of space debris.¹²² Further companies, such as OneWeb has delivered more than 630 satellites in LEO by 2023, but has asked for permission to launch just over 6000.¹²³ Another company, Amazon under its project Kuiper, must launch half of its planned 3236 satellites it foresees in the constellation, according to its license from the United States’ Federal Communications Commission (FCC), by July 2026.¹²⁴

Large constellations can provide services such as voice communication, data transmission, satellite television and many others involving a great number of potential users.

¹¹⁸ Audrey L. Allison, *The ITU and Managing Satellite Orbital and Spectrum Resources in the 21st Century* (Springer 2014) 26.

¹¹⁹ Tereza Pultarova ‘Starlink satellites: Facts, tracking and impact on astronomy’ (*Space.com*, August 2025) <<https://www.space.com/spacex-starlink-satellites.html>> accessed 20 October 2025.

¹²⁰ Starlink applications can be found in the United States Federal Communications Commission’s (FCC) database, IBFS File No. SAT-LOA-20161115-00118 Available: <<https://fcc.report/IBFS/SAT-LOA-20161115-00118>> accessed 20 October 2025.

¹²¹ Tereza Pultarova, ‘French court revokes SpaceX’s Starlink internet license, citing monopolization concerns’ (*Space.com*, 14 April 2022) <<https://www.space.com/starlink-french-court-revokes-license-monopolization>> accessed 20 October 2025.

¹²² Matt Williams, ‘About 3% of Starlinks Have Failed So Far’ (*Universe Today*, October 24, 2020) <<https://www.universetoday.com/articles/about-3-of-starlinks-have-failed-so-far>> accessed 20 October 2025; and Denise Chow, ‘SpaceX says up to 40 Starlink satellites lost to geomagnetic storm’ *NBC News* (10 Feb 2022) <<https://www.nbcnews.com/science/space/spacex-says-40-starlink-satellites-lost-geomagnetic-storm-rcna15516>> accessed 20 October 2025.

¹²³ OneWeb applications can be found in the United States Federal Communications Commission’s (FCC) database, IBFS File No. SAT-LOI-20160428-00041 <<https://fcc.report/IBFS/SAT-LOI-20160428-00041>> accessed 20 October 2025.

¹²⁴ Christian Davenport, ‘Amazon launches first internet satellites in bid to compete with Starlink’, *Washington Post* (6 October 2023) <<https://www.washingtonpost.com/technology/2023/10/06/amazon-launch-kuiper-internet-satellite-starlink/>>; and Joey Roulette, ‘Amazon launches first Kuiper internet satellites, taking on Starlink’ *Reuters* (29 April 2025) <<https://www.reuters.com/business/media-telecom/amazon-launches-first-kuiper-internet-satellites-taking-starlink-2025-04-28/>>.

This is especially important in remote or difficult-to-reach areas. Furthermore, LEO constellations generate a wide range of benefits for different actors. For private operators, they offer clear commercial advantage in terms of financial returns, competitiveness, and service quality. At the same time, they can contribute to broader public benefits by supporting economic development and improving access to internet connectivity and other services for communities worldwide.¹²⁵ As mentioned above, states also see the benefit of LEO constellations in the establishment of independent communication services and in the support of the SDGs in their region.

Owing to their socio-economic benefits, the number of satellites launched in LEO constellations is rapidly increasing. However, this trend raises several concerns, including: (a) the accelerated densification of the orbital space environment, heightening the risk of collisions between space objects; (b) the emergence of monopolistic dynamics and growing disparities among space actors; (c) light pollution induced by satellite constellations, potentially interfering with the visibility of the night sky and impede astronomical observations; (d) the growing demand for effective space traffic management and coordination among satellite operators; and (e) their environmental impact on both the atmosphere and the Earth surface due to satellite launches and re-entries. To provide a clearer understanding of the severity of these risks and their legal implications, each of these issues is examined in detail in the following sections. In addition, ongoing international discussions concerning LEO constellations and their associated challenges are briefly outlined to offer insight into the present state of policy developments.

a) Accelerated densification of LEO

As a result of the socio-economic benefits of large LEO constellations, there is an exponentially growing number of satellites placed in LEO. By applying a probability-weighted approach, Quilty Space, a research and consulting firm, has estimated that approximately 20,000 satellites are likely to reach orbit by 2030.¹²⁶ The United States Government

¹²⁵ Damian M. Bielicki, 'Legal Aspects of Satellite Constellations' (2020) 45(3) *Air and Space Law* 245, 262.

¹²⁶ Sandra Erwin, 'Industry report: Demand for satellites is rising but not skyrocketing' (*SpaceNews*, December 2023) <<https://spacenews.com/industry-report-demand-for-satellites-is-rising-but-not-skyrocketing/>> accessed 20 October 2025.

Accountability Office in a report in 2022 projected about 63,000 satellites would be deployed by 2030.¹²⁷ The increasing amount of active LEO satellites adds to the congestion of the low-Earth trajectory, leading to the likelihood of conjunctions, creating space debris that further densifies LEO, threatening humanity's overall access to space, and to the associated satellite services. Such dreaded scenario has been projected by many scientists and professionals, stating that LEO is already an unstable environment, hence further collisions are unavoidable even without considering new launches.¹²⁸ Even though we cannot escape from new collisions in the already dense LEO environment, the more accelerated the race to LEO is, the bigger the likelihood of accidental collisions in the orbit becomes with the potential for the most useful orbital altitudes – such as LEO – steadily approaching its carrying capacity. It is certain that the unregulated use of LEO based on the first-come, first-served mentality accelerates the overpopulation of LEO, without the guarantee of sufficient optimization between growth and equitable sharing of the orbital and spectral resources and the respect of the integrity of the space environment.

Other concerns linked directly to the overuse of LEO include the jeopardization of the safety of astronauts and space stations, as well as the narrowing of safety launch windows. In July and October 2021, the Starlink satellites for example approached China's Tiangong space station, forcing it to perform orbital manoeuvres, posing a realistic threat to the safety of the space station and taikonauts within.¹²⁹ Most recently, in 2025, reports indicated that the return mission of three taikonauts from the Tiangong space station was delayed after their spacecraft was impacted by space debris.¹³⁰ Additionally, scientists and public officials have warned

¹²⁷ United States Government Accountability Office, 'Large Constellation of Satellites – Mitigating Environmental and Other Effects, Technology Assessment, Report to Congressional Addressees' (September 2022) 1, 1 <<https://www.gao.gov/assets/gao-22-105166.pdf>> accessed 20 October 2025.

¹²⁸ See for example J.-C. Liou and A.K. Anil Kumar, et al., 'Stability of the Future LEO Environment – An IADC comparison study' (April 2013) 1, 7 <https://www.researchgate.net/publication/266584674_STABILITY_OF_THE_FUTURE_LEO_ENVIRONMENT_-_AN_IADC_COMPARISON_STUDY> accessed 20 October 2025; or Moriba Jah, 'Space Debris Will Block Space Exploration Unless We Start Acting Sustainably', *Scientific American* (August 1, 2023) <<https://www.scientificamerican.com/article/space-debris-will-block-space-exploration-unless-we-start-acting-sustainably/>> accessed 20 September 2025.

¹²⁹ Chen Lan, 'The Starlink-China Space Station near-collision: Questions, solutions, and an opportunity' (*The Space Review*, 18 February 2022) <<https://www.thespacereview.com/article/4338/1>> accessed 20 October 2025.

¹³⁰ Helen Davidson, 'Return of Chinese astronauts delayed after spacecraft struck by debris' *The Guardian* (5 November 2025) <<https://www.theguardian.com/world/2025/nov/05/chinese-astronauts-delayed-spacecraft-struck-by-debris-tiangong-space-station-shenzhou-20>>

about significant reduction of global safety launch windows as a result of the new LEO constellations.¹³¹ At the international level, no formal mechanism exist for coordinating launch windows. Instead, coordination primarily relies on launching states voluntarily adjusting their launch timings.¹³² This process is becoming increasingly burdensome as large LEO constellations continue to be deployed. On February 8th, 2022, for instance, NASA sent a letter to the United States Federal Communications Commission (FCC) – a US government agency, responsible for regulating national and international communications by radio, television, wire, satellite – arguing that the second generation Starlink constellation would interfere with NASA’s normal launch and scientific activities, affecting the transportation of personnel and cargo on the International Space Station (ISS), and worrying that the safety launch window would become less available.¹³³

Despite the haunting future scenario due to the growing number of satellites, space actors keep focusing on the enormous potential of large constellations. At the same time, general awareness has grown regarding the risks of LEO exploitation, which led satellite manufacturers and operators to invest in sustainable designs and practices as well. Furthermore, increasing number of countries and non-governmental entities see the benefit of gathering information on the aggregate orbital risk “to develop smart ways to more efficiently make use of the finite orbital volume and risk budget, and to understand the opportunity costs imposed by placing a particular constellation configuration at a particular altitude”.¹³⁴ There are more scientific projects for instance to estimate the carrying capacity of LEO.¹³⁵ Some see a quick-fix to the growing issue by investing in remediation technologies, such as active debris removal

¹³¹ See for example: China Xi’an Satellite Control Center, ‘LEO Mega-constellation is deeply influencing space activities of the world’ (June 2022) <https://www.unoosa.org/documents/pdf/copuos/2022/1.China_LEO_Mega-Constellation_is_Deeply_Changing_Space_Activities_of_the_World.pdf> accessed 20 October 2025.

¹³² Hanhui Zha and Jinyuan Su, ‘The “due regard” obligation in the deployment and operation of satellite mega-constellations’ (2025) 73 *Space Policy* 1, 6 <<https://doi.org/10.1016/j.spacepol.2024.101674>>.

¹³³ Jeff Foust, ‘NASA outlines concerns about Starlink next-generation constellation in FCC letter’ (*SpaceNews*, 9 February 2022) <<https://spacenews.com/nasa-outlines-concerns-about-starlink-next-generation-constellation-in-fcc-letter/>> accessed 20 October 2025.

¹³⁴ Miles Lifson, ‘Low Earth Orbit Spacecraft Slotting: Towards an Implementable Proposal’ (Doctoral thesis, Massachusetts Institute of Technology, 2024) 68 <<https://dspace.mit.edu/handle/1721.1/155421>> accessed 20 October 2025.

¹³⁵ Secure World Foundation and European Space Policy Institute, ‘Summary: Regulator to Regulator Dialogue on Approaches to Licensing of Large Constellations’ (June 21, 2022) <https://www.espi.or.at/wp-content/uploads/2023/03/Summary_SWF-ESPI-R2R-Dialogue_Vienna_Final.pdf> accessed 20 October 2025.

that allows for the continuous promotion of LEO satellite development.¹³⁶ Even with the consideration of existing mitigation tools, there are worrying views, that without sufficient limitations and regulations, we are heading towards the *tragedy of the commons* in space, akin to what occurs on the Earth's surface.¹³⁷

The limitation of the orbits arises because a satellite, when positioned in an orbital slot, requires a specific radio frequency within the electromagnetic spectrum. To prevent interference between transmissions, these radio frequencies must be distinct, and satellites must maintain an approximate separation – at least eighteen kilometres from one another in GEO –. In theory, GEO can accommodate only a finite number of satellites – estimated at around 1800-2000, depending on available technologies.¹³⁸ With the advancement of LEO satellite constellations, we see similar conversations and considerations taking place regarding the management of the orbit and its spectrum. Nonetheless, in order to set up a regulatory regime similar to the GEO one, scientists believe, calculation of the orbit's carrying capacity is necessary. When it comes to non-GSO, such as LEO, however, where satellites do not appear to be stationary compared to GEO spacecrafts, the calculation of the orbit's carrying capacity proves to be more difficult. Considering the numerous ITU large constellation filings, all the potential configurations make it clear that the total number of LEO satellites could number in the hundreds of thousands. This enormous number is what concerns the wider space community, as it also feeds the first-come, first-served mentality, giving advantage to the more developed nations, and calls into question the ability of any other user to operate in LEO if

¹³⁶ J.-C. Liou and A.K. Anil Kumar, et al., 'Stability of the Future LEO Environment – An IADC comparison study' (April 2013) 1, 7

⟨https://www.researchgate.net/publication/266584674_STABILITY_OF_THE_FUTURE_LEO_ENVIRONMENT_-_AN_IADC_COMPARISON_STUDY⟩ accessed 20 October 2025.

¹³⁷ The concept of the "tragedy of the commons" was coined in 1968 by biologist, Gerret Hardin, applying that each individual with access to a public resource (also known as a common) acts its own interest and, in doing so, ultimately depletes the resource. The tragedy of the commons applied to orbital space, will be further analysed in Chapter IV of this this dissertation.

¹³⁸ See: Lawrence D. Roberts, 'A Lost Connection: Geostationary Satellite Networks and the International Telecommunication Union' (Fall 2000) 15 (3) *Berkeley Technology Law Journal* 1095, 1101; Paris Arnopolous, 'The International Politics of the Orbit-Spectrum Issue' (1982) 7 *Annals of Air & Space Law* 215, 216.

such large numbers of communication satellites are launched.¹³⁹ Such approach, as space experts fear, might lead to the monopolization of both orbital slots and radiofrequencies.¹⁴⁰

From the regulation of LEO's point of view, it has been pointed out that, "in light of the foregoing governance regimes, comprised of rights, obligations, and principles, there remains a lack of clear limits to the extent that constellations can be deployed and operated in increasingly valuable and congested orbits".¹⁴¹ As there is no single "architecture" for LEO, rulemaking is complicated. Further elements that highlight the challenges of LEO conversation are uncertainties behind how many satellites will eventually be needed for a quality service, or indeed how many constellations will be commercially successful.

While leading scientists have been predicted for decades the above tendencies and likely devastating outcomes associated with the wide deployment of large constellations, not enough has been done at the international governance (COPUOS and ITU) level. Therefore, this dissertation argues that there is a lack of mechanism, serious hurdle of the initiatives to launch such a quantity of objects in low Earth orbit within and outside the global space community.¹⁴² Large LEO constellations, however, are a cause of concern not only due to the overpopulation of a limited resource and environment that the orbits represent, but also to potentially contributing to the rapidly growing space debris concern. The question whether the ITU may be able to similarly govern the exponentially increasing number of satellites placed in LEO as it has done so in GEO has already entered the scholar and multilateral discussions, which option will be further analysed in this dissertation later. Moreover, additional legal concerns such as the question of the freedom principle, appropriation, government of the orbit as commons, registration, frequency and orbital management, or the right to internet will be discussed in Part II of this document.

¹³⁹ Ruth Pritchard-Kelly, 'WRC-23 on the Horizon: Large Satellite Constellations, ITU Issues, and Industry Perspective' (2023) 48 *Air & Space Law* 179, 180.

¹⁴⁰ Griffin Davis, 'SpaceX's Competitors Claims Elon Musk could monopolize space' (*Tech Times*, 29 May 2021) <<https://www.techtimes.com/articles/260823/20210529/spacexs-competitors-claims-elon-musk-monopolize-space-starlink-constellation-unsustainable.htm>> accessed 20 October 2025; or Tereza Pultarova, 'French court revokes SpaceX's Starlink internet license, citing monopolization concerns' (Space.com, 14 April 2022) <<https://www.space.com/starlink-french-court-revokes-license-monopolization>> accessed 20 October 2025.

¹⁴¹ Christopher Johnson, 'The Legal Status of MegaLEO Constellations and Concerns About Appropriation of Large Swaths of Earth Orbit' in J. Pelton (ed.) *Handbook of Small Satellites* (Springer 2020) 1337, 1348.

¹⁴² The term "global space community" encompasses all states, as well as other governmental and non-governmental entities that are involved in the exploration and utilization of outer space for the purpose of this thesis.

b) Monopolization in LEO?

*“It is concerning that, for example, one person could make the decision to take down the [internet] service for hundreds of thousands of people”.*¹⁴³

As of early 2025, SpaceX’s Starlink constellations accounts two-thirds of all active satellites orbiting the Earth,¹⁴⁴ with over 7000 operation units.¹⁴⁵ Leveraging its reusable Falcon launch vehicle, the US-based space company led by Elon Musk is capable of deploying hundreds of satellites into orbit each month. It aims to scale its constellation to 42,000 satellites in the coming years, potentially making Starlink to world’s largest internet service provider.¹⁴⁶

Already available in more than 100 countries, Starlink initially targeted remote and underserved communities.¹⁴⁷ Today, it serves around three million subscribers globally, each paying a monthly fee to access high-speed broadband via a user terminal priced at approximately \$300.¹⁴⁸ The sheer scale of this satellite network – and the concentration of control in the hands of a single private actor – raises significant concerns. While Starlink has demonstrated its value in critical situations,¹⁴⁹ the constellation’s growing dominance also

¹⁴³ Anthony Cuthbertson, ‘Elon Musk is turning himself into a space superpower – this is why it matters’ (9 Sept 2024) *Independent* <<https://www.the-independent.com/space/elon-musk-satellite-control-starlink-spacex-b2608427.html>> accessed 20 October 2025.

¹⁴⁴ “We do have one player that’s got almost two-thirds of the satellites that are in space right now and has a very high portion of internet traffic,” See: David Shepardson, ‘FCC chair wants more competition to SpaceX’s Starlink unit’ *Reuters* (11 September 2024) <<https://www.reuters.com/technology/space/fcc-chair-wants-more-competition-spacexs-starlink-unit-2024-09-11/>>.

¹⁴⁵ Anthony Cuthbertson, ‘Elon Musk is turning himself into a space superpower – this is why it matters’ (9 Sept 2024) *Independent* <<https://www.the-independent.com/space/elon-musk-satellite-control-starlink-spacex-b2608427.html>>.

¹⁴⁶ *Ibid.*

¹⁴⁷ Internet Society, ‘Perspectives in LEO Satellites – Using Low Earth Orbit Satellites for Internet Access’, (November 2022) 1 <<https://www.internetsociety.org/resources/doc/2022/perspectives-on-leo-satellites/>> accessed 20 October 2025.

¹⁴⁸ A user terminal also sometimes called a ground terminal or simply an antenna or dish is how the users receive data from and transmit data to the satellites. See: Internet Society, ‘Perspectives in LEO Satellites – Using Low Earth Orbit Satellites for Internet Access’, (November 2022) 3 <<https://www.internetsociety.org/resources/doc/2022/perspectives-on-leo-satellites/>> accessed 20 October 2025.

¹⁴⁹ For instance, following Russia’s attack on Ukraine’s telecommunications infrastructure in 2022, Starlink provided a vital means of connectivity. Ukraine’s digital minister, Mykhailo Fedorov, told The New York Times that the number of lives saved through continued digital access “can be measured in the thousands”. See: The New York Times ‘With Starlink, Elon Musk’s Satellite Dominance Is Raising Global Alarms’ *The New York Times* <<https://www.nytimes.com/interactive/2023/07/28/business/starlink.html>>.

poses a potential existential threat to the decentralized architecture of the internet as we know it.¹⁵⁰

Concerns about market concentration in LEO are growing. A 2022 report by the Internet Society warned of the risks posed by insufficient competition in the satellite broadband sector. Like other areas of technology, the report argued, the satellite internet industry is susceptible to issues of market power and economic consolidation.¹⁵¹ The study cautioned that such dominance could result in the emergence of “control choke points”, where key access and infrastructure are concentrated in the hands of a few actors.¹⁵² The report also underscored the absence of a regulatory framework at the international level for allocating orbital slots in LEO. This lack of regulation allows dominant providers such as Starlink to secure the most desirable orbital positions, potentially “leaving later entrants with less optimal choices – or none” at all.¹⁵³

While exact wording varies, a monopoly is generally understood in international competition law: as a situation where a single firm (or group of firms) has dominant market power, allowing it to control prices or exclude competitors.¹⁵⁴ By now, Starlink has become

¹⁵⁰ In terms of geopolitical rivalry, it is crucial to recognize the inherent dual nature of satellite infrastructure. Since 2000, all users worldwide have enjoyed free access to the high-precision GPS signal provided by US satellites; yet, under the mechanism of Selective Availability, the United States retains the legal and technical capacity to restrict or degrade this access if national security so requires. This possibility raises profound concerns given the extent to which GPS underpins critical civilian applications, including air traffic control, international shipping, and financial transactions – where any degradation of signal could generate severe economic disruption or even risks to human life. A comparable dynamic is now emerging in LEO. Although satellite internet services are formally offered by private operators, most notably SpaceX’s Starlink, Article VI and VIII OST allow states to retain jurisdiction and control as well as authorization and continuing supervision over registered satellites. This means that, much like with GPS, the US government could in principle direct or constrain the provision of Starlink services on national security grounds, thereby shaping access to orbital infrastructure during international conflict. Such dependencies illustrate how orbital services, though formally part of the global commons, can be leveraged as instruments of geopolitical power, complicating efforts to design equitable and sustainable governance arrangements. See on Selective Authority: Tanja Masson-Zwaan and Mahulena Hofmann, *Introduction to Space Law* (5th edn, Wolters Kluwer 2024) 187. On LEO constellations and Starlink: Mathieu Pollet, ‘Ukraine is stuck with Musk’s Starlink for now’ *Politico* (7 April 2025) <<https://www.politico.eu/article/ukraine-stuck-with-elon-musk-starlink-satellite-internet/>> accessed 20 October 2025.

¹⁵¹ Economic consolidation can be understood as the process by which a few firms or entities gain increasing control over a market or sector, often through mergers, acquisition, or market dominance. It results in the accumulation of economic influence among a limited number of dominant actors.

¹⁵² Internet Society, ‘Perspectives in LEO Satellites – Using Low Earth Orbit Satellites for Internet Access’, (November 2022) 7 <<https://www.internetsociety.org/resources/doc/2022/perspectives-on-leo-satellites/>> accessed 20 October 2025.

¹⁵³ *Ibid.*, 7.

¹⁵⁴ See for example: Richard Whish and David Bailey, *Competition Law* (7th edn, Oxford 2012) 7-8.

the only high-bandwidth internet system covering the entire planet.¹⁵⁵ In the continuing absence of sufficient competition in the satellite broadband sector, concerns extend beyond Starlink's physical dominance of orbital space in LEO. Experts fear that SpaceX – and by extension, Elon Musk – could reach such concentrated control resulting in reduced consumer choice, increased risks of surveillance and data misuse, and the erosion of national sovereignty in both economic and strategic terms.¹⁵⁶ Moreover, the dominant position allows SpaceX to exert disproportionate influence over regulatory institutions due to its technical and market power.¹⁵⁷

c) Increased magnitude of the Dark and Quiet Skies' problem

Socrates: *“Shall we set down astronomy as a third [brunch of study]?”*

Glauccon: *I think so, to know something about the seasons, the months and the years is of use for military purposes, as well as for agriculture and for navigation.*

Socrates: *It amuses me to see how afraid you are, lest the common herd of people should accuse you of recommending useless studies”.*¹⁵⁸

¹⁵⁵ David Shepardson, 'FCC chair wants more competition to SpaceX's Starlink unit' *Reuters* (11 September 2024) <<https://www.reuters.com/technology/space/fcc-chair-wants-more-competition-spacexs-starlink-unit-2024-09-11/>>.

¹⁵⁶ See: Mathieu Pollett, 'Ukraine is stuck with Elon Musk's Starlink for Now' *Politico* (April 2025) <<https://www.politico.eu/article/ukraine-stuck-with-elon-musk-starlink-satellite-internet/>> article, which details how Ukraine's wartime reliance on SpaceX's Starlink system underscores the strategic leverage a single private actor can acquire in armed conflict. The article highlights Ukraine's dependence on Starlink for military communications, noting that Elon Musk's personal decisions – such as restricting service during specific military operations – exposed the vulnerabilities of relying on privatized infrastructure without state or multilateral oversight. According to the article, while Eutelsat – a Franco-British satellite operator and direct competitor – remains unprepared to challenge Musk's dominance, the European Union has initiated the IRIS² programme, a multibillion-euro project aimed at developing a sovereign satellite constellation to rival Starlink in Europe, with operations expected to begin in the early 2030s.

¹⁵⁷ For instance, SpaceX has aggressively lobbied both at the ITU and the US Federal Communication Commission (FCC) to relax the out-of-band emission power flux density (EPFD) limits, which currently restrict its satellite-to-device services in LEO. These ITU-imposed interference limits presently allow only text-based services, preventing the provision of full voice and data capabilities. For the lobbying activities at ITU, see: Alliance for Satellite Broadband, 'WRC-23: Time to Get the Rules Right for Satellite Broadband' (*SpaceNews*, 18 November 2023) <<https://spacenews.com/wrc-23-time-to-get-the-rules-right-for-satellite-broadband/>> accessed 20 October 2025; and on the lobbying activities of SpaceX before the FCC, see: David Goldman, 'Petition for Rulemaking before the Federal Communications Commission' (9 August 2024) <<https://www.fcc.gov/ecfs/document/10809160739016/1>> accessed 20 October 2025.

¹⁵⁸ Plato; Paul Shorey, Translator. Plato, *The Republic* (1930) Book VII, 173.

Astronomy is one of humanity's oldest sciences and underpins our exploration and use of outer space. There are numerous artificial interferences that can have a negative impact on the visibility of the night sky. Advancements in understanding our universe have been achieved through the creation of modern observatories, both in space and on Earth, working collaboratively across the entire electromagnetic spectrum. Astronomical insights are critical not only for deep space navigation and exploration but also for investigating the conditions on celestial bodies within our Solar System, safeguarding Earth from potential asteroid threats, exploring the possibility of extraterrestrial life, and unravelling the origins of our planet. The continued exploration of cutting-edge astronomical phenomena relies on maintaining unobstructed and undisturbed access to cosmic electromagnetic signals. This necessitates safeguarding the dark and quiet skies of major professional observatories from anthropogenic interference.¹⁵⁹ Astronomers have been also acquiring information on our place in the universe, through the study of celestial phenomena, which inevitably leads to technological progress. It is therefore in the interest of all sectors of society to enable astronomy and cosmology to access the sky, free of manmade interference. Moreover, beyond science and technology, "the pristine spectacle of the starry night sky has been inspirational to humankind since prehistoric times, and this world cultural heritage should be zealously protected".¹⁶⁰

Although LEO constellations can bring technological, economic and societal benefits, satellite constellations fundamentally change the view of the night sky for everyone on the planet.¹⁶¹ This change to the pristine night sky has impacts on religious and cultural practices, dark sky reserves, astrophotography, animal and insect life and scientific inquiry. At the same time, impacts of fully deployed constellations on the visibility of the night sky and professional astronomical observations have not been thoroughly taken into consideration. The issue arises from the fact that, due to their low orbit, a significant number of satellites are easily visible to the naked eye, particularly when situated at low elevations above the horizon and during

¹⁵⁹ UNOOSA and IAU, 'Dark and Quiet Skies for Science and Society Report and Recommendations On-line Workshop (January 2021) 1, 12 <https://www.researchgate.net/publication/350387205_Dark_and_Quiet_Skies_for_Science_and_Society_Report_and_Recommendations_On-line_Workshop_United_Nations_Office_for_Outer_Space_Affairs_International_Astronomical_Union_Instituto_de_Astrofisica_de_Cana> accessed 20 October 2025.

¹⁶⁰ Ibid., 12.

¹⁶¹ Ibid., 14.

twilight and dawn. Even more, the light paths of the large number of satellites belonging to constellations have become easily detected by the highly sensitive astronomical detectors of the modern telescopes, during the night. To assess the impact of LEO satellites to astronomy research, we must consider more than just the satellites' brightness but also their apparent velocity, position in the sky, and frequency of sightings.¹⁶²



Starlink satellites' trail during sunset in Godshell, Isle of Wight, visible to the naked eye. Credit: Charlie Norman, Source: BBC¹⁶³

According to the International Astronomical Union (IAU), the scientific concerns regarding satellite constellations are two-fold: a) to minimize solar heating effects, the surfaces of these satellites are often made of highly reflective metal, and reflections from the Sun in the hours after sunset and before sunrise make them appear as illuminated dots moving in the night sky; b) despite notable efforts to avoid interfering with radio astronomy frequencies, aggregate radio signals emitted from the satellite constellations can still threaten astronomical observations at radio wavelengths. Thus, for astronomers, impact of constellations is

¹⁶² Ibid., 12.

¹⁶³ Lydia Wilson, 'Elon Musk's Starlink Satellites Light Up Night Sky' *BBC News* (23 October 2023) <https://www.bbc.com/news/articles/crg1xn3pd4ro>.

enormous, especially when taking into consideration the large numbers of satellites proposed and the low altitude of their orbits.¹⁶⁴

According to a 2021 document submitted by Chile, Ethiopia, Jordan, Slovakia, Spain and the International Astronomical Union, to the Scientific and Technical Subcommittee of COPUOS, the allocated spectrum fraction for scientific purposes is insufficient to support radio astronomy and presents a significant challenge for other scientific applications.¹⁶⁵ The submitters argued that the current measures in place to protect radio astronomy operations are not well-prepared to handle the expected increase in LEO satellites. With 5300 satellites orbiting, and around 300 visible above the horizon at any given moment across a large portion of the visible sky in 2021, the average distance between satellites poses a challenge for a radio telescope to point at the sky without encountering a satellite within about 4 degrees.¹⁶⁶ As the number of satellites in orbit is anticipated to reach 50,000, this proximity increases to within 1.3 degrees. It's crucial to note that this interference doesn't only occur when satellites pass directly in front of the telescope; their signals can disrupt what the telescope is trying to observe even if they're positioned off to the side.¹⁶⁷

The night sky encompasses our understanding of nature. However, there are additional societal implications as well: every citizen might claim a fundamental right to view and enjoy a pristine night sky. Observations conducted on the wide field of view telescopes and radio telescopes will likely be severely impacted in the absence of substantial mitigations. Although, so far, no consensus has been reached, the issue of the protection of dark and quiet skies from large satellite constellation interference, as a result of the accelerated densification of LEO, has

¹⁶⁴ Piero Benvenuti, general secretary of the International Astronomical Union, told the Independent, “The core of the issue is their increasing numerosity, which makes it very difficult to avoid their traces in the astronomical images. If the total number of LEO satellites becomes larger than about 100,000 then any mitigating measures, like predicting with high accuracy the position of all the satellites from any ground observatory, will become very difficult to implement and to be effective. This is the worst-case scenario”. See: Anthony Cuthbertson, ‘Elon Musk is turning himself into a space superpower – this is why it matters’ (9 Sept 2024) *Independent* <<https://www.the-independent.com/space/elon-musk-satellite-control-starlink-spacex-b2608427.html>> accessed 20 October 2025.

¹⁶⁵ UNCOPUOS, STSC, ‘Recommendations to Keep Dark and Quiet Skies for Science and Society, Paper submitted by Chile, Ethiopia, Jordan, Slovakia, Spain and the International Astronomical Union’ (19 April 2021) Un Doc. A/AC.105/C.1/2021/CRP.17, 4-7.

¹⁶⁶ Ibid., 18.

¹⁶⁷ Ibid., 18.

been featuring prominently at most recent UNCOPUOS meetings.¹⁶⁸ In 2024, all these efforts resulted in the adoption of a single issue/item for discussion on the agenda of the Scientific and Technical Subcommittee of UNCOPUOS, titled ‘Dark and Quiet Skies, Astronomy and Large Constellations: Addressing Emerging Issues and Challenges’.¹⁶⁹

d) Lack of space traffic coordination

*“It is time to seriously consider a global legal regime for STM to ensure the sustainability of space activities and the safety of spacecraft in orbit, and to avoid potential collisions or accidents”.*¹⁷⁰

As space technologies advance swiftly, the realization of large satellite constellations in low Earth Orbit (LEO), private human spaceflights to LEO and beyond, and various innovative space endeavours has become a tangible and ongoing aspect of space commercialization and privatization. Moreover, it has become evident that existing rules in space law are insufficient to address the demands of upcoming space activities.¹⁷¹ Beyond safety concerns, the international community has begun to focus on the preservation of the orbital space environment; and Space Traffic Management (STM) – many believe – is a crucial tool to achieve this objective.¹⁷²

There is to date no widely accepted definition of STM. Nevertheless, numerous legal scholars, international organizations and governmental entities have come up with their own

¹⁶⁸ See for example: UNCOPUOS, ‘Report of the Committee on the Peaceful Uses of Outer Space’ (20 June 2023) UN Doc. A/78/20, 20.

¹⁶⁹ UNCOPUOS STSC, ‘Report of the Scientific and Technical Subcommittee on its sixty-first session, held in Vienna from 29 January to 9 February 2024’ (9 February 2024) UN Doc. A/AC.105/1307, 27-29; See also European Southern Observatory (ESO), United Nations Agrees to Address Impact of Satellite Constellations on Astronomy (15 February 2024) <https://www.eso.org/public/announcements/ann24003/> accessed 20 October 2025.

¹⁷⁰ Tanja Masson-Zwaan & Yun Zhao, ‘Towards an International Regime for Space Traffic Management’ (2023) 48 *Air & Space Law* 75, 75.

¹⁷¹ *Ibid.*, 75.

¹⁷² See for example: Haydar Cukurtepe & Ilker Akgun, ‘Towards Space Traffic Management System’ (2009) 65(5-6) *Acta Astronautica* 870, 874; or Paul B. Larsen, ‘Space Traffic Management Standards’ (2018) 83(2) *Journal of Air Law and Commerce* 359, 365–366; or Yu Takeuchi, ‘Legal Aspects of International Regime for Space Traffic Management’ (LLM thesis, McGill University 2015) 1, 18.

description. STM is commonly known as legal and technical measures used to manage operators in the orbital space environment, to stabilize and minimize collision risk.¹⁷³ Accordingly, STM has a broad scope, as it covers the pre-launch, operation, and re-entry of space objects. Moreover, STM takes into consideration two dimensions of space traffic, the scientific-technical area, and the regulatory field.¹⁷⁴

By now, three esteemed international organizations, the International Academy of Astronautics (IAA), the International Astronautical Federation (IAF) and the International Institute of Space Law (IISL), agreed to join in a cooperative initiative to develop comprehensive approaches and proposals for STM and formalized the initiative with a Memorandum of Understanding, signed in 2022.¹⁷⁵ Although Space Traffic Management supports space safety entirely, the MoU underlined that STM plays a central piece also in ensuring space security and space sustainability. According to the document, space safety issues primarily fall under STM and exist between the many operational spacecraft as well as in their interaction with the current space debris and space security environments. Furthermore, under space safety, collision risk – the product of the likelihood and consequence of space object collisions – is mitigated through a combination of licensing, aspirational best practices, international guidelines and standards, national regulations, responsive onboard collision avoidance capability, and operational synchronization via data and information sharing.¹⁷⁶ Moreover, safety issues extend into Space Traffic Coordination (STC) because no operator functions in isolation. STC facilitates essential collective communications, information exchange, and coordinated actions among space actors to ensure the secure movement of spacecraft in orbit. To uphold compliance and accountability in line with overarching safety and sustainability objectives, operators must meet regulatory and licensing conditions

¹⁷³ P.J. Blount, 'Legal Issues Related to Satellite Orbits' (December 2022) *Oxford Research Encyclopedia of Planetary Science* 1, 9 <<https://doi.org/10.1093/acrefore/9780190647926.013.78>>.

¹⁷⁴ Kai-Uwe Schrogl, 'Space Traffic Management Toward a Roadmap for Implementation' (Presentation at UNOOSA Space Law Conference, Vienna, 10 December 2020) <https://www.unoosa.org/documents/pdf/spacelaw/activities/2020/SLC2020Presentations/SLC2020PDFPresentations/P_Schrogl_-_10_Dec_2020_-_201210_UN_Space_Law_STM.pdf> accessed 20 October 2025.

¹⁷⁵ International Academy of Astronautics (IAA), the International Astronautical Federation (IAF) and the International Institute of Space Law (IISL), 'Memorandum of Understanding (MoU) of the International on a Cooperative initiative to develop comprehensive approaches and proposals for Space Traffic Management' (2022) 1, 4 <<https://iaaspace.org/wp-content/uploads/iaa/Communication/stm-mou.pdf>> accessed 20 October 2025.

¹⁷⁶ *Ibid.*, 4.

established by their governing authority.¹⁷⁷ Space sustainability, or space environment preservation uses Space Situational Awareness (SSA) to describe the space environment and how it changes over time.¹⁷⁸ With this comprehension, it becomes possible to create updated mitigation standards and STM regulations aimed at stabilizing and reducing the risk of collisions.¹⁷⁹ A notable distinction emerges between the European and US approaches when considering STM rules. While Europe tends to conceptualize STM as a regulatory framework with formal rule sand standards, based on international cooperation – not just among EU Member States, but also on regional and global cooperation between among the EU and other countries –,¹⁸⁰ the US frames STM more narrowly as a set of operational activities – focused on planning, coordination, and on-orbit synchronization – rather than as binding legal obligations. Consequently, the US emphasizes regulatory measures at the domestic level over international collaboration, placing a greater emphasis on individual management actions to address space-related challenges.¹⁸¹

Even though STM may ensure a safer and more secure on-orbit operation, it is unclear in what form such regulation may be manageable under the current geopolitical circumstances. Such a mechanism can include various formats, such as with the lead of a central international organization or as a result of domestic systems working through an international agreement.¹⁸² Nonetheless, legal professionals have argued that measures on STM cannot be effective if approached in a disparate manner through national or regional silos, but it is necessary “to look into a possible legal framework for regulating space traffic and improving global space

¹⁷⁷ Ibid., 4.

¹⁷⁸ Space Situational Awareness (SSA) mostly refers to keeping track of objects in orbit and predicting where they will be at any given time, and it is planned to be part of STM.

¹⁷⁹ When two or more space objects face a potential collision, the rule of right of way determines which vehicle is obligated to take evasive action and which may maintain its orbit and trajectory. In situations involving mega-constellation satellites and other spacecraft, several factors should be assessed, including manoeuvrability, the nature of the mission (public or private), economic implications, and the degree of responsibility each party would bear in the event of collision. See: Hanhui Zha and Jinyuan Su, ‘The “due regard” obligation in the deployment and operation of satellite mega-constellations’ (2025) 73 *Space Policy* 1, 5 <<https://doi.org/10.1016/j.spacepol.2024.101674>>.

¹⁸⁰ Giulia Pavesi, Claudiu Taiatu & Tanja Masson-Zwaan, ‘An EU Approach for Space Traffic Management: Updated Instruments to Tackle Rising Challenges’ IAC-22-A6, 8-E9.1. (2022) <<https://iafastro.directory/iac/paper/id/73942/summary/>> accessed 20 October 2025.

¹⁸¹ Tanja Masson-Zwaan & Yun Zhao, ‘Towards an International Regime for Space Traffic Management’ (2023) 48 *Air & Space Law* 75, 78.

¹⁸² Ibid., 78.

situational awareness to further development and ensure that space technologies can serve and enhance human well-being at a wider, deeper, and higher level”.¹⁸³

It is also important to note, relevant to the topic of this dissertation, that STM discussions highlight the limited nature of the orbits, and consequently implemented the notion of “space capacity management”.¹⁸⁴ As a first step toward space capacity management, the space community needs to “develop a scientific and technical understanding of precisely what is meant by this limited capacity [of the orbits], how to quantify it, and how to measure its use”.¹⁸⁵ Besides measuring the capacity, however, new indicators and thresholds are necessary to be defined, and a transparent methodology to seek for global consensus and implementation in countries’ regulatory approach should be set up.¹⁸⁶ On the one hand, one can see that STM is a necessary set of tools and mechanisms to monitor and manage satellite activities in the orbits, on the other hand, we may be critical about the willingness of decision-makers to interrupt the first-come, first-served approach by introducing certain limitations a part of a larger STM mechanism regarding the number of satellites that LEO can sustain. With the reluctance of the United States, it is unlikely that a global and encompassing “space traffic regime” will be reached in the near-term future.

e) Lack of re-entry risk assessment

From 2010 to 2020, observations revealed that, on average, around 90 metric tons of human-made space objects re-enter the Earth's atmosphere without control each year.¹⁸⁷ Approximately 80% of this mass is composed of spent orbital stages, while the remaining 20% consists of spacecraft. Objects weighing more than 500 kg re-enter uncontrolled approximately

¹⁸³ Ibid., 75.

¹⁸⁴ International Academy of Astronautics (IAA), the International Astronautical Federation (IAF) and the International Institute of Space Law (IISL), ‘Memorandum of Understanding (MoU) of the International on a Cooperative initiative to develop comprehensive approaches and proposals for Space Traffic Management’ (2022) 1, 17 <<https://iaaspace.org/wp-content/uploads/iaa/Communication/stm-mou.pdf>> accessed 20 October 2025.

¹⁸⁵ Ibid., 17.

¹⁸⁶ Ibid., 17.

¹⁸⁷ Carmen Pardini and Luciano Anselmo, ‘The Kinetic casualty risk of uncontrolled re-entries before and after the transition to small satellites and mega-constellations’ (2022) 9(3) *Journal of Space Safety Engineering* 414, 414.

every eight days, and those exceeding five metric tons re-enter once or twice a year.¹⁸⁸ Such accidents with the increasing space activities are estimated to grow as well.

The assessment of re-entry risk until today involves two main aspects: evaluating the survivability of the re-entering object and assessing the risk it poses to people, property, or aircraft on the ground. Since the 1990s, there has been a growing international consensus that a casualty expectancy of 10^{-4} is considered the risk threshold for uncontrolled re-entry.¹⁸⁹ The current global expectation of casualties, however, due to the re-entry of human-made spacecraft is estimated to be around 10^{-2} annually.¹⁹⁰ Additionally, the responsibility for evaluating the risk is typically left to the owner or operator of the object, and there is often limited disclosure of the expected casualty expectancy before uncontrolled re-entry.¹⁹¹ This lack of transparency could potentially lead to frequent breaches of the risk threshold, possibly occurring once a week or at least once a month. This situation has been deemed unsatisfactory.¹⁹² Additionally, the risk to aircraft in flight is also becoming concerning as airplanes are more vulnerable to small debris and global flight corridors are dynamic and steadily growing.¹⁹³ Thus, experts on the subject of STM believe that re-entry management should be also part of an efficient STM regime.

In addition, recent scientific research has shown that burn-up of satellites during re-entry inducing potential changes in the stratospheric aerosol layer.¹⁹⁴ Planned increases in the number of LEO satellites within the next few decades could cause up to half of stratospheric sulfuric acid particles to contain metals from re-entry.¹⁹⁵ The influence of this level of metallic content on the properties of stratospheric aerosol is yet unknown. A possible outcome is that aluminium and other materials may have an impact on the creation of ice crystals in the

¹⁸⁸ Ibid., 414.

¹⁸⁹ Ibid., 414.

¹⁹⁰ Ibid., 416.

¹⁹¹ International Academy of Astronautics (IAA), the International Astronautical Federation (IAF) and the International Institute of Space Law (IISL), 'Memorandum of Understanding (MoU) of the International on a Cooperative initiative to develop comprehensive approaches and proposals for Space Traffic Management' (2022) 1, 7 <<https://iaaspace.org/wp-content/uploads/iaa/Communication/stm-mou.pdf>> accessed 20 October 2025.

¹⁹² Ibid., 7.

¹⁹³ See for example: UNCOPUOS 'Report of the Legal Subcommittee on its sixty-second session, held in Vienna from 20 to 31 March 2023' (13 April 2023) UN Doc. A/AC.105/1285 Para 253.

¹⁹⁴ Daniel M. Murphy, et al., 'Metals from Spacecraft Reentry in Stratospheric Aerosol Particles' (24 October 2023) 120(43) *Proceedings of the National Academy of Sciences* 1, 1.

¹⁹⁵ Aerosol particles that are formed in the stratosphere are composed primarily of sulfuric acid derived from the oxidation of carbonyl sulfide and, after volcanic eruptions, sulfur dioxide. See: Ibid., 1, 1.

stratosphere, potentially altering the formation of polar stratospheric clouds and contributing to ozone depletion. Additionally, these metals could lead to chemical reactions or optical effects that influence solar radiation and the albedo of the upper atmosphere, among other factors. Although the exact harmful effects of deorbiting artificial objects are not yet fully understood, large constellation operators and their respective states may be held accountable for any atmospheric damage and required to internalize the externality costs of orbital re-entry. Consequently, incorporating the environmental footprint of satellite re-entry into the re-entry risk assessments is becoming increasingly crucial for the near-term future.

f) International policy discussions on LEO constellations in the context of space sustainability

*“The emergence of operational constellations is disrupting legal regimes for states and industrial players, and future Agenda Items (AIs) should be added to World Radiocommunications Conference (WRC)-27 or future Committee on the Peaceful uses of Outer Space (COPUOS) sessions”.*¹⁹⁶

Although this document does not wish to thoroughly analyse procedural concerns, it is valuable to touch upon the latest multilateral discussions on the protection and management of the orbital space environment as a limited resource, for a thorough understanding. The legal sources relevant to both UN institutions (COPUOS and ITU) will be analysed in more details in Part II of this dissertation.

The United Nations Committee on the Peaceful Uses of Outer Space (COPUOS)

The United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) was set up by the United Nations General Assembly in 1959 to govern the exploration and use of

¹⁹⁶ Ruth Pritchard-Kelly, ‘WRC-23 on the Horizon: Large Satellite Constellations, ITU Issues, and Industry Perspective’ (2023) 48 *Air & Space Law* 179, 179.

space for the benefit of all humanity.¹⁹⁷ The Committee was instrumental in the creation of the five treaties and five principles of outer space.¹⁹⁸ International cooperation in space exploration and the use of space technology applications to meet global development goals are discussed in the Committee every year. The Committee has two subsidiary bodies: the Scientific and Technical Subcommittee, and the Legal Subcommittee.

At COPUOS, the limited capacity of LEO has been discussed since the beginning of the 2000s, first relevant to the adoption of the COPUOS Space Debris Guidelines in 2007,¹⁹⁹ and later under the almost-decade-long multilateral discussions in the Working Group of the Long-term Sustainability of Outer Space Activities, resulting the adoption of the 21 LTS Guidelines in 2019.²⁰⁰ The LTS Guidelines comprises key aspects of space sustainability and represents the willingness and consensus of all COPUOS States members. Nevertheless, it is a voluntary and political instrument, meaning that it has no binding effect to its Member States, and thus it does not entail international responsibility in the case of non-implementation. Overall, it is important to highlight that the drafters of the LTS Guidelines have recognized crucial aspects of the orbital space environment – for instance that it constitutes a finite resource – and provided an inexhaustible list of the associated challenges that may affect the long-term sustainability of outer space activities, among which the emergence of large constellations is also specified.²⁰¹

The subject of space debris mitigation and the limited capacity has also been part of COPUOS discussions relevant to the topic of Space Traffic Management. Pursuant to General Assembly resolution 77/121 for example, the Legal Subcommittee considered agenda item 13, entitled “General exchange of views on the legal aspects of space traffic management”, as a

¹⁹⁷ See: UNGA, International co-operation in the peaceful uses of outer space, UN Doc. A/RES/1472 (XIV) of 12 December 1959).

¹⁹⁸ The five UN treaties and other sources of international space law will be elaborated in Chapter III of this dissertation.

¹⁹⁹ UNCOPUOS, Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, Report of the Committee on the Peaceful Uses of Outer Space, Fiftieth Session, 6-15 June 2007, General Assembly, Official Records, Sixty-second Session, Supplement No. 20 (A/62/20), Annex of 2007 (Space Debris Mitigation Guidelines).

²⁰⁰ United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), ‘Guidelines for the Long-Term Sustainability of Outer Space Activities’ U.N. Doc. A/AC.105/2018/CRP.20 (2018) [hereinafter: LTS Guidelines].

²⁰¹ The challenges mentioned in the LTS Guidelines, are “proliferation of space debris, the increasing complexity of space operations, emergence of large constellations and the increased risks of collision and interference with the operation of space objects”. See: LTS Guidelines Preamble.

single issue for discussion at COPUOS. During the discussions held in 2023 under the mentioned agenda item, differing opinions emerged regarding the extent to which space law could contribute to restoring stability to the increasingly limited orbital environment. Accordingly, some Member States have expressed the need for specific rules to ensure the efficient use of different orbital regions. However, most countries remained doubtful and instead argued only for continuing discussions on the capacity limitations of these orbital regions, including the requirements necessary for protecting the space environment.²⁰² Interestingly, many perspectives shared included a link to the broader discussion about the definition and delimitation of outer space. The long-standing debate has been centred around the question of whether it is necessary to establish a distinct and legally defined border between airspace (regulated by individual nations) and outer space (governed by international space law) for the development of an STM regime, or a more flexible STM mechanism should be developed – without delimitation – to allow for adaptability to innovation in a rapidly evolving sector. Additionally, although there is a widespread perspective that a potential space traffic management regime should take into account the diverse space capabilities and technical levels of different countries, there is also a concern that imposing "excessive restrictions" on outer space exploration and utilization could have adverse effects. Consequently, it is believed that such restrictions should be avoidable.²⁰³

In 2022, COPUOS approved a new single issue/item for discussion on the agenda of the Scientific and Technical Subcommittee (STSC), a “general exchange of views on dark and quiet skies for science and society,” recognizing an increasing impact of space activities of the night sky and on astronomy. The subjects also featured prominently at the 66th meeting of COPUOS which took place in June 2023. The issue of light pollution caused by satellite constellations, under the above Agenda item, was the first one in COPUOS to directly bring up concerns especially of developing countries about the uncontrolled increase in the planned and

²⁰² UNCOPUOS, ‘Report of the Legal Subcommittee on its sixty-second session’ (13 April 2023) A/AC.105/1285, 27.

²⁰³ Defining what qualifies as an "excessive restriction" on the exploration and use of space is challenging. However, it seems reasonable to assume that Member States are not in favour of the restriction on the number of satellites and regarding the establishment of an international Space Traffic Management (STM) regime – similar to the one, referred to in Article 11 of the Moon Agreement – because these measures are perceived as overly restrictive. See more in: UNCOPUOS, ‘Report of the Legal Subcommittee on its sixty-second session’ (13 April 2023) A/AC.105/1285, 27.

launched number of satellite constellations. Owing to a disagreement about whether the proposed Agenda item should encompass discussions on the growing number of constellations, “the view was expressed that the agenda item could be beneficial if it were to be reformatted”, thus no agreement was reached.²⁰⁴

The International Telecommunication Union – World Radio Conference

*“What has to be insured is that the gain from interference more than offsets the harm it produces. There is no reason to suppose that the optimum situation is one in which there is no interference”.*²⁰⁵

Besides UNCOPUOS, the International Telecommunication Union (ITU), a specialized UN agency for telecommunications with 193 Member States has competence to regulate the peaceful use of outer space, more specifically relevant to the efficient management of radio frequencies and GEO and associated orbits.²⁰⁶ To guarantee operability without harmful interference, ITU allocates frequencies, and positions (for GEO satellites)²⁰⁷ or orbital characteristics (for non-geostationary satellites) for every radio transmitting and/or receiving satellite in each orbital category, recording all these allocations in the Master International Frequency Register (MIFR). The ITU Member States have established a legal regime, which is codified through the ITU Constitution and Convention, including the Radio Regulations.²⁰⁸

The ITU hosts every three to four years the World Radiocommunication Conference (WRC). It is the job of WRC to review, and, if necessary, revise the Radio Regulations, the international treaty governing the use of the radio-frequency spectrum and the geostationary-satellite and non-geostationary-satellite orbits. Revisions are made on the basis of an agenda

²⁰⁴ UNCOPUOS, ‘Report of the Committee on the Peaceful Uses of Outer Space’ (20 June 2023) UN Doc. A/78/20, para. 165.

²⁰⁵ Ronald H. Coase, ‘The Federal Communications Commission’ (1959) 2(1) *The Journal of Law & Economics* 1, 25.

²⁰⁶ The ITU is a specialized agency under Article 57 of the United Nations (UN) Charter.

²⁰⁷ The ITU allocates orbital positions only in the geostationary orbit (GEO), which in ITU terminology is abbreviated as GSO.

²⁰⁸ The legal regime of ITU will be discussed in more details in Chapter III of this dissertation.

determined by the ITU Council, which considers recommendations made by previous world radiocommunication conferences.

During the latest conference, at WRC-23 in December 2023, discussions centred around procedural and technical matters pertaining to non-GSO constellations. These included topics such as the orbital tolerance between LEO constellations, built-out milestones and most-milestone procedures; the potential review of Equivalent Power Flux Density (EPFD) limits; inter-satellite links; and regulations concerning mobile Earth stations.²⁰⁹ Of the aforementioned subjects, it is pivotal to emphasize the conflicting views surrounding EPFD limits.²¹⁰ Some argue that there is a need for the modernization of global regulations, which are perceived as restrictive, in response to the goal of achieving universal broadband access. Notably, non-GSO newcomers,²¹¹ like SpaceX and Amazon, have actively engaged in lobbying efforts to advocate for a review of the ITU's EPFD limits, with Amazon even forming a dedicated coalition to support this effort.²¹² According to the coalition, EPFD rules constrain LEO constellation operators' plans more than necessary to protect satellites in GEO. They argue, revised EPFD limits could potentially lead to increased capacity for satellite communication systems. This might allow for the deployment of more satellite services and the enhancement of existing services. Consequently, the advocacy for EPFD rule reform introduces additional tension between the rights for internet access and digital inclusion on one side, and the preservation and conservation of the orbital space environment and associated space activities on the other. As for example, David Goldman, Vice President of Satellite Policy at SpaceX stated that they hope "to correct those who [...] try to delay updates [regarding the EPFD limits] that will be critical to connecting more people as expeditiously as possible".²¹³ "After weeks of intense treaty-level talks that pitted non-GSO newcomers seeking greater power and capacity against

²⁰⁹ Ruth Pritchard-Kelly, 'WRC-23 on the Horizon: Large Satellite Constellations, ITU Issues, and Industry Perspective' (2023) 48 *Air & Space Law* 179, 184.

²¹⁰ Satellite power limits refer to the regulations that determine the strength of a radio signal as it reaches different areas on the Earth's surface. These limits are in place to prevent interference into Geosynchronous Orbit (GSO) networks.

²¹¹ The term "non-GSO" (or more precisely, non-geostationary) is primarily employed within the ITU framework and commonly pertains to LEO satellites.

²¹² Alliance for Satellite Broadband, 'WRC-23: Time to Get the Rules Right for Satellite Broadband' (SpaceNews, 18 November 2023) <<https://spacenews.com/wrc-23-time-to-get-the-rules-right-for-satellite-broadband/>> accessed 20 October 2025.

²¹³ Jason Rainbow, 'Satellite transmission power battle drags on after WRC-23' (*SpaceNews*, 15 December 2023) <<https://spacenews.com/satellite-transmission-power-battle-drags-on-after-wrc-23/>> accessed 20 October 2025

more established GSO players concerned about increased interference, a compromise was reached: Technical EPFD studies can advance without regulatory consequences”.²¹⁴

As the global community addresses the sustainability of outer space, there is an increasing discourse about the oversight role, specifically regarding which international organization, whether a governmental or non-governmental entity, should serve as the “space sustainability secretariat” and enforce regulations.²¹⁵ Various international agencies have long examined matters related to debris, space situational awareness (SSA), STM, and collision avoidance. However, in the past year, the ITU has frequently emerged in discussions for the role of the secretariat, tasked with consolidating and facilitating easier access to the work of other agencies. At the same time, some argue that the United Nations already has an agency responsible for the sustainability of outer space – UNCOPUOS – and that expanding ITU’s remit into this area would be overreaching and duplicative of another UN agency’s mandate.²¹⁶ Furthermore, COPUOS – although without the direct involvement of the private sector – has been involved in developing debris-mitigation guidelines and other space sustainability issues for decades, and thus already has a much deeper knowledge about these issues than the ITU does. Nonetheless, the majority of nations involved in space activities are not relying on the establishment of a singular sustainability secretariat. Instead, they actively engage in forums such as the ITU, COPUOS, and develop domestic frameworks to contribute to the sustainability of outer space.²¹⁷

4. Proliferation of space debris

*“It appears that we are at the threshold of a new epoch in which environmental preservation of outer space has taken on a new meaning and sense of urgency not only for purposes of protecting valuable space assets in the short-term, but also to ensure the continued sustainability of space activities in the long-term”.*²¹⁸

²¹⁴ Ibid.

²¹⁵ Ruth Pritchard-Kelly, ‘WRC-23 on the Horizon: Large Satellite Constellations, ITU Issues, and Industry Perspective’ (2023) 48 *Air & Space Law* 179, 186.

²¹⁶ Ibid., 187.

²¹⁷ Ibid., 187.

²¹⁸ Ram S. Jakhu, ‘Active Debris Removal – An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space’ (Presentation at COPUOS, Vienna, 10 February 2012) 5 <https://www.unoosa.org/pdf/pres/stsc2012/tech-21E.pdf> accessed 20 October 2025.

Space debris, also known as space junk or orbital debris, is defined in the space debris mitigation guidelines of UNCOPUOS and the Inter-Agency Space Debris Coordination Committee's (IADC) as "all man-made objects including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional".²¹⁹ Space debris consists of spent rocket stages, defunct satellites, fragments from disintegration, and other remnants from space missions. The presence of space debris has become a growing concern due to its potential impact on both current and future space activities and on the orbital space environment.²²⁰ Reflecting the severity of the issue, Viikari, describes space debris as the "most common and hazardous form of potential damage related to space activities".²²¹

a) The instability of the orbital space environment

According to the observation of scientists, Don Kessler and Cour Palais, summarized in a 1978 article, the growing number of space debris is directly linked to increased risks of collision and interference with the operation of space objects, creating a snow-ball effect or cascade of collisions – in other words, the Kessler-syndrome –.²²² Subsequent to this consideration, further studies have shown that the orbital space environment has been unstable for many years.²²³ This means that even in the absence of new space launches ("no-future-launches scenario") or space security threats (e.g. execution of anti-satellite tests), the debris population has been increasing, and will continue to increase due to orbital explosions,

²¹⁹ The Inter-Agency Space Debris Coordination Committee (IADC) is an international forum or platform for governmental bodies created for the purpose of coordination in mitigation activities with regard to man-made space debris. See: UNCOPUOS, 'Inter-Agency Space Debris Coordination Committee (IADC), Space Debris Mitigation Guidelines' (Revision 4, January 2025) UN Doc. A/AC.105/C.1/2025/CRP.9 Para. 3.1.

²²⁰ See for example: LTS Guidelines Preamble.

²²¹ Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff, 2008) 70.

²²² Donald J. Kessler and Burton G. Cour-Palais, 'Collision frequency of artificial satellites: The creation of a debris belt' (1978) 83(A6) *Journal of Geophysical Research* 2637, 2637.

²²³ J.-C. Liou, 'An Active Debris Removal Parametric Study for LEO Environment Remediation' (2011) 47(11) *Advances in Space Research* 1865, 1865.

fragmentation events, and collisions between debris fragments, derelict spacecraft, and upper stages.²²⁴ This pollution issue jeopardizes current and future space activities.

While Kessler acknowledges that collisional cascading is a slow and gradual process, its pace is significantly influenced by the population density and size of objects in orbit. In a subsequent article penned 30 years after introducing the initial concepts about the cascade of collisions, the scientist noted that reaching a(n unusable) state where Earth is entirely isolated from outer space may take an extended period. Nevertheless, in his later work, Kessler points out that “some ill-planned rapid expansion in the use of low Earth orbit could produce a much more rapid increase in small debris as a result of collisional cascading”.²²⁵ Recognizing the projections made by Kessler and his co-authors, it is conceivable that the present situation, in the escalating utilization of LEO without any binding international regulation specifically applicable to LEO, aligns with the notion of “poorly planned expansion”. Drawing from Kessler's viewpoint, a pertinent question arises: when might the occurrence of such a dire scenario, often referred to as the “tragedy of the commons,” occur if we fail to implement adequate planning? Furthermore, how can we adequately regulate (or plan) LEO’s space activities to delay or prevent the unusable state of the orbit?

Although earlier modelling studies of the orbital debris population in LEO have suggested that most of the current orbits have the number of satellites in most of the unstable region is well above the unstable threshold,²²⁶ we have to keep in mind that instability does not

²²⁴ J.-C. Liou, ‘An Active Debris Removal Parametric Study for LEO Environment Remediation’ (2011) 47(11) *Advances in Space Research* 1865, 1865; and International Academy of Astronautics (IAA), the International Astronautical Federation (IAF) and the International Institute of Space Law (IISL), ‘Memorandum of Understanding (MoU) of the International on a Cooperative initiative to develop comprehensive approaches and proposals for Space Traffic Management’ (2022) 1 <<https://iaaspace.org/wp-content/uploads/iaa/Communication/stm-mou.pdf>> accessed 20 October 2025.

²²⁵ Donald J. Kessler, Nicholas L. Johnson, J.-C. Liou, and Mark Matney, ‘The Kessler Syndrome: Implications to Future Space Operations’ (2010) 138(8) *Advances in Astronautical Sciences* 1, 2 <<https://aquarid.physics.uwo.ca/kessler/Kessler%20Syndrome-AAS%20Paper.pdf>> accessed 20 October 2025.

²²⁶ According to Kessler and his colleagues, there are two types of instabilities relevant to orbital space: (1) An unstable environment, characterized by an insufficient number of fragments for the number of intact objects present. The number of fragments in such an environment will increase with time but eventually reach equilibrium. Afterwards, the environment would be stable with this higher number of fragments for as long as the number of intact objects remained constant. (2) A “runaway” environment, characterized by the number of fragments increasing to infinity for as long as the intact population remained constant. For more, see: Donald J. Kessler, Nicholas L. Johnson, J.-C. Liou, and Mark Matney, ‘The Kessler Syndrome: Implications to Future Space

match the notion of “unusefulness”. Pursuant to this consideration, more recent reports have noted that, even though human-created debris ring in GEO and more scattered systems in LEO and MEO might have been created, which also implies the instability of the orbits, there is no indication that on our current path, orbital space will be unusable in the “foreseeable future”.²²⁷ Furthermore, it has been pointed out that the Kessler-syndrome suggests an apocalyptic “myth” based on Kessler’s work, which, while it stimulates interest, also hinders informed discussions about space debris, thus should not be over-emphasized. In fact, Kessler himself noted in his 2010’s article that the orbit being unstable does not necessarily mean that immediate action is required, although it does raise some long-term policy considerations.²²⁸ Moreover, the scientist called for another crucial consideration, which is the rate that the environment increases.²²⁹

b) Increasing amount of space debris

As of October 2025, the European Space Agency’s statistical models estimated 54000 pieces over ten centimetres, 1.2 million from one to ten centimetres, and 140 million from one millimetre to one centimetre of space debris in orbit.²³⁰ Furthermore, about 24% of the catalogued objects are satellites (less than a third of which are operational), and about 11% are spent upper stages and mission-related objects such as launch adapters and lens covers.²³¹ More than 560 in-orbit fragmentation events have been recorded since 1961. Only 7 events were

Operations’ (2010) 138(8) *Advances in Astronautical Sciences* 1, 2-3
<https://aquarid.physics.uwo.ca/kessler/Kessler%20Syndrome-AAS%20Paper.pdf> accessed 20 October 2025;
 J.-C. Liou and A.K. Anil Kumar, et al., ‘Stability of the Future LEO Environment – An IADC comparison study’ (April 2013) 1, 1-7
https://www.researchgate.net/publication/266584674_STABILITY_OF_THE_FUTURE_LEO_ENVIRONME
[NT - AN IADC COMPARISON STUDY](https://www.researchgate.net/publication/266584674_STABILITY_OF_THE_FUTURE_LEO_ENVIRONME) accessed 20 October 2025.

²²⁷ Mark Matney, ‘Misconceptions and Reality of Orbital Debris Risk’ (NASA, presentation, 2023) 1, 14
https://ntrs.nasa.gov/api/citations/20230014345/downloads/ASEC%202023%20Talk_Matney_final.pdf
 accessed October 2025.

²²⁸ Donald J. Kessler, Nicholas L. Johnson, J.-C. Liou, and Mark Matney, ‘The Kessler Syndrome: Implications to Future Space Operations’ (2010) 138(8) *Advances in Astronautical Sciences* 1, 8
<https://aquarid.physics.uwo.ca/kessler/Kessler%20Syndrome-AAS%20Paper.pdf> accessed 20 October 2025.

²²⁹ Ibid., 9.

²³⁰ For comparison, in May 2022, ESA models estimated, 36500 pieces over ten centimetres, 1,000000 from one to ten centimetres, and 130 million from one millimetre to one centimetre of space debris in orbit. See: European Space Agency (ESA), ‘Space Debris by the Numbers’ (ESA, 20 October 2025)
https://www.esa.int/Safety_Security/Space_Debris/Space_debris_by_the_numbers accessed 20 October 2025

²³¹ European Space Agency (ESA), ‘About Space Debris’
https://www.esa.int/Space_Safety/Space_Debris/About_space_debris accessed 20 October 2025.

associated with collisions and the majority of the current events were explosions of spacecraft and upper stages.²³² A significant contributor to space debris that does not involve the fragmentation (or break-up) of existing objects is solid rocket-motor firings.²³³ During these firings, aluminium oxide (Al₂O₃) is released in the form of micrometre-sized dust and millimetre- to centimetre-sized slag particles. This suggests that the debris is generated as a byproduct of the propulsion systems, specifically the solid rocket motors, and consists of tiny dust particles as well as larger slag particles of varying sizes. Additionally, under the influence of extreme ultraviolet radiation, impinging atomic oxygen and impacting micro particles erode the surfaces of space objects.²³⁴ This leads to mass loss of surface coatings and to the detachment of paint flakes with sizes from micrometre to millimetre.²³⁵ Even though such particles seem to be too small to have any effect on the orbital space environment, one must keep in mind that even if a small piece of space debris between one millimetre to one centimetre in diameter collides with a functioning space object, the former object is likely to cause severe damage or destroy the individual components of the other space object due to the high orbital velocity of the debris (which may give rise to the creation of new, uncontrollable space debris).²³⁶ Indeed, as reported by the European Space Agency, “an object up to 1 cm in size could disable an instrument or a critical flight system on a satellite. Anything above 1 cm could penetrate the shields of the Station’s crew modules”.²³⁷ However, because of sensitivity limits, only objects down to a minimum size can be tracked. This means, historically, objects larger

²³² As time passes, the severe conditions in space may compromise the structural integrity of both external and internal components. This could result in leaks or the blending of fuel elements, potentially causing self-ignition. The ensuing explosion has the capacity to obliterate the object, dispersing its mass into numerous fragments with varying masses and velocities. For further, see: European Space Agency (ESA), ‘About Space Debris’ <https://www.esa.int/Space_Safety/Space_Debris/About_space_debris> accessed 20 October 2025.

²³³ Joseph Kurt, ‘Triumph of the Space Commons: Addressing the Impeding Space Debris Crisis Without an International Treaty’ (2015) 40(1) *William & Mary Environmental Law and Policy Review* 305, 307.

²³⁴ European Space Agency (ESA), ‘About Space Debris’ <https://www.esa.int/Space_Safety/Space_Debris/About_space_debris> accessed 20 October 2025.

²³⁵ Ibid.

²³⁶ See for example: David Finkleman, ‘The Dilemma of Space Debris’, *American Scientist* <<https://www.americanscientist.org/article/the-dilemma-of-space-debris>> accessed 20 October 2025

²³⁷ European Space Agency, ‘Impact Chip’ (ESA, 2016) <https://www.esa.int/ESA_Multimedia/Images/2016/05/Impact_chip> accessed 20 October 2025.

than 10cm in LEO, and larger than 1m in GEO are traceable.²³⁸ This implies that preventing collisions with space debris particles smaller than 10 cm is highly challenging because, currently, there is no technology available to track such objects. A further important element relevant to space debris is the cataloguing of any new non-functional space object, as without such practice, collision with such new objects of any size cannot be avoided.

Even though predominant incidents had been associated mostly with explosions of a spacecraft, it is expected that in the future, collisions will become the dominant source of space debris.²³⁹ According to the 2010 NASA Orbital Debris Quarterly Review, the unintentional collision between the operational Iridium 33 satellite and the non-functional Russian Cosmos 2251 satellite on 10 February 2009 marked the first instance of two satellites colliding in orbit.²⁴⁰ Analysis by both NASA and outside experts indicates that more than half of the Iridium debris will remain in orbit for at least 100 years, and much of the Cosmos debris will remain in orbit at least from 25-50 years after the collision.²⁴¹ The next chapter of this document will provide an explanation of the relevant international law and liability mechanism pertaining to the incident.

Last but not least, it is important to distinguish between the characteristics of space debris in LEO and GEO, as the risks they pose differ significantly. In GEO, the orbital environment is far more constrained: satellites occupy fixed longitudinal slots. Because satellites in GEO move in the same direction at roughly the same speed, the immediate probability of high-velocity collisions is lower than in the densely populated and dynamically unstable LEO.²⁴² Yet this apparent stability masks a more serious long-term vulnerability: debris created in GEO does not naturally decay but can remain in orbit for thousands of years

²³⁸ Mark Matney, 'Misconceptions and Reality of Orbital Debris Risk' (NASA, presentation, 2023) 1, 7 https://ntrs.nasa.gov/api/citations/20230014345/downloads/ASEC%202023%20Talk_Matney_final.pdf accessed 20 October 2025; Secure World Foundation, 'Global Counterspace Capabilities, An Open Source Assessment' (April 2025) 1, 184 https://drive.google.com/file/d/1FA8aLXiQeAEK1Z8mTpHFIs_c27Ne50qa/view accessed 20 October 2025.

²³⁹ European Space Agency (ESA), 'About Space Debris' https://www.esa.int/Space_Safety/Space_Debris/About_space_debris accessed 20 October 2025.

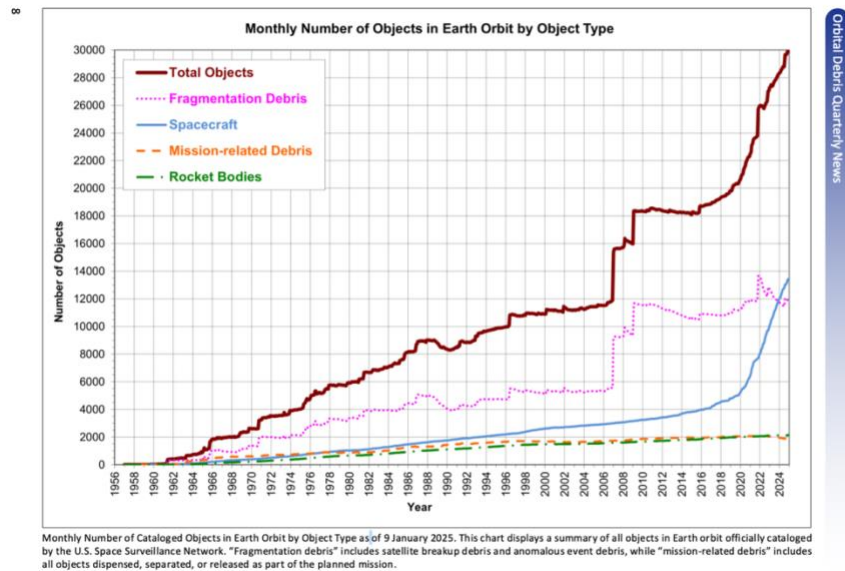
²⁴⁰ NASA, 'Orbital Debris Quarterly News' 19(1) (January 2015) 1, 1 <https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/odqnv19i1.pdf> accessed 20 October 2025.

²⁴¹ T. S. Kelso, 'Analysis of the Iridium 33 and Cosmos 22 51 Collision' (2009) 1, 8 <https://comspoc.com/research/cssi> accessed 20 October 2025.

²⁴² See for example: Philip Chrystal 'Space debris: On collision course for insurers?' (Swiss Re, 2011) 1, 12 https://www.swissre.com/dam/jcr:b359fb24-857a-412a-ae5c-72cdff0eaa94/Publ11_Space+debris.pdf accessed 20 October 2025.

or longer. Even a single collision or fragmentation event can scatter large fragments along the GSO belt, permanently reducing the usable capacity of this scarce and strategically vital orbit unless active debris-removal measures are undertaken.

c) Intentional collision events – anti-satellite tests



Source: The Figure shows a historical increase of the catalogued objects in orbital space based on data available on 9 January 2025. The three upward jumps in fragmentation debris correspond to (1) the Anti-satellite (ASAT) test conducted by China in 2007, (2) the accidental collision between Iridium 33 and Cosmos 2251 in 2009, and (3) the ASAT test conducted by the Russian Federation in November 2021. Credit: NASA Orbital Debris Quarterly News.²⁴³

As depicted on the above figure, it is not only accidental but also intentional destructive events – such as anti-satellite (ASAT) weapon tests – that produce large quantities of orbital debris remaining as threats for years or centuries on the Earth's orbits. We can differentiate between two types of destructive ASAT tests: co-orbital weapons, which are placed in orbit and manoeuvre close to a target and attack it by various means, including direct collision, fragmentation, or using robotic arms; and direct ascent missiles that are launched from the Earth's surface or from the air to destroy a satellite target. Debris from ASAT tests can spread

²⁴³ NASA, 'Debris Quarterly News' 29(1) (February 2025) 1, 8 <<https://orbitaldebris.jsc.nasa.gov/quarterly-news/pdfs/ODQNv29i1.pdf>> accessed October 2020.

both vertically across orbits and horizontally within orbits. Until 2023, there have been four countries, namely, China, Russia, the United States and India, which have successfully shot down their own satellite to demonstrate their ASAT capabilities in a show of force and to remove decommissioned satellites.²⁴⁴

As a reaction to the last ASAT test, executed by Russia in 2021, Vice President of the United States, Kamala Harris announced the United States' pledge against conducting destructive ASAT tests and to promote responsible behaviour in space.²⁴⁵ Since the unilateral declaration of the United States, thirty-seven countries (including all Member States of the European Union, as of 20 October 2023) have made a similar commitment.²⁴⁶ From a legal point of view, unilateral declaration of states can be regarded as a source of international law that relies on the notion of obligation of states through their own voluntary restraint, whether expressed in a treaty or a unilateral action. Despite Article 38 of the ICJ Statute remains silent about unilateral acts of states as source of international law, it is widely acknowledged in legal doctrine,²⁴⁷ and through the ICJ's juridical practice,²⁴⁸ that unilateral declarations of states – with certain criteria – can create international legal obligations for the state itself. In addition to the unilateral commitments, in December 2022 the United Nations General Assembly (UNGA) adopted a non-binding resolution by a vote of 155-9-9 calling upon countries not to conduct direct-ascent (DA) ASAT tests.²⁴⁹ The United States was the only country that has conducted such tests to vote in favour of the resolution, while China and Russia voted against,

²⁴⁴ To learn more on the potential legality of anti-satellite weapons, see: Chris O'Meara, 'Self-defence in outer space: Anti-satellite weapons and the jus ad bellum' (26 March 2025) 527 *Leiden Journal of International Law* 527, 527-549.

²⁴⁵ Marcia Smith, 'VP Harris Pledges No U.S. Destructive Asat Tests, Calls for Others to Join' (*Space Policy Online*, 17 April 2022) <<https://spacepolicyonline.com/news/vp-harris-pledges-no-u-s-destructive-asat-tests-calls-for-others-to-join/>> accessed 20 October 2025.

²⁴⁶ Secure World Foundation, 'Space Industry Statement in Support of International Commitments to Not Conduct Anti-Satellite Testing' (March 2025) <https://cdn.prod.website-files.com/66dcc6872f6ed23bce1db235/68641e5ca00afad730f46a7e_DA-ASAT%20Statement_March%202025.pdf> accessed 20 October 2025.

²⁴⁷ To find a short overview of state and judicial practice regarding unilateral acts of states, see for instance: Vladimir Degan, *Sources of International Law* (Kluwer Law International 1997) 293-305; Christian Eckart, *Promises of States under International Law* (Hart Publishing 2012) pp 81-173; James Crawford, *Brownlie's Principles of Public International Law* (9th edn, Oxford University Press 2019) 422-425; Malcolm N. Shaw, *International Law* (6th edn, Cambridge University Press 2008) 121-122; Pierre-Marie Dupuy and Jorge E. Viñuales, *International Environmental Law* (2nd edn, Cambridge University Press 2018) 63-65.

²⁴⁸ PCIJ, *Legal Status of Eastern Greenland*, A/B53 [1933] PCIJ Rep 22, 71; ICJ, *Nuclear Tests (Australia v France)* [1974] ICJ Rep 253, 18.

²⁴⁹ UNGA, Destructive direct-ascent anti-satellite missile testing, UN Doc. A/RES/77/41 (LXXVII) of 7 December 2022.

and India abstained.²⁵⁰ Interestingly, following the UNGA resolution, 26 companies from nine countries endorsed a statement led by the Secure World Foundation, formally applauding countries for agreeing not to conduct debris-generating anti-satellite tests and to encouraging additional countries to adopt the same restraint.²⁵¹

Drawing from the information provided above, one may recognize that topics of anti-satellite tests, and space security are highly relevant to the long-term sustainability of orbital space, as even one ASAT test can easily accelerate the proliferation of space debris in the most essential orbits, such as LEO. While the topic is of great importance, the scope of this dissertation does not allow for a more detailed exploration of the legal issues surrounding ASAT tests.

5. Stabilizing low Earth orbit: current tools and strategies

As a result of the trends and challenges outlined above, we are witnessing growing instability and increasing congestion in orbital space – particularly in LEO. Consequently, civil society actors, international organizations, and private companies have begun to address space sustainability in a more comprehensive manner, prompting a growing number of initiatives aimed at promoting the sustainable use of Earth’s orbital environment.²⁵² These efforts have gradually culminated in the concept of the long-term sustainability of outer space activities, as reflected in the adoption of the UNCOPUOS Guidelines for the Long-term Sustainability of Outer Space Activities. While (1) space debris mitigation refers to the prevention of the creation of future debris (e.g., collision avoidance, passivation, end-of-life disposal and launch

²⁵⁰ Ibid.

²⁵¹ Secure World Foundation, ‘Space Industry Statement in Support of International Commitments to Not Conduct Anti-Satellite Testing’ (March 2025) <https://cdn.prod.website-files.com/66dcc6872f6ed23bce1db235/68641e5ca00afad730f46a7e_DA-ASAT%20Statement_March%202025.pdf> accessed 20 October 2025.

²⁵² See for example: UNOOSA, ‘Awareness-raising and capacity-building related to the implementation of the Guidelines for the Long-term Sustainability of Outer Space Activities Project’ <<https://spacesustainability.unoosa.org/>> accessed 20 October 2025; and European Space Policy Institute (ESPI), ‘A Party for Everyone? Analysing international efforts in space debris mitigation’ (2024) 1, 5-24 <<https://www.espi.or.at/wp-content/uploads/2024/09/ESPI-Report-93-Space-Debris-Mitigation.pdf>> accessed 20 October 2025; or European Space Agency, Zero Debris Charter (2023) <https://esoc.esa.int/sites/default/files/Zero_Debris_Charter_EN.pdf> accessed 20 October 2025.

rate mitigation/limitation); (2) (re)mediation practices (such as active debris removal – ADR) address the elimination of existing debris from Earth orbit. Additionally, a complementary measure, worth highlighting – constituting a third (3) category – is on-orbit servicing, which involves extending the operational lifetime of spacecraft through activities such as refuelling, recycling, and repurposing of satellites. Depending on its specific application, on-orbit servicing can be classified as both a mitigation and a remediation practice.²⁵³ Moreover, mitigation measures can be subdivided into two categories: those aimed at ensuring the safety of space operations, and those related to limiting the rate of launches.

The subsequent paragraphs delve into the classification of the space sustainability tools, offering insights into methods that contribute to the preservation of the orbital space environment. Although launch rate limitation is itself a mitigation measure, its discussion is deferred to the latter part of this chapter, given the central role it plays in the broader argument of this dissertation.

a) Safety of space operations

According to a report filed by SpaceX with the United States FCC in June 2023, the Starlink constellation executed approximately 25,000 collision-avoidance manoeuvres in just six months, between 1 December 2022 and 31 May 2023, in order to avoid potentially hazardous conjunctions with other spacecraft and orbital debris.²⁵⁴ More recent submissions indicate that this figure increased dramatically to around 145,000 collision-avoidance manoeuvres in the six months prior to July 2025.²⁵⁵ This corresponds to approximately four

²⁵³ See on the legal aspects of on-orbit servicing and active-debris removal: Zhuang Tian, *Legal Aspects of Active Debris Removal* (Kluwer Law International 2025); Jason Forshaw and Laura Cummings, ‘Future regulatory and licensing trends for active debris removal and on-orbit servicing in the UK and US’ in: Lesley Jane Smith, Ingo Baumann, Susan-Gale Wintermuth (eds.) *Routledge Handbook of Commercial Space Law* (Routledge 2023) 467, 469-489.

²⁵⁴ Tereza Pultarova, ‘SpaceX Starlink satellites had to make 25,000 collision-avoidance manoeuvres in just 6 months – and it will only get worse’ (SpaceNews, 6 July 2023) <<https://www.space.com/starlink-satellite-conjunction-increase-threatens-space-sustainability>> accessed 20 October 2025.

²⁵⁵ Tereza Pultarova, ‘Is low Earth orbit getting too crowded? New study rings an alarm bell’ (SpaceNews, 13 October 2025) <<https://www.space.com/space-exploration/satellites/is-low-earth-orbit-getting-too-crowded-new-study-rings-an-alarm-bell>> accessed 20 October 2025.

manoeuvres per satellite per month, illustrating the rapidly escalating congestion and collision risk in LEO.

Collision avoidance can be understood as the process of planning and possibly executing a manoeuvre to mitigate the risk of collision between two space objects.²⁵⁶ To perform collision-avoidance manoeuvres, satellites must be equipped with an appropriate propulsion system. However, many developers and operators choose not to include such systems, arguing that these “extra” or “environmental” design features substantially increase mission costs. While the design and construction of the satellite constitute significant cost drivers, other major expenditures must also be taken into account, including propulsion hardware, launch services,²⁵⁷ insurance, and regulatory compliance and licensing fees. Incorporating a propulsion system, in particular, adds mass and complexity but provides the necessary thrust and manoeuvring capability to ensure safe operations in orbit. This is essential for keeping a satellite in its intended positions within a specific orbit and may be also utilized for collision avoidance and to the satellite's post-mission disposal.

In order to limit the future growth of the space object population due to collisions and explosions of spacecrafts and upper stages, voluntary guidelines and standards on space debris mitigation have been developed at the international level. Such guidelines, among others, are, the Guidelines for the Long-term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space;²⁵⁸ the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space;²⁵⁹ the Inter-Agency Space Debris Coordination

²⁵⁶ The three parts of the collision avoidance process are conjunction assessment screening; conjunction analysis and risk assessment; and collision mitigation planning. See: International Academy of Astronautics (IAA), the International Astronautical Federation (IAF) and the International Institute of Space Law (IISL), ‘Memorandum of Understanding (MoU) of the International on a Cooperative initiative to develop comprehensive approaches and proposals for Space Traffic Management’ (2022) 1, 7 <<https://iaaspace.org/wp-content/uploads/iaa/Communication/stm-mou.pdf>> accessed 20 October 2025.

²⁵⁷ The cost of launching a satellite mostly depends on the size and weight of the satellite, as well as the desired orbit. Moreover, the type of propulsion system chosen, such as chemical or electric propulsion, impacts the cost of the satellite. Electric propulsion systems for instance, although more efficient, tend to be more expensive to develop and implement.

²⁵⁸ Guidelines for the Long-term Sustainability of Outer Space Activities Conference room paper by the Chair of the Working Group on the Long-term Sustainability of Outer Space Activities, A/AC.105/2018/CRP.20, 27 June 2018.

²⁵⁹ Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, Report of the Committee on the Peaceful Uses of Outer Space, Fiftieth Session, 6-15 June 2007, General Assembly, Official Records, Sixty-second Session, Supplement No. 20 (A/62/20), Annex, 2007. (Space Debris Mitigation Guidelines).

Committee's IADC Space Debris Mitigation Guidelines; and the ISO 24113:2023 – Standards on Space debris mitigation requirements.²⁶⁰

The efficient, rational, and sustainable utilization of orbital regions occupied by satellites necessitates the efficient passivation and disposal of spacecraft and launch vehicle orbital stages that have concluded their operational phases. Guideline 5 of the Space Debris Mitigation Guidelines for example emphasizes that "the most effective mitigation measures have been the passivation of spacecraft and launch vehicle orbital stages at the end of their mission. Passivation involves the removal of all forms of stored energy, including residual propellants and compressed fluids, and the discharge of electrical storage devices".²⁶¹ Furthermore, end-of-life disposal techniques are addressed in LTS Guideline A.4 and the IADC Guidelines, with distinctions based on whether a space object is traversing the LEO or GEO region. Under the IADC Guidelines, deorbiting can take place either by performing controlled re-entry, or through assisting non-operational spacecrafts into a graveyard (disposal) orbit.²⁶²

Additionally, the IADC Guidelines stipulates that the desirable approach to LEO disposal is to either (1) perform a controlled, direct re-entry into an unpopulated region of ocean, or (2) through an appropriate manoeuvre, into a decay (or graveyard) orbit, with residual orbital lifetime limited to be 25 years after the end of the mission,²⁶³ mostly using onboard propulsion. Indeed, operators may safely remove derelict satellites from their operational region by boosting them into a graveyard orbit, which lies away from common operational orbits and active satellites. The criterion of the so-called "25-year rule" has become a globally known rule-of-thumb since its incorporation in the IADC Guidelines. It is a positive development that several states now require shorter post-mission disposal timeframes – for example, the five-year rule adopted in the United States – for both governmental and non-

²⁶⁰ International Organization for Standardization, ISO 24113:2023 Space systems – Space debris mitigation requirements.

²⁶¹ Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space, Report of the Committee on the Peaceful Uses of Outer Space, Fiftieth Session, 6-15 June 2007, General Assembly, Official Records, Sixty-second Session, Supplement No. 20 (A/62/20), Annex, 2007. (Space Debris Mitigation Guidelines) Guideline 5.

²⁶² UNCOPUOS, 'Inter-Agency Space Debris Coordination Committee (IADC), Space Debris Mitigation Guidelines' (Revision 4, February 2025) UN Doc. A/AC.105/C.1/2025/CRP.9 para. 5.3.

²⁶³ Ibid., para 5.3.

governmental operators.²⁶⁴ While it is unlikely that the post mission disposal success rate will ever reach 100%, the general aim must be to reach this goal. Furthermore, information sharing, and international cooperation are essential components of safe space operations. Transparency, however, depends on trust within the global space community – a trust that can be strengthened through the involvement of third-party actors, such as the United Nations, regional intergovernmental bodies, and relevant non-governmental entities.

b) Remediation of space debris – active debris removal

Space debris encompasses not only defunct satellites but also large quantities of hazardous trackable and non-trackable fragments – many generated by past collisions – which are dispersed throughout LEO. There has been a widespread misconception that LEO is inherently “self-cleaning”, leading some to assume that collisions between manoeuvrable or derelict satellites are inconsequential. The notion of “self-cleaning” can refer to the natural deorbiting process of space objects. After a satellite reaches the end of its operational life or suffers technical failure, it eventually begins to descend towards Earth under the influence of gravity and atmospheric drag. The same principle applies to orbital debris, whose rate of descent depends primarily on altitude: objects in lower orbits re-enter the atmosphere more quickly, whereas those at higher altitudes may remain in orbit for decades or even centuries. As debris gradually loses altitude due to gravitational pull and atmospheric drag, it eventually descends into denser layers of the atmosphere, where it experiences extreme heating caused by friction. This process typically results in the incineration of the object and, ideally, its complete destruction upon re-entry.

²⁶⁴ “We believe strong compliance with post-mission disposal guidelines is an effective tool that can help stabilize the orbital debris environment. Currently, it is recommended that operators with objects in LEO ensure that their spacecraft are either removed from orbit immediately post-mission or left in an orbit that will decay and re-enter Earth’s atmosphere within no more than 25 years to mitigate the creation of more orbital debris. However, we believe it is no longer sustainable to leave satellites in LEO to deorbit over decades. Accordingly, in this Second Report and Order, as part of our continued efforts to mitigate the generation of orbital debris, we shorten the 25-year benchmark for post-mission disposal of space stations in LEO to five years.” See: United States of America, Federal Communications Commission (FCC), ‘FCC Fact Sheet, Space Innovation; Mitigation of orbital Debris in the New Space Age’ Second Report and Order, IB Docket Nos. 22-271 and 18-313 (2022) 2 <<https://docs.fcc.gov/public/attachments/DOC-387024A1.pdf>> accessed 20 October 2025.

While natural satellite decay offers a modest balancing mechanism, it does not meaningfully restore orbital capacity within human timescales, particularly at higher altitudes. Orbital debris decay due to atmospheric drag can take millions of years in GEO, while in LEO it ranges from a several months at altitudes near 180 km, to a few years around 600 km, and up to decades or even centuries at around 800 km.²⁶⁵ The Starlink constellation is particularly relevant, as it represents the largest deployment of an entity to date. By 2025, SpaceX had launched nearly 8,100 satellites, most of them operating at an altitude of about 550 km, with a lifespan of approximately 5 years.²⁶⁶ According to numerous estimates, an intact derelict satellite at this altitude would indeed naturally deorbit due to atmospheric drag in less than six years.²⁶⁷ However, while intact satellites in heavily used LEO positions (around 550 km) are expected to deorbit relatively quickly, whether through controlled manoeuvres or natural decay, collision fragments can persist far longer and do not follow the same self-cleaning pattern.²⁶⁸ In fact, a single catastrophic event between a Starlink satellite and a small piece of space debris could produce more than 17,000 lethal fragments, out of which lethal and non-trackable objects can be created with fragments spreading throughout LEO, not just at the

²⁶⁵ Besides altitude of satellites, several other factors influence orbital decay, or how quickly a satellite or space debris loses altitude and eventually re-enters the Earth's atmosphere. These are, air density of the atmosphere; solar activity; shape, size and mass of the space object; gravitational perturbations; solar radiation pressure, etc. See for example: David S. F. Portree and Joseph Loftus, 'Orbital Debris: A Chronology' (NASA, 1999) 47 <<https://ntrs.nasa.gov/api/citations/19990041784/downloads/19990041784.pdf>> accessed 20 October 2025; and Miguél C. N. Fiolhais et al., 'Orbital Decay in the Classroom' City University of New York (CUNY) Academic Works (2023) 2 <https://academicworks.cuny.edu/cgi/viewcontent.cgi?article=2051&context=ny_pubs> accessed 20 October 2025.

²⁶⁶ Tereza Pultarova 'Starlink satellites: Facts, tracking and impact on astronomy' (*Space.com*, August 2025) <<https://www.space.com/spacex-starlink-satellites.html>> accessed 20 October 2025.

²⁶⁷ See for example: Viasat, 'White Paper – Self-cleaning Orbit Myth' (December 2021) 2 <<https://www.viasat.com/content/dam/us-site/corporate/documents/Viasat-White-Paper-Self-Cleaning-Orbit-Myth-20211220.pdf>> accessed 20 October 2025; Aaron C. Boley and Michael Byers, 'Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth' (2021) 11(1) *Science Reports* 1, 3; OECD, 'Earth's Orbits at Risk, The Economics of Space Sustainability' (*OECD Publishing*, 2022) 29 <https://www.oecd.org/content/dam/oecd/en/publications/reports/2022/09/earth-s-orbits-at-risk_d8902e97/16543990-en.pdf> accessed 20 October 2025.

²⁶⁸ Viasat, 'White Paper – Self-cleaning Orbit Myth' (December 2021) 3-4 <<https://www.viasat.com/content/dam/us-site/corporate/documents/Viasat-White-Paper-Self-Cleaning-Orbit-Myth-20211220.pdf>> accessed 20 October 2025; Aaron C. Boley and Michael Byers, 'Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth' (2021) 11(1) *Science Reports* 1, 2-5

collision altitude but much higher, where natural decay would not occur in centuries.²⁶⁹ Thus, even if 90-99% of uncontrollable fragments eventually re-enter the Earth's atmosphere, the remaining fraction is sufficient to destroy satellites, trigger further fragmentations, and drive cascading collisions. In other words, fragment debris does not "self-clean" quickly enough to eliminate long-term risks. Collisions at these altitudes can have consequences lasting decades, making policies or claims that treat such orbit as "safe" or "self-cleaning" dangerously misleading.

Recognizing that the problem regarding space debris fragments, (especially as a result of the Iridium-Cosmos collision) need to be addressed in addition to the ones concerning intact derelict satellites, numerous experts and space sector stakeholders advocate for the introduction of remitigation measures, such as Active Debris Removal (ADR).²⁷⁰ While space debris mitigation refers to the prevention of the creation of future debris, (re)mediation practices (and ADR within) addresses the elimination of existing debris from Earth orbit. Currently, governments, space agencies, and private entities are engaging in efforts to develop and showcase technologies and methodologies for actively removing space debris. The focus for removal comprises objects with the highest mass and collision probability products.²⁷¹ Proposed technologies for capturing and eliminating debris encompass a spectrum from robotic arms, nets, and harpoons to laser systems and drag augmentation devices.²⁷² Nevertheless, the deployment of these technologies gives rise to numerous legal and political inquiries and

²⁶⁹ Estimates suggest that the probability of a single piece of untracked debris colliding with a satellite in the 550 km shell is about 0.003 per year. Accordingly, if approximately 230 pieces of untracked debris are transiting through this orbital region at any given time, there is a 50% chance of at least one collision between a satellite and debris within a year. Depending on the balance between deorbit rates and collision rates, if subsequent fragmentation events generate comparable amounts of debris within the same orbital shell, a runaway cascade of collisions could develop. See: Aaron C. Boley and Michael Byers, 'Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth' (2021) 11(1) *Science Reports* 1, 3-4.

²⁷⁰ The idea of ADR is not new, but it has never been widely accepted as necessary or feasible, primarily due to the tremendous technical, political, legal challenges and cost involved. See: J.-C. Liou, 'An Active Debris Removal Parametric Study for LEO Environment Remediation' (2011) 47(11) *Advances in Space Research* 1865, 1865; J.-C. Liou and A.K. Anil Kumar, et al., 'Stability of the Future LEO Environment – An IADC comparison study' (April 2013) 1, 6
<https://www.researchgate.net/publication/266584674_STABILITY_OF_THE_FUTURE_LEO_ENVIRONMENT_-_AN_IADC_COMPARISON_STUDY> accessed 20 October 2025.

²⁷¹ J.-C. Liou, 'An Active Debris Removal Parametric Study for LEO Environment Remediation' (2011) 47(11) *Advances in Space Research* 1865, 1865.

²⁷² Minghe Shan, Jian Guo and Eberhard Gill, 'Review and comparison of active space debris capturing and removal methods' (January 2016) 80 *Progress in Aerospace Sciences* 18, 18-32; Victoria V. Svtina, 'Space debris removal – Review of technologies and techniques. Rigid coupling between space debris and service spacecraft' (April 2024) 11(2) *Journal of Space Safety Engineering* 252, 252-267.

apprehensions. These encompass queries about the existence of an obligation to remove space debris under international law, the potential encroachment on states' jurisdiction and control over registered space objects, the international responsibility of states concerning space debris removal endeavours, the dual-use nature (security considerations) of removal technologies, and liability for potential damage arising from debris removal operations.

Of particular note is a 2012 interdisciplinary report, with Ram Jakhu, a prominent space legal expert, serving as editor-in-chief, differentiates three major mechanisms from each other to return the LEO population of intact objects to a sustainable and stable level.²⁷³ These three elements that should be applied in combination, according to the researchers, are: (1) lifetime limitation;²⁷⁴ (2) launch rate reduction; and (3) active debris removal. The authors of the document further detail that, “Given that current trends in the use of space are not expected to change drastically, a more realistic scenario will be one under which (1) the lifetime [of spacecrafts is limited to] 25 years [...];²⁷⁵ (2) the total number of launches is kept at 36 per year; and, (3) [...] there will be the need to remove 9.1 objects per year from LEO by means of active debris removal in order to achieve the threshold of stability within the 200-year timeframe”.²⁷⁶ Last but not least, the report emphasizes ADR above the other two means and stipulates that “active debris removal can be a more efficient alternative as compared to launch rate and lifetime reduction, because the targets can be selected and optimized”.²⁷⁷

Current level of space debris is not expected to decline. Considering the dire picture even with the “no-future-launches” scenario and the false belief in self-cleaning of critical LEO regions, investing in research and development in ADR is essential, particularly in addressing the legal challenges it presents. At the same time, the political sensitivity surrounding the issue

²⁷³ UNCOPUOS, ‘Active Debris Removal — An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space – A Report of the International Interdisciplinary Congress on Space Debris Remediation and On-Orbit Satellite Servicing’ (January 2012) UN Doc. A/AC.105/C.1/2012/CRP.16, 20.

²⁷⁴ Lifetime limitation refers to restricting the operational duration of objects launched into LEO. It is based on the idea that the total number of objects in orbit depends on both the annual launch rate and the lifetime of each object, with longer lifetimes resulting in a greater accumulation of objects in orbit at any given time. See: Ibid., 20-21.

²⁷⁵ It is important to distinguish between the 25-year lifetime limitation of a spacecraft under this mechanism and the deorbiting threshold that applies from the end of a spacecraft’s mission, as previously described.

²⁷⁶ UNCOPUOS, ‘Active Debris Removal — An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space – A Report of the International Interdisciplinary Congress on Space Debris Remediation and On-Orbit Satellite Servicing’ (January 2012) UN Doc. A/AC.105/C.1/2012/CRP.16, 21.

²⁷⁷ Ibid., 21.

has so far prevented any concrete outcomes in COPUOS. Still, one may recognize that under Section D of the LTS Guidelines, “technological solutions [...] to manage the space debris population in the long term” are mentioned, where ADR indeed can be argued to fit. Further technological methods “for the extension of operational lifetime, novel techniques to prevent collision with and among debris and objects with no means of changing their trajectory, advanced measures for spacecraft passivation and post-mission disposal and designs to enhance the disintegration of space systems during uncontrolled atmospheric re-entry” are also touched upon in Section D of the LTS Guidelines.²⁷⁸ Thus, as far as the outlook for new technological advancements in space debris remediation is concerned, it is apparent that the consensus-based, voluntary LTS Guidelines offer somewhat ambiguous guidance, but already recognizes the need for new technologies tackling existing space debris, as well as the need for assistance to developing countries on the issue.

To date, no fully functional ADR system has been implemented. Experts believe that the maturation of active debris removal (ADR) technologies, reaching a stage of robustness, high accuracy, and consistently high success rates, will likely take a significant amount of time.²⁷⁹ Consequently, the acceptance and utilization of these technological solutions will hinge on their technical feasibility and economic viability. Importantly, these solutions must align with the existing international regulatory framework. Addressing intricate legal challenges, particularly at the international level, is crucial in the context ADR and on-orbit servicing of space objects (such as functional or non-functional satellites) owned and/or controlled by foreign states or their private entities. While this doctoral project is not aimed to address legal challenges associated with remediation technologies, it is essential to recognize that discussions about ADR may be deceptive to the point that governments and private operators could be already factoring in prospective technologies as future solutions in their current decision-making. However, the functionality of these solutions remains uncertain and may not meet the anticipated expectations. In other words, large LEO satellite constellation operators, with their overabundant launch rate, appear to be conducting their space endeavours by taking

²⁷⁸ LTS Guidelines section D, guideline D.2, para 3.

²⁷⁹ Ram S. Jakhu, Yaw Otu M. Nyampong, and Tommaso Sgobba, ‘Regulatory framework and organization for space debris removal and on orbit servicing of satellites’ (2017) 4(3-4) *Journal of Space Safety Engineering* 129, 130.

a chance on a technology that might not materialize for years, if not decades to come. The situation of excessive reliance on potential technology, often referred to as techno-fix approach (or techno-optimism) might remind us as how we grapple with the challenges of climate change on Earth.²⁸⁰

Nevertheless, as previously noted, the specific condition of the space debris environment depends not only on the development of future remediation solutions but also, and perhaps more critically, on the effective implementation of existing mitigation measures. It was, however, projected already in 2010, that even with a 90% compliance of the commonly-adopted mitigation measures, based on the space debris population of 2009, the LEO debris population would increase by an average of approximately 30% in the next 200 years.²⁸¹ Additionally, catastrophic collisions are expected to continue to occur every 5 to 9 years.²⁸² The renowned forecasters envisioned the resolution to the escalating space debris issue through the implementation of active debris removal. While recognizing the importance of continuous investment, research, and development in such remediation technologies, it does not presently seem wise viewing these technologies as immediately viable tools for ensuring space sustainability. Rather, as the exponential increase of space objects in LEO also adds to the likelihood of collisions and expected space debris population, an additional mitigation measure, the introduction of global launch rate limitation is advisable. A revaluation of such limitation may could take place after the realization of critical remediation technologies.

c) Recycling and repurposing

Some of the future technologies and solutions within the space debris mitigation approach are recycling, repurposing and the ultimate development of a circular space economy. Such technologies can reduce the need for new launches (and the associated debris risks),

²⁸⁰ See for example topics on biorefineries, carbon capture technologies or renewable energy in terms of tackling climate change on Earth. This approach is further examined in Chapter IV of this dissertation.

²⁸¹ J.-C. Liou and A.K. Anil Kumar, et al., 'Stability of the Future LEO Environment – An IADC comparison study' (April 2013) 1, 1

⟨https://www.researchgate.net/publication/266584674_STABILITY_OF_THE_FUTURE_LEO_ENVIRONMENT_-_AN_IADC_COMPARISON_STUDY⟩ accessed 20 Octboer 2025.

²⁸² Ibid., 1.

enable the use of non-functional satellites without necessarily deorbiting them, and support the application of circular economy principles in space.

Guideline D.1 of the LTS Guidelines for example calls the attention of states and international intergovernmental organizations to promote the development of technologies that reduce the environmental impacts of manufacturing and launching space objects, while also promoting reusability and the repurposing of hardware as a means of enhancing the long-term sustainability of outer space activities. While reusability can serve as an important mitigation measure by reducing the number of satellites that must re-enter the atmosphere, it does not directly address the overexploitation of LEO that results from a first-come, first-served approach to orbital access.

d) The quantitative approach – launch rate reduction through orbital and frequency limitations

Launch rate reduction can be understood as the reduction in the current rate of launches into orbits, and especially into LEO.²⁸³ In the previously mentioned 2012 interdisciplinary report concerning remediation measures, there has obviously been a misjudgement in projecting the future total number of launch rate, by projecting a stable total launches with average of 72 new objects injected into LEO per year – an estimate based on the assumption that space activity trends would not change “drastically”.²⁸⁴ However, this projection failed to anticipate emerging challenges, particularly the proliferation of small satellites deployed in large LEO constellations. Furthermore, the persistent reluctance of States to commit to annual launch caps intended to stabilise LEO remains an unresolved governance challenge. Thus, it is crucial to clarify how the globally defined launch rate can be collectively agreed upon, especially considering that current trends appear to be moving in the opposite direction. A recent scholarly article, for instance, found that “more than 300 constellations representing

²⁸³ UNCOPUOS, ‘Active Debris Removal — An Essential Mechanism for Ensuring the Safety and Sustainability of Outer Space – A Report of the International Interdisciplinary Congress on Space Debris Remediation and On-Orbit Satellite Servicing’ (January 2012) UN Doc. A/AC.105/C.1/2012/CRP.16, 21.

²⁸⁴ Ibid., 21.

more than 1 million satellites were filed between 1 January 2017 and 31 December 2022, [which] is greater than 115 times the number of operational satellites currently in orbit”.²⁸⁵

In light of the above rapid increase, by 2023 it had become evident that proponents of large LEO constellations often regard orbital space as only a “partially” limited resource, available for utilization on a first-come, first-served basis.²⁸⁶ Although mitigation requirements, such as design elements emphasized in relevant guidelines and standards, have been acknowledged and progressively incorporated by satellite designers and operators through the implementation of soft law instruments, other measures, such as launch rate restriction has been largely neglected and barely considered. In fact, the opposite trend can be observed among major LEO satellite operators, such as SpaceX and Amazon, which recently formed a coalition to advocate for a review of ITU’s EPFD limits. According to these companies, the current EPFD constraints restrict their constellation plans more than is necessary to protect satellites in GEO, as discussed earlier.²⁸⁷

In contrast, as previously noted, many experts in space debris mitigation contend that both large and small satellite constellations inevitably exerts a significant negative impact on the existing space debris environment. Constellations do not only intensify the strain on orbit and frequency resources but also significantly raise the risk of space collisions, exacerbating the existing trend. Pertaining to that, existing non-binding guidelines for space debris mitigation and relevant space traffic management policies fail to consider the explosive growth of satellite constellations, making it difficult to adequately address their substantial challenges. Currently, no legal instrument addresses the possibility of implementing launch rate mitigation. This issue warrants further examination and will be discussed in greater detail in the following chapters.

²⁸⁵ Andrew Falle et al., ‘One million (paper) satellites’, (12 October 2023) 382(6667) *Science* 150, 150.

²⁸⁶ The “partially limited approach” refers to the growing willingness to comply with existing mitigation measures, while at the same time reflecting a reluctance to challenge the inequitable exploitation of LEO.

²⁸⁷ Alliance for Satellite Broadband, ‘WRC-23: Time to Get the Rules Right for Satellite Broadband’ (*SpaceNews*, 18 November 2023) <<https://spacenews.com/wrc-23-time-to-get-the-rules-right-for-satellite-broadband/>> accessed 20 October 2025.

D. Chapter conclusion

*“The odds of the need for a specific legal regime being considered for orbits such as the LEO (...) largely depend on the likelihood that such orbits and the associated spectrum approach scarcity”.*²⁸⁸

The trajectory of this chapter has revealed that the sustainability of orbital space is no longer a peripheral concern but a critical condition for the continued use of outer space. As global reliance on satellite-based services intensifies, the increasing and unequal strain on LEO cannot be ignored. The exponential rise in launches, propelled by the commercialization of space, and miniaturization of space objects have transformed LEO into a congested and fragile environment. These tendencies are closely interrelated. The rapid increase in the number of satellites reinforces the creation of additional debris, while stabilizing measures function only as weak counterbalances. This dynamic resembles the behaviour of complex systems, in which feedback loops play a central role in shaping overall outcomes.²⁸⁹ A fuller theoretical discussion of system thinking will follow in the final chapter, but it is already useful to underscore that orbital space is not merely a physical environment; it is also a system with inherent limits.

Moreover, current trends in space activity disproportionately benefit established spacefaring nations, as access to orbital positions and frequencies continues to be shaped by a de facto first-come, first-served mechanism. These dynamics highlight not only the pressing challenge of ensuring the long-term sustainability of outer space, but also the question of reciprocal equity – a foundational principle of space law – which becomes ever more salient as rising demand begins to outstrip the safe and effective capacity of orbital and spectral resources.

²⁸⁸ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 188.

²⁸⁹ In systems thinking, a “feedback loop” describes a circular cause-and-effect relationship, where an action influences the system in a way that either reinforces or counteracts the original change. For example, in orbital space, continuous satellite launches may reinforce congestion, while deorbiting mechanisms act slowly to counter it.

Upon examining the growing challenges in LEO, it is clear that lessons from Earth's environmental challenges must inform our actions in space and avoid placing undue reliance on technologies that do not yet exist to mitigate the harmful effects of the escalating problem of space debris. Conversely, it is evident that current international space law and soft law frameworks and their interpretations remain inadequate for regulating the rapid expansion of LEO constellations, thereby jeopardizing equitable and sustainable access to outer space. Thus, the upcoming chapters will explore the legal framework of space law, emphasizing the so-called freedom principle that seemingly serves as the basis for the "unrestricted" launching of satellites into our orbits. Existing limitations on the freedom principle will be scrutinized, and a comparison between the regimes applicable to LEO and GEO will be undertaken. The subsequent question then will arise, which type(s) of limitation may be possible and necessary to meaningfully slow down the overexploitation of LEO and thus to ensure a sustainable space environment in the long-term.

CHAPTER II. Natural Resources – The Earth’s orbits and radio-frequency spectrums

“The anthropocentric character of the law of outer space is the obvious result of man’s being its sole architect. Far from reducing, this increases his responsibilities. Not only must he see it that the law be established in the interest of mankind as a whole, and prevent whatever dangers human action in outer space may produce to life and security on our globe, but he is also bound to provide adequate safeguards to ensure that nothing be done to upset the balance of nature (...).”²⁹⁰

A. Natural resources in international law

General international law does not provide a universally agreed-upon definition of natural resources. A key source on the topic, UNGA Resolution 1803 (1962) on the Permanent Sovereignty over Natural Resources refers to natural resources broadly as "natural wealth and resources", a basic constituent of the right to self-determination, without description of the phenomena.²⁹¹ Various sectoral regimes of public international law likewise regulate natural resources within their respective contexts. For instance, the United Nations Convention on the Law of the Sea (UNCLOS) explicitly recognizes natural resources in the exclusive economic zone and the continental shelf under Articles 56 and 77, by distinguishing between living and non-living resources.²⁹² Another example, Article 2 of the Convention on Biological Diversity (CBD) refers to biological resources, as “genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity”.²⁹³ Genetic resources, in the same source, are described as genetic material “of

²⁹⁰ Manfred Lachs, *The International Law of Outer Space: An Experience in Contemporary Law-Making* (Martinus Nijhoff, 1972 (2012 reprint) 22.

²⁹¹ UNGA, Permanent Sovereignty over Natural Resources, UN Doc. A/RES/1803 (XVII) of 14 December 1962.

²⁹² While the treaty does not specify examples, natural resources are generally understood to include living resources, such as fish stocks, and non-living resources, such as oil, gas, and minerals. See: Convention on the law of the sea of 10 December 1982, entered into force 16 November 1994, 1833 UNTS 397 (UNCLOS).

²⁹³ Convention on Biological Diversity, 5 June 1992, 1760 UNTS 79, articles 3; 56 and 77.

actual or potential value”.²⁹⁴ It may be also acknowledged that, broadly in international law, the concept of a resource is frequently defined by its economic value as realized through human use or interaction.²⁹⁵ This understanding is further reflected in widely accepted definitions, such as that provided by the Oxford English Dictionary, which describes natural resources as “those materials or substances of a place which can be used to sustain life or for economic exploitation; also, in extended use”.²⁹⁶

With respect to legal dictionaries, most do not provide a dedicated entry for the term, *natural resources*, indicating that, in the absence of explicit legal definitions, the term’s ordinary meaning should guide its legal interpretation.²⁹⁷ One exception we may find indeed is provided by Black’s Law Dictionary defining natural resource as “any material from nature having potential economic value or providing for the sustenance of life, such as timber, minerals, oil, water, and wildlife.”.²⁹⁸ According to all the above description, natural resources can be defined by their function, not sole material existence. It may thus be interpreted that within the framework of international law, it is the act of economic utilization – namely, *exploitation* – that confers legal relevance upon natural resources, effectively bringing them “into existence” as such. The crucial question of whether exploitation constitutes a form of “use” under space law, and how it should be distinguished from the concept of appropriation, will be examined in a greater detail.

Another key aspect of regulation of exploitation of natural resources under international law is the distinction between resources located within the jurisdiction of a state and those found in areas beyond national jurisdiction. Each category is subject to distinct legal principles and governance frameworks, with orbital space falling within the latter domain. To assess the potential applicability of the principle of permanent sovereignty in the context of outer space, it is essential first to understand its operation in both terrestrial and extraterrestrial domains.

²⁹⁴ Ibid., articles 56 and 77.

²⁹⁵ This idea can be also traced back to the Spaniards’ view of the *just price*. Accordingly, the goods on the market had no essential or natural value and that the just price was relative to how a thing is valued in the market. This common estimation was a function of many things, including the product’s relative abundance or scarcity, in other words, supply and demand. See: Martti Koskenniemi, ‘International Law and the Emergence of Mercantile Capitalism: Grotius to Smith’ in: Pierre-Marie Dupuy and Vincent Chetail (eds.) *The Roots of International Law* (Brill | Nijhoff 2014) 1, 14-15.

²⁹⁶ ‘Natural resources’ in Oxford English Dictionary <https://www.oed.com/search/dictionary/?scope=Entries&q=natural+resources> accessed 20 October 2025.

²⁹⁷ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 182.

²⁹⁸ ‘Natural resource’ in Bryan A Garner (ed), *Black’s Law Dictionary* (9th edn, Thomson Reuters 2009) 1127.

1. Permanent Sovereignty over Natural Resources

Resources located within a state's territorial boundaries, including its land, subsoil, and territorial waters, are subject to that state's jurisdiction. Accordingly, the state holds sovereign rights to exploit, use and manage these resources, while remaining bound by international obligations, such as compliance with environmental treaties.²⁹⁹ This is according to the principle of Permanent Sovereignty Over Natural Resources (PSNR) that emerged as a foundational concept in international law during the transformative period following the Second World War.³⁰⁰ The term *permanent sovereignty over natural resources (PSNR)* was formally introduced in the United Nations General Assembly Resolution 1803 in 1962.³⁰¹ The International Court of Justice (ICJ) in *Congo v. Uganda* (2005) recognized PSNR as a customary international law principle, though it stopped short of explicitly labelling it *jus cogens*. Given its growing prominence and normative weight, some scholars have argued that the principle may be evolving toward the status of a *jus cogens* norm,³⁰² while others contend that it remains a widely accepted customary international law, without peremptory status.³⁰³

PSNR can be traced back to the notion of territorial sovereignty, a concept anchored in international relations and international law since the 1648 Treaty of Westphalia, which marked

²⁹⁹ Nico Schrijver, *Sovereignty over Natural Resources: Balancing Rights and Duties* (Cambridge University Press, 1997) 368-396.

³⁰⁰ The principle of the permanent sovereignty over natural resources has been developed and reiterated in several pertinent resolutions of the United Nations General Assembly. The resolutions include: UNGA, Right to exploit freely natural wealth and resources, UN Doc. A/RES/626 (VII) of 21 December 1952; UNGA, Recommendations concerning international respect for the right of peoples and nations to self-determination, UN Doc. A/RES/837 (IX) of 14 December 1954; UNGA, Recommendations concerning international respect for the right of peoples and nations to self-determination, UN Doc. A/RES/1314 (XIII) of 12 December 1958; and UNGA, Concerted action for economic development of economically less developed countries, A/RES/1515 (XV) of 15 December 1960.

³⁰¹ UNGA, Permanent Sovereignty over Natural Resources, UN Doc. A/RES/1803 (XVII) of 14 December 1962.

³⁰² See for example: Schrijver, Nico, *Sovereignty over Natural Resources: balancing rights and duties in an interdependent world* (Cambridge University Press, 1995) 375; Ian Brownlie, 'Legal Status of Natural Resources in International Law' (1979) 162 *Recueil des Cours* 245, 255; and Alexander Orakhelashvili, *Peremptory Norms in International Law* (Oxford University Press 2008) 52-53.

³⁰³ See: ICJ, *Armed Activities on the Territory of the Congo (Democratic Republic of the Congo v. Uganda)*, [2005] See also: Nico Schrijver, *Sovereignty over Natural Resources: balancing rights and duties in an interdependent world* (Cambridge University Press, 1995) 377.

the emergence of the modern nation-state system.³⁰⁴ PSNR grants states significant discretion in the management of their natural resources. Initially, PSNR was championed to bolster the authority and independence of newly decolonized and developing nations. Furthermore, it was also the primary aim of PSNR to support developing countries in integrating into the global economy.³⁰⁵ This goal has been hardly achieved, as many developing states have continued to experience economic difficulties and struggled to fully integrate into the international economic system.³⁰⁶ Moreover, PSNR reinforced the rights of states to oversee and manage foreign investment within national boundaries, patterns of resource extraction that characterized colonialism seems to persist in modern times. Instead of being seized through force, these resources are now extracted and sold at low prices by governments that remain heavily reliant on foreign investment.³⁰⁷ This reliance is further driven by growth imperatives of the global economic system, perpetuating a cycle of dependency and exploitation under new guises.

The right of a state to exploit, use, and manage its own resources is coupled with the obligation, as articulated in the 1962 Declaration, that permanent sovereignty over natural wealth and resources “must be exercised” in a manner that promotes “national development and the well-being of the people concerned”.³⁰⁸ Similarly, subsequent resolutions increasingly stressed that natural resources under jurisdiction of a state should be used to advance a

³⁰⁴ Territorial sovereignty has a positive and a negative aspect. The former relates to the exclusivity of the competence of the state regarding its own territory, while the latter refers to the obligation to protect the rights of other states. See: Malcolm N. Shaw, *International Law* (6th edn, Cambridge University Press 2008) 490. See also: Scott, J. Shackelford, ‘The Law of Cyber Peace’ (2017) 18(1) *Chicago Journal of International Law* 1, 30.

³⁰⁵ Jahid Hossain Bhuiyan, ‘Evolution of the permanent sovereignty over natural resources in the context of the investment regime’ in Shawkat Alam, Jahid Hossain Bhuiyan, Jona Razzaque (eds.) *International Natural Resources Law, Investment and Sustainability* (Routledge, 2017) 62, 62.

³⁰⁶ Natural resources are often regarded as a “resource curse,” referring to the phenomenon where countries heavily reliant on the export of primary natural resources tend to experience slower economic growth compared to resource-scarce nations. Additionally, in many developing countries, such as Nigeria, a critical challenge arises when states assert their rights over natural resources without fully recognizing or fulfilling their responsibility to use these resources for the benefit of their populations. Lastly, the presence of natural resources within a state can also lead to both domestic and international conflicts. See: Jahid Hossain Bhuiyan, ‘Evolution of the permanent sovereignty over natural resources in the context of the investment regime’ in Shawkat Alam, Jahid Hossain Bhuiyan, Jona Razzaque (eds.) *International Natural Resources Law, Investment and Sustainability* (Routledge, 2017) 62, 63.

³⁰⁷ Miriam Lang & Ulrich Brand & Kristina Dietz, ‘Neo-Extractivism in Latin America. One Side of a New Phase of Global Capitalist Dynamics’ (2016) 11(21) *Ciencia Política* 125, 131-133.

³⁰⁸ Para. 1 UNGA, Permanent Sovereignty over Natural Resources, UN Doc. A/RES/1803 (XVII) of 14 December 1962.

country's development and to benefit its population.³⁰⁹ The recognition of peoples' rights in relation to PSNR is significant for several reasons, and its interpretation has evolved over time. On the one hand, PSNR provides a foundation for contesting governmental decisions that allow multinational corporations to exploit a state's natural resources.³¹⁰ On the other hand – and more importantly for the development of international law – it has been argued that the traditional, purely sovereignty-based understanding has increasingly given way to principles that function as safeguards, affirming that states, as holders of the right to permanent sovereignty, also bear a corresponding *duty* to manage the natural resources within their jurisdiction in an environmentally sustainable manner. Article 56 of the 1982 UN Convention on the Law of the Sea for example spells out that sovereign right to natural resources is conferred upon states for the purpose of exploring and exploiting, conserving and managing the natural resources.³¹¹ This shift introduced a delicate balancing act between resource management for national development and the imperative of environmental preservation, a dynamic that continues to shape international environmental law today.³¹² While PSNR continues to enable host states to maintain ownership and control over their natural resources often in collaboration with foreign investors through various agreements, international law plays a pivotal role in defining, supporting, and shaping the environmental limits of natural resource exploitation.³¹³

³⁰⁹ Para. 5 UNGA, Permanent Sovereignty over Natural Resources, UN Doc. A/RES/2158 (XXI) of 25 November 1966.

³¹⁰ Ricardo Pereira and Orla Gough, 'Permanent Sovereignty over Natural Resources in the 21st Century: Natural Resource Governance and the Right to Self-Determination of Indigenous Peoples under International Law', (2013) 14(2) *Melbourne Journal of International Law* 1, 10.

³¹¹ UNCLOS article 56.

³¹² See for example: Sumudu Atapattu and Carmen Gonzalez, 'The North–South Divide in International Environmental Law: Framing the Issues' in Shawkat Alam, Sumudu Atapattu, Carmen Gonzalez and Jona Razzaque (eds.) *International Environmental Law and the Global South* (Cambridge University Press, 2016) 1-23; Claire Brighton, 'Unlikely Bedfellows: The Evolution of the Relationship between Environmental Protection and Development' (2017) 66 *International and Comparative Law Quarterly* 209, 209.

³¹³ In the international environmental law context, the well-established Roman law principle, *sic utere tuo, ut alienum non laedas*, already implied that states may not use their territory and the resources under their control in such a way as to cause significant harm to the environment of other states or even to areas beyond any national jurisdiction. This principle was referred to already in numerous ICJ cases, such as the 1940 Trail Smelter arbitration, and the Corfu Channel case of the ICJ. It has also been codified in the 1972 Stockholm Declaration on Human Environment, in which form it is widely considered reflecting customary international law. See: *Trail Smelter Arbitration (U.S. v. Canada)* (Awards, 1938 and 1941) 3 Rep of International Arbitral Awards 1905; ICJ, *Corfu Channel case (UK v. Albania)* [1949] ICJ Rep 4; 'Declaration of the United Nations Conference on the Human Environment' UNGA Res 2994 (15 December 1972) UN Doc. A/RES/2994 (Stockholm Declaration); Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff, 2008) 150.

Although outer space, including the Moon and other celestial bodies, is designated as an area beyond national jurisdiction under the non-appropriation principle enshrined in Article II of the Outer Space Treaty (OST), post-Second World War developments – particularly the emergence of the PSNR principle – prompted various initiatives by developing countries seeking to challenge or reinterpret this framework. Notably, the Bogotá Declaration, issued by eight equatorial States, argued that the geographical alignment between their national territories and the corresponding segments of GEO entitled them to assert full and permanent sovereignty over the natural resources located within those orbital regions.³¹⁴ The Declaration contended that “both the geostationary orbit and the frequencies have been used in a way that does not allow the equitable access of the developing countries that do not have the technical and financial means that the great powers have”.³¹⁵ Notably, Colombia – one of the principal proponents of the Bogotá Declaration – subsequently enshrined its position in its national constitution, where it remains in force today.³¹⁶ This is particularly striking given that Colombia is also a state party to the Outer Space Treaty, thereby simultaneously upholding a national claim to GSO segments while formally adhering to the principle of non-appropriation under international space law.³¹⁷

Besides the Bogotá Declaration, it is undeniable that latecomers to outer space activities have often encountered significant difficulty in accessing desirable orbital slots, largely due to prior use by other states and the prevailing characteristics of the ITU’s registration process, which is frequently described as following a first-come, first-served, or an *a posteriori* model. This and subsequent initiatives, particularly those led by developing countries – will be discussed below, as they reflect elements of the PSNR principle adapted to the prospective governance of the orbital space environment.

³¹⁴ ITU, Declaration of the first meeting of equatorial countries, [Bogotá Declaration] ITU Doc. WARC-BS (1977) 81-E of 3 December 1976 art. 2.

³¹⁵ *Ibid.*, art. 1.

³¹⁶ Article 101 para 4 of the Colombian constitution stipulates, “Also part of Colombia is the subsoil, the territorial sea, the contiguous zone, the continental shelf, the exclusive economic zone, the airspace, the segment of the geostationary orbit, the electromagnetic spectrum and the space where it applies, in accordance with international law or the laws of Colombia in the absence of international regulations.” See: Constitution of the Republic of Colombia of 1991 art. 101 https://www.constituteproject.org/constitution/Colombia_2015 accessed 20 October 2025.

³¹⁷ UNCOPUOS, ‘Status of International Agreements relating to activities in outer space’ Un Doc. A/AC.105/C.2/2025/CRP.9 of 1 January 2025.

2. Natural resources in areas beyond national jurisdiction

The legal framework governing areas beyond national jurisdiction has its roots in Roman civil law, particularly in the dialectical tension between two foundational concepts: *res communis* (object which cannot be owned by anyone and which is subject to use by all) and *res* (or *terra*) *nullius* (object owned by no one but subject to appropriation).³¹⁸ A classical example is found in the Roman conception of the seas as *res communis omnium* – things held in common and free for the use of all.³¹⁹ Hugo Grotius, the leading natural law theorist, likewise rejected the idea that the sea could be subjected to exclusive jurisdiction or private ownership.³²⁰ Drawing on earlier arguments by the Spanish jurist Vázquez de Menchaca, Grotius maintained that *dominium* (property) over the seas was impossible because they could not be physically possessed. Moreover, no terrestrial authority – such as the Pope – could lawfully confer rights over such a domain, as no such authority extended over the high seas.³²¹

Hans Kelsen, the positivist legal philosopher, later extended this reasoning to outer space, asserting that it too should be considered *res communis* and therefore open to exploration and navigation by all.³²² Nonetheless, Kelsen interpreted this freedom – by analogy with the law of the sea – as permitting certain acts of sovereignty, such as launching a satellite in GEO as a sovereign object, but the orbit itself is not appropriated, provided they did not infringe

³¹⁸ In the Western Sahara ICJ advisory opinion, the Court ruled that the concept of *terra nullius* was a legal term of art used in connection with the mode of acquisition of territory known as ‘occupation’. In the same decision, the Court held that, during the colonial era, state practice demonstrated that territories inhabited by tribes or peoples with an established social and political organization were not considered *terrae nullius*. See: ICJ, *Western Sahara, Advisory Opinion* of 16 October 1975 ICJ Rep 12; and Malcolm Shaw, ‘The Western Sahara case’ (1978) 49(1) *British Yearbook of International Law* 119, 127–134. See also: Henry Hertzfeld, Brian Weeden and Christopher Johnson, ‘How Simple Terms Mislead Us: The Pitfalls of Thinking about Outer Space as a Commons’ (International Astronautical Congress, Jerusalem, October 2015) IAC-15 - E7.5.2 x 29369, 7.

³¹⁹ Thomas W. Fulton, *Sovereignty of the Sea* (William Blackwood and Sons, 1911) 3.

³²⁰ Grotius, following the scholastic tradition held that under natural law, there was originally no concept of lordship or private property; no individual had authority, and all ownership was shared and communal. As described in the Book of Genesis, only God possessed dominium over the world, and He had given it to human beings in common. However, over time, this original state was altered through the influence of positive law and evolving practices. In response to changing circumstances, property rights and jurisdiction gradually emerged through the division of what was once shared. “As communities became more cultivated and individuals more ambitious, they began to see benefits in the division of land and other properties.” See: Martti Koskenniemi, ‘International Law and the Emergence of Mercantile Capitalism: Grotius to Smith’ in: Pierre-Marie Dupuy and Vincent Chetail (eds.) *The Roots of International Law* (Brill | Nijhoff 2014) 1, 10.

³²¹ Hugo Grotius, *Commentary on the Law of Prize and Booty* (Martine Julia van Ittersum ed, Liberty Fund 2006) 346-353.

³²² Hans Kelsen, *Principles of International Law* (2nd edn, revised by R.W. Tucker, 1966) 343.

upon the freedoms of other states. Whether these certain acts of sovereignty can be regarded as *res nullius* or *res communis* is a topic of scholarly debate. This paper, however, does not seek to endorse either side of the debate. Rather, it argues that resolving this binary question is not a prerequisite for addressing the more pressing issue: where should the boundary be drawn between lawful and unlawful use and exploitation of outer space, particularly in light of recent developments affecting the orbital environment? This central concern will be explored in the sections that follow.

An alternative concept and research approach may offer valuable insights into the management of areas beyond national jurisdiction and their associated resources. In economic discourse, these regions are often – though not universally –³²³ referred to as *global commons*.³²⁴ A “commons” can be described as a resource shared by a group of people.³²⁵ This concept of the commons has shaped the modern legal understanding of areas beyond national jurisdiction, encompassing spaces like outer space, the high seas, the deep seabed, and Antarctica. Additionally, technological advancements and emerging global challenges have led to the recognition of new domains as potential global commons or “expanded commons” requiring forms of international governance. These include digital and cyberspace governance, genetic resources and biodiversity, artificial intelligence and algorithmic systems, and even aspects of global health.³²⁶ According to the notion of the global commons, certain areas are considered to belong to all humankind and must be preserved for future generations, rather than being subject to exclusive control by private actors or individual states.³²⁷ Indeed, the concept of the global commons has long served as a foundational point of reference for lawmakers

³²³ One may consider the United States statement relevant to the topic of resource exploitation that “[o]uter space is a legally and physically unique domain of human activity, and the United States does not view space as a global commons”. Executive Order No 13914, ‘Encouraging International Support for the Recovery and Use of Space Resources’ 85 Fed Reg. 20161 (10 April 2020).

³²⁴ On whether outer space may be regarded as a global commons, see, for instance: Daniel Patton, ‘Is space a global commons?’ (*Secure World Foundation Briefs*, 2022) 1, 1-36 <https://cdn.prod.website-files.com/66dcc6872f6ed23bce1db235/68470f0b0107aa4d7a8f77bb_is-space-a-global-commons-swf-brief-2022.pdf> accessed 20 October 2025; Frans von der Dunk, ‘A Tale of Two Oceans: Governance of Terrestrial and Outer Space ‘Global Commons’’ (2012) *Asian Journal of Air and Space Law* 2(1) 31, 31-60.

³²⁵ Charlotte Hess & Elinor Ostrom, ‘Introduction: An Overview of the Knowledge Commons’ in Charlotte Hess and Elinor Ostrom (eds.) *Understanding Knowledge as a Commons: From Theory to Practice* (The MIT Press 2006) 3, 3-26.

³²⁶ See for example: Xiao-Shan Yap, et al., ‘Four Alternative Scenarios of Commons in Space: Prospects and Challenges’ 2023) 17(1) *International Journal of the Commons* 390–410.

³²⁷ See, for example: James Fawcett, ‘How Free Are the Seas?’ (1973) 49(1) *International Affairs* 14, 14-22.

addressing outer space, prompting frequent analogies – particularly from two established branches of international law: The Antarctic Treaty System and the Law of the Sea. Since the 1960s, it has been recognized that the deep seabed beyond national jurisdiction contains abundant mineral resources.³²⁸ In 1970, in a significant act of multilateral cooperation, states reached a consensus that these seabed resources should be shared and remain exempt from any claims of sovereignty or sovereign rights. The UN General Assembly adopted the Declaration of Principles Governing the Seabed and Ocean Floor, affirming that the Area (the seabed beyond national jurisdiction) and its resources constitute the common heritage of mankind (CHM).³²⁹ This principle was reaffirmed in Articles 136 and 137 of the UN Convention on the Law of the Sea (UNCLOS), which clarified that no state sovereignty or other rights would be recognized over the Area – except for minerals extracted in accordance with the Convention.³³⁰ According to UNCLOS, all rights over the mineral resources in the Area are held by humankind collectively, and any activities conducted there, including exploitation of CHM resources, must comply with the regulatory framework and institutional mechanism established by the Convention, and must be undertaken exclusively for peaceful purposes and in the interest of humanity as a whole. Furthermore, Article XI of the 1979 Moon Agreement (MA), one of the five main treaty sources of space law, affirms that the Moon and its natural resources constitute the common heritage of mankind, rendering them ineligible for national appropriation and subject to a specific international regime governing their exploitation.³³¹ Last but not least, attempts were being made to establish a CHM regime over Antarctica.³³² The CHM concept shares several core characteristics, including the principle that the areas concerned cannot be subject to national appropriation: sovereignty does not apply, and no ownership or jurisdictional rights may arise outside the institutional framework established by the relevant common heritage regime. However, unlike a *res communis* system, which allows open access,

³²⁸ See: Zachary Douglas, Taulupapa Brenda Heather-Latu, Toby Fisher and Jessica Jones, ‘In the Matter of a Proposed Moratorium or Precautionary Pause on Deep-Sea Mining Beyond National Jurisdiction’ (10 February 2023) 1, 1-52 <<https://www.pew.org/-/media/assets/2023/03/deep-sea-mining-moratorium.pdf>> accessed 20 October 2025.

³²⁹ UNGA, Declaration of Principles Governing the Sea-Bed and the Ocean Floor, and the Subsoil Thereof, beyond the Limits of National Jurisdiction, UN Doc. A/RES/25/2749 (XXV) of 12 December 1970, art 1.

³³⁰ UNCLOS, article 136 and 137.

³³¹ Article XI Agreement governing the activities of states on the Moon and other celestial bodies of 18 December 1979, entered into force 11 July 1984, 1363 UNTS 21 [hereinafter: Moon Agreement].

³³² Malcolm N. Shaw, *International Law* (6th edn, Cambridge University Press 2008) 533-538.

exploration, and exploitation, a common heritage regime – such as those mentioned above – impose strict regulation on these activities. It establishes governance mechanisms and incorporates equity as a guiding principle for the distribution of resulting benefits.³³³

Although UNCLOS does not provide a formal definition of the CHM principle, its essential framework is articulated primarily in Part XI of the Convention and includes: i) the prohibition on claims to sovereignty or sovereign rights,³³⁴ ii) the requirement that activities be conducted for peaceful purposes,³³⁵ iii) common management of the Area and its resources,³³⁶ iv) the protection of the marine environment,³³⁷ v) the sharing of benefits derived from activities in the Area,³³⁸ and vi) the promotion of effective participation by developing and landlocked states,³³⁹ vii) including through the so-called *parallel system*.³⁴⁰ Additionally, several commentators have emphasized that the CHM principle incorporates both intergenerational and international equity, and thus embodies an aspiration toward sustainable long-term development.

In discussions on the regulation of space resource exploitation, analogies are frequently drawn to the Antarctic Treaty System and the high seas, reflecting a broader tendency to rely on established regimes governing areas beyond national jurisdiction. Proponents of the use of analogy believe that through the comparative method, analogies facilitate reliance on familiar legal frameworks and offer a means to draw parallels with previously addressed legal challenges.³⁴¹ On the contrary, experts, such as Jakhu and De Man warns against the danger of

³³³ Ibid., 533-534.

³³⁴ UNCLOS art 137(1).

³³⁵ UNCLOS art 141.

³³⁶ UNCLOS arts 153 and 158-185.

³³⁷ Joanna Dingwall, *International Law and Corporate Actors in Deep Seabed Mining* (Oxford University Press 2021) 94.

³³⁸ UNCLOS art 140.

³³⁹ UNCLOS art 148.

³⁴⁰ UNCLOS annex III, art 8; and UNGA Agreement relating to the implementation of Part XI of the United Nations Convention on the Law of the Sea, UN Doc A/RES/48/263 of 28 July 1994. The *parallel system* was originally designed to ensure that seabed mining is not dominated solely by private or state actors from developed countries. Accordingly, each territory licensed for mining within the Area is divided into two parts: one, assigned to the Contractor (often a private company or state-sponsored actor), the other, reserved for developing states or the International Seabed Authority's Enterprise. Through this process, the Enterprise is responsible to act on behalf of humankind as a whole, and especially allowing developing nations through the institution, to participate in deep seabed mining.

³⁴¹ Houston Lay and Howard Taubenfeld, 'The law relating to activities of man in space', (1970) 37(1) *Journal of Air Law and Commerce* 151, 57; Rüdiger Wolfrum, *Die Internationalisierung staatsfreier Räume: die Entwicklung einer internationalen Verwaltung für Antarktis, Weltraum, Hohe See und Meeresboden* (Springer 1984).

analogous reasoning and argue for the further development of space law as a sui generis regime, stating that “use” of outer space must be considered primarily according to the law applicable to outer space, rather than resort to some abstract concept and analogies to other areas.³⁴²

B. Natural resources in space law

Neither the UN space treaties, nor the ITU contain any indications that one should distinguish between exhaustible, renewable, consumptive or abundantly available resources, and those that are not.³⁴³ Even within the framework of the Moon Agreement, the term ‘natural resource’ is not necessarily confined to material deposits located on or beneath the surface of the Moon or other celestial bodies. This is because the treaty broadens the definition of celestial bodies to encompass associated orbits and trajectories to or around them.³⁴⁴ This recurring reference to natural resources suggest that, although physical characteristics like renewability, exhaustibility, and location are relevant, they are not the decisive factors shaping the legal rules governing space resource exploitation. Rather, as De Man’s analysis demonstrates, regulatory approaches have been driven primarily by the activities, interests, and objectives of the international space community. Accordingly, the legal framework for the use of space resources does not emerge automatically from the intrinsic nature of those resources; instead, it is shaped by the priorities of spacefaring nations, the practices they pursue, and the ways in which those practices align with broader international interests. This approach reflects a departure from frameworks that rigidly derive legal status from the natural attribute of a resource and instead emphasizes the role of human agency in determining the structure and direction of legal norms.

³⁴² See for example. “[t]he rights and duties of the states with respect to access to and use of the geostationary orbit must be considered primarily according to the law applicable to outer space, rather than in the light of abstract concepts and analogies applicable to other areas”. Ram S. Jakhu, ‘The legal regime of the geostationary orbit’ (Doctoral thesis, McGill University, 1983) 98 < <https://escholarship.mcgill.ca/concern/theses/bg257f82k> accessed 20 October 2025.

³⁴³ De Man, Philip, *Exclusive Use in an Inclusive Environment* (Springer 2016) 142, 191-192.

³⁴⁴ Moon Agreement, article 1 para 2.

In policy discussions, the term “space resources” is most commonly associated with tangible, extractable materials found on celestial bodies – such as the Moon, asteroids, comets and other planets.³⁴⁵ These include water ice, regolith, and rare metals like platinum or nickel. Such material celestial resources are often framed in terms of their commercial value and strategic importance, particularly for sustaining long-term human presence, scientific research, and space-based industrial activity. However, space law must also account for less tangible but equally critical resources – namely orbital slots and radio-frequency spectrum. Although these functional resources differ in physical character from mineral deposits, they are essential for satellite operations, the backbone of modern space activities, and are regulated as limited resources due to their finite availability and rising demand. Together, both categories of resources underpin discussions on equitable access, sustainable use, and regulatory oversight within the broader legal framework governing outer space, albeit from distinct perspectives.³⁴⁶

The space treaties that address the use of natural resources offer only limited guidance for interpreting the concept of “natural resources” within the framework of international space law. While the OST articulates several principles relevant to the use of natural resources, it does not mention the term explicitly. Moreover, the few international instruments that refer to the exploitation of natural resources provide no definition of the term. In the Moon Agreement, references to the resources of celestial bodies appear primarily in Article 11, which designates them as the *common heritage of mankind* – a principle that, as previously discussed, remains vague and insufficiently developed.³⁴⁷ The only other mention of natural resource in binding

³⁴⁵ See for example Part 1 of the Initial draft set of recommended principles for space resource activities, UNCOPUOS, ‘Initial Draft set of recommended principles for space resource activities’ (May 2025) UN Doc. A/AC.105/C.2/L.339, “Noting that [„whilst there are currently no internationally agreed definitions of ‘space resources’ or ‘space resource activities’], the following clarifications apply to the application of these Principles: (a) for the purposes of these Principles, space resources include extractable and/or recoverable natural, abiotic resources [material] [such as minerals, water, ice, other liquids, and gases] located [in situ] in outer space, including [on the surface or in the subsurface of] the Moon and other celestial bodies [and do not include satellite orbits, radio spectrum, solar energy or other resources not of a physical nature]”. This approach appears to align with the definition of space resources found in the US Space Resource Act, which seems to recognize only tangibly, physical materials. See: §51301 U.S. Commercial Space Launch Competitiveness Act, HR 2262, 114th Congress (2015).

³⁴⁶ While discussions on the use of „space resources” – typically limited to tangible resources found on the Moon and other celestial bodies – take place within the Legal Subcommittee (LSC) of COPUOS, matters concerning the use and management of orbits, such as the long-term sustainability of outer space activities, space debris, and the governance of the geostationary orbit, and dark and quiet skies, are predominantly addressed by the Scientific and Technical Subcommittee (STSC).

³⁴⁷ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 141.

international space law appears in Article 44(2) of the International Telecommunication Union (ITU) Constitution, which merely states that Member States should bear in mind that “radio frequencies and any associated orbits, including the geostationary-satellite orbit, are limited natural resources (...)”.³⁴⁸ This legal framing – directed specifically at the geostationary orbit as a finite and valuable resource – is further underscored, albeit in a contested manner, by the 1976 Bogotá Declaration, discussed earlier.

In terms of orbital positions and radio frequencies, these two resources are generally treated as a unified resource, especially relevant to the telecommunication regime given that their practical value emerges only “through the simultaneous exploitation of both phenomena”.³⁴⁹ A satellite in orbit is useless without a frequency through which to transmit and receive data, just as a frequency allocation is meaningless without a satellite to utilise it. Thus, even though orbits and frequencies are technically distinct, they are often treated as a single resource in legal and regulatory contexts. Nevertheless, the following section explores some distinctions between the two elements as natural resources.

1. Earth orbits as (natural) resources

The Earth’s orbits represent a fundamental characteristic of outer space and are integral to humanity’s ability to utilize and exploit them. In fact, it is reasonable to suggest, that the beginning of the Space Age is commonly traced back not to the 1944 launch of the sub-orbital V-2 rocket, – the first space object that has ever reached outer space – but to the Soviet Union’s 1957 launch of Sputnik I. This distinction is largely due to the fact that Sputnik I has marked the commencement of *orbital* spaceflight. Indeed, until today it can be argued that being “in space” is, to a significant extent, commonly understood as occupying an orbital trajectory,

³⁴⁸ ITU Constitution, art 44.

³⁴⁹ Martin A. Rothblatt, ‘Satellite communication and spectrum allocation’ (1982) 76(1) *American Journal of International Law* 56, 56.

rather than merely surpassing a threshold of altitude, deemed to mark the beginning of outer space.³⁵⁰

Given that this dissertation centres on the subject matter of Earth's orbits, it is noteworthy that references to orbital positions as a distinct legal subject appear only ten times across the five United Nations space treaties: twice in the Outer Space Treaty (OST), four times in the Registration Convention, and four times in the Moon Agreement. The OST only mentions the word in relation to the placement in orbit of weapons of mass destruction, once in the preamble and once in the substantive text. Accordingly, Article IV OST asserts that States Parties to the Treaty shall undertake not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction. This provision stands as the only explicit textual restriction within the space treaties on a specific use of orbital space. In other words, beyond this, international space law contains no direct limitations on the purposes for which orbits may be used. Nonetheless, the practical interpretation of Article IV has indirectly reinforced the legal significance of orbit. In particular, as Blount observes, Article IV OST has contributed to the understanding that occupying an orbital trajectory constitutes *prima facie* evidence that an activity falls under the regime of space law.³⁵¹ This interpretation is exemplified by Blount by the legal treatment of so-called, fractional orbital bombardment systems (FOBS) that are nuclear delivery systems designed to enter an orbital path, but deorbit before completing a full revolution. At the time of their development by the Soviet Union, it was argued that such systems did not fall under the OST's Article IV prohibition, because they never completed a full orbit.³⁵² Notably, both the Soviet Union and the US agreed that the system did not constitute the placement of a weapon in orbit, and therefore concluded that Article IV OST was not applicable to FOBS.³⁵³

³⁵⁰ While the first artificial object to reach outer space, the V-2 rocket, attained high altitudes, it lacked the velocity required to sustain an orbit and ultimately fell back to Earth. In contrast, Sputnik I was propelled to a speed sufficient to balance gravitational pull with forward momentum, enabling it to continuously circle the blue Planet. In this way, Sputnik I achieved true orbital flight and became the first satellite in the proper sense. See: P.J. Blount, 'Legal Issues Related to Satellite Orbits' (December 2022) *Oxford Research Encyclopedia of Planetary Science* 1, 1-3 <<https://doi.org/10.1093/acrefore/9780190647926.013.78>>.

³⁵¹ *Ibid.*, 2.

³⁵² *Ibid.*, 2.

³⁵³ Raymond L. Garthoff, 'Banning the Bomb in Outer Space' (Winter 1980-1981) 5(3) *International Security* 25, 25-34.

Furthermore, in discussions surrounding the classification of orbits as limited natural resources, it becomes evident that the term “orbit” refers not to the abstract technological construct associated with a satellite, but to the continuous sequence of physical spatial positions that the satellite occupies.³⁵⁴ This path is not only limited in availability but also uniquely defined for each satellite. Therefore, if orbits are accepted as limited in quantity, physically extant, and subject to human use for valuable purposes, their classification as natural resources follow logically and ought not to be a matter of dispute.³⁵⁵ This idea is also supported by Blount, who claims that due to their unique features, orbits can be considered as resources from a legal perspective.³⁵⁶ To facilitate the management of orbits as natural resources, the International Telecommunication Union (ITU) establishes the regulatory frameworks and procedural mechanisms governing, the geostationary orbit. Importantly, the language of the ITU Constitution is not confined solely to the geostationary orbit, but extends to “any associated orbits”, encompassing other orbital regimes beyond the geostationary orbit (non-GSO).³⁵⁷ While the number of theoretical orbital paths can be considered infinite, the number of practically usable orbits is limited. In fact, the occupation of one orbit can diminish the functionality of nearby or intersecting orbits, thereby reducing the availability of orbital space for other users. This is the reason, some theorists even consider Earth’s orbital space in an economic term, *common-pool resource* – a category of resource that is both non-excludable, in that users cannot prevent others from accessing it, and rivalrous, in that one user’s exploitation of the resource limits its availability to others.³⁵⁸ This economic concept, along with the ITU’s regulatory function, will be analysed in greater depth in the subsequent chapters of this dissertation.

In the early development of the regulatory framework governing orbital positions and radio-frequency spectrum – particularly in the context of balancing competing interests between technologically advanced and developing states – spacefaring nations initially

³⁵⁴ Philip De Man, ‘The Exploitation of Outer Space and Celestial Bodies – A Functional Solution to the Natural Resource Challenge’ (2010) 54 *KU Leuven Working Paper* 1, 16 https://ghum.kuleuven.be/ggs/publications/working_papers/2010/54DeMan.

³⁵⁵ Ibid., 16.

³⁵⁶ P.J. Blount, ‘Legal Issues Related to Satellite Orbits’ (December 2022) *Oxford Research Encyclopedia of Planetary Science* 1, 3 <<https://doi.org/10.1093/acrefore/9780190647926.013.78>>.

³⁵⁷ ITU Constitution, art 44.

³⁵⁸ Jean-Frédéric Morin and Benjamin Richard, ‘Astro-Environmentalism: Towards a Polycentric Governance of Space Debris’ (2021) 12(4) *Global Policy* 568, 568–569.

favoured a first-come, first-served system. Under this approach, registering an orbital slot early effectively guaranteed long-term access, at times amounting to quasi-permanent control.³⁵⁹ Developing countries, many of which lacked launch capabilities, objected to this approach. They pushed for a planned (*a priori*) allocation system that would reserve orbital slots in advance for every country, thereby ensuring fair access even for those lacking immediate capacity to utilise them. In practice, however, few states supported this “extreme” position. An *a priori* allocation system risks becoming rigid and inefficient, as many developing countries that would otherwise receive an equitable share of orbital slots do not yet possess the technical or financial means to make effective use of their reserved orbital slots. Moreover, under such a system some orbital slots would remain idle while others became congested, reducing flexibility and preventing their use by states capable of deploying satellites immediately. Critics of the *a priori* approach also argue that it would effectively freeze global orbital capacity, hindering the ability to respond dynamically to technological, scientific, and commercial developments. In its most rigid form, *a priori* allocation could even resemble de facto appropriation, whereby unused paper rights preclude the functional use of orbital positions by others – potentially violating the non-appropriation principle. Consequently, most ITU Member States favoured a compromise, seeking a practical regime that balances efficiency and fairness.³⁶⁰

Although the *a priori* system was set aside, it never completely disappeared – especially as developing nations joined the ITU in large numbers during the 1960s and 1970s. These states renewed pressure for a system that would guarantee equitable access, arguing that efficiency alone could not justify exclusive or long-term control by a few spacefaring states. This led to renewed interest in *a priori* planning as a mechanism for promoting equity, particularly in the context of broadcasting and fixed-satellite services. The result was the adoption of Appendices

³⁵⁹ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 218-219.

³⁶⁰ The idea of engineering a perfectly organized, pre-allocated spectrum was initially popular. For instance, the USA strongly advocated such an approach during the 1947 Atlantic City Radio Conference. However, this engineering vision failed early on, as by 1959 it became clear that global demand far outstripped available spectrum, and such rigid planning was not manageable. As a result, the ITU shifted to an *a posteriori* model, where countries would request slots as needed, rather than receive them in advance. This system was codified in the Final Acts of the 1963 and 1971 Radio Conferences. See: Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 218-219; Edward Ducharme, Robert R. Bowen and Irwin M.J.R., ‘The Genesis of the 1985/87 ITU World Administrative Radio Conference on the use of geostationary satellite orbit and the planning of space services utilizing it’ (1982) 7 *Annual Air & Space Law* 261, 265–266.

30, 30A, and 30B of the ITU Radio Regulations, which establish pre-planned allocations for certain types of services in the geostationary orbit.³⁶¹ Although these provisions apply only to a limited subset of orbital uses, they are significant precedents that embody a fundamentally different legal philosophy about orbital slot allocation – one centred on fairness and guaranteed access rather than purely on operational need. The dichotomy between “first-come, first-served” and “*a priori* planning” has become so entrenched in legal and policy discourse that it is often treated as an essential reference point in discussions of orbital resource governance.³⁶²

2. Radio-frequency spectrum

When addressing natural resources, it is worthwhile to treat radio-frequency spectrum as a distinct category that warrants separate analysis. Radio-frequency spectrum is an abundant resource that uniformly covers the planet and is available for a wide variety of useful purposes.³⁶³ In evaluating the radio-frequency spectrum as a natural resource, an important consideration arises: according to several scientists, only certain portions of the electromagnetic spectrum can properly be considered as part of the natural environment.³⁶⁴ Radio signals observed by passive services appear only to form part of the natural environment, as they are physical phenomena that originate independently of human activity and control.³⁶⁵ Radio signals studied by the passive services refer to naturally occurring electromagnetic emissions – such as cosmic background radiation, emissions from stars, or other celestial

³⁶¹ Fixed Satellite Service (FSS) Plan and Broadcasting-Satellite Service (BSS) and Feeder-link Plans transform the broad freedom of use (Article I OST) into a concrete option: every state retains the possibility of accessing specific geostationary slots once it has the technical capacity to do so. Crucially, however, these arrangements stop short of creating immediately enforceable rights that would block other states from using the same positions in the meantime. Instead, the plans permit additional, interim uses of currently unoccupied slots, thereby preventing resource hoarding. Full international protection and recognition arises only once an orbital position is actually brought into use and formally entered into the Master Register – at which point it becomes shielded against harmful interference and acknowledged as an established right of use. See: Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 279-280.

³⁶² Francis Lyall and Larsen Paul B, *Space Law: A Treatise* (3rd edn, Routledge 2025) 231-232.

³⁶³ Dennis Roberson and William Webb, ‘Radio frequency spectrum and regulation’ in Alexander Wyglinsky et al. (eds.) *Cognitive Radio Communications and Networks* (Academic Press, 2010) 15, 15.

³⁶⁴ Mark A. Stull, and George Alexander, ‘Passive use of the radio spectrum for scientific purposes and the frequency allocation process’ (1977) 43(3) *Journal of Air Law and Commerce* 459, 517-518.

³⁶⁵ European Science Foundation, Committee on Radio Astronomy Frequencies (CRAF) ‘Handbook for Radio Astronomy’ (3rd edn 2005) 18 <https://craf.eu/wp-content/uploads/2015/02/CRAFhandbook3.pdf> accessed 20 October 2025.

phenomena – that are detected and analysed without any human transmission or interference.³⁶⁶ Passive services, in the context of the ITU Radio Regulations are services like radio astronomy, passive Earth exploration-satellite services, and passive space research.³⁶⁷ These services do not transmit radio waves, but only receive and study natural emissions that are already present in the environment, in other words, they do not owe their existence to human activity. It is also highlighted by experts, that passive services are not driven by commercial interests or profit motives but are dedicated to advancing public knowledge and scientific discovery through academic research.³⁶⁸ This commitment to the public good is absolute. In contrast to passive radio service – which are limited to the reception and study of naturally occurring electromagnetic emissions, such as those originating from celestial bodies or the Earth’s atmosphere – active radio services depend entirely on deliberate human intervention for their existence. Active services involve the generation and transmission of radio signals for defined purposes, including mobile communications, broadcasting, radar, and satellite communications, and active Earth observation via synthetic aperture radar. Whereas passive services treat outer space as an observational environment, active services utilize it as a transmission medium.³⁶⁹ Although passive radio services – often regarded as natural resources – occupy only a small portion of the total radio-frequency spectrum, the vast majority of spectrum allocations are dominated by active services.³⁷⁰

³⁶⁶ Mark A. Stull, and George Alexander, ‘Passive use of the radio spectrum for scientific purposes and the frequency allocation process’ (1977) 43(3) *Journal of Air Law and Commerce* 459, 517-518.

³⁶⁷ International Telecommunication Union (ITU), *Radio Regulations* (rev WRC-19 ITU 2020) arts 1.52–1.58.

³⁶⁸ Research conducted in fields such as radio astronomy, space science, and search for extraterrestrial intelligence (SETI), is disseminated openly in the scientific literature, without the constraints of patents or copyrights, ensuring unrestricted access and use by all. Mark A. Stull, and George Alexander, ‘Passive use of the radio spectrum for scientific purposes and the frequency allocation process’ (1977) 43(3) *Journal of Air Law and Commerce* 459, 514.

³⁶⁹ See for example in Milton L. Smith, ‘International Regulation of Satellite Telecommunications After the Space WARC’ (Doctoral thesis, McGill University, 1989) 345 <https://central.bac-lac.gc.ca/.item?id=TC-QMM-75947&op=pdf&app=Library&oclc_number=897816738> accessed 20 October 2025, stating that while radio-frequency signals may travel to the Earth from a telecommunications satellite in space, the signals themselves originate on Earth and are merely relayed back through the satellite; accordingly, they do not qualify as outer space resources.

³⁷⁰ John Zuzek, ‘Spectrum Allocations and Interference in Scientific Services’ (RFI 2022 Workshop, 2022) <https://events.ecmwf.int/event/258/contributions/2863/attachments/1536/2775/RFI2022_Zuzek.pdf> accessed 20 October 2025; International Telecommunication Union, ‘ITU-R: Managing the radio-frequency spectrum for the world’ (ITU, April 2025) <<https://www.itu.int/en/mediacentre/backgrounders/Pages/itu-r-managing-the-radio-frequency-spectrum-for-the-world.aspx>> accessed 20 October 2025.

Nonetheless, the majority of scholars continue to classify the entire radio-frequency spectrum as a natural resource, albeit largely on legal rather than physical grounds.³⁷¹ As De Man notes, the explicit language of binding international instruments should not be disregarded simply because it does not correspond neatly with physical and scientific classifications.³⁷² The designation of radio frequencies as natural resources in ITU instruments – despite diverging from the term’s conventional physical meaning – indicates that such provisions must be considered when interpreting the concept of “natural resource” within the framework of international law, particularly in justifying international coordination, scarcity management, and equitable access under the ITU regime.

While radio frequencies may be regarded as natural resources by virtue of their classification in binding international legal instruments, they cannot be treated in the same legal manner as mineral deposits or orbital positions under the principles of space law. The functional orientation of international space law does not negate its spatial dimension. “Radio waves, whose existence as a physical phenomenon relies on their artificial generation, merely use outer space on of many possible medium, without, however, forming part of it. It follows that the use of the resource is not immediately affected by the fundamental provisions on the use of outer space, as it is not part of the space law’s scope in the same way that outer space and its celestial bodies are”.³⁷³ Accordingly, the regulation of radio frequencies falls primarily within the domain of telecommunications law rather than space law in the strict sense. The ITU Radio Regulations allocate frequency bands to various services, many of which serve terrestrial functions and are not exclusively reserved for space-related activities. Consequently, radio frequencies are not governed by space law principles such as non-appropriation, but by the rules of telecommunications law, unless specific space-based uses bring them under the orbit of space law.³⁷⁴

³⁷¹ European Science Foundation, Committee on Radio Astronomy Frequencies (CRAF) ‘Handbook for Radio Astronomy’ (3rd edn 2005) 18 <<https://craf.eu/wp-content/uploads/2015/02/CRAFhandbook3.pdf>> accessed 20 October 2025; Marvin S Soroos, ‘The Commons in the Sky: The Radio Spectrum and Geosynchronous Orbit as Issues in Global Policy’ (1982) 36(3) *International Organization* 665, 676.

³⁷² Ibid.

³⁷³ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 143.

³⁷⁴ Ram S. Jakhu and Joseph N Pelton, *Global Space Governance: An International Study* (Springer, 2017) 163-165.

At the same time, even if (active) radio frequencies do not originate from space or qualify as natural resources under space law, interference via radio waves can still directly disrupt and affect activities that are governed by space law – such as satellite operations or scientific missions. Therefore, Article IX OST remains applicable. Since the OST aims to protect space activities from harm, what matters is the effect of the interference on space operations, not the origin. From a functionalist perspective, it is irrelevant whether harmful interference originates on Earth or in outer space – the determining factor is its impact on space activities.

CHAPTER III. De lege lata – The legal status of Earth’s orbits under space law

International space law is a relatively new field.³⁷⁵ While other areas, such as diplomatic and consular law, international humanitarian law, or the Law of the Sea having evolved from ancient practices and customs into well-defined areas of modern public international law, international space law began to emerge as a distinct field of public international law in the mid-20th century, coinciding with the beginning of the space age with the launch of Sputnik 1 in 1957.³⁷⁶

Although there is no official definition of space law, there is a common understanding among scholars of space law that one can distinguish between space law in a wider sense and space law in a narrower sense (or international space law). For instance, Gyula Gál defines space law in its broader sense as encompassing all national regulations and private international law, that pertain to space activities or their effects.³⁷⁷ In contrast, Manfred Lachs, one of the most prominent space law scholars, emphasizes the international nature of space law, defining it as the “law meant to regulate relations between states to determine their rights and duties resulting from all activities directed towards outer space and within it”.³⁷⁸ If only the latter perspective would be adopted, the sources of space law would be limited exclusively to instruments of international law. However, as non-state entities have emerged as key players in outer space activities – particularly since the emergence of the New Space movement since the 2010s – many scholars now argue that legal sources beyond those governing inter-state relations must also be considered under international space law.³⁷⁹ Building on this broader conceptual framework, the present analysis considers not only the binding sources of

³⁷⁵ As Gyula Gál, one of the earliest scholars dealing with international space law, noted in 1964, [space activity] is an entirely novel type of human activity, the regulation of which is aimed at by space law”. See: Gyula Gál, *Space law* (A. W. Stijhoff and Akadémiai Kiadó 1969) 16.

³⁷⁶ Frans Von der Dunk, *Advanced Introduction to Space Law* (Edward Elgar 2020) 8–9; Thomas Neger and Edith Walter, ‘Space Law—an Independent Branch of the Legal System’ in Christian Brünner and Alexander Soucek (eds.) *Outer Space in Society, Politics and Law* (Springer 2011) 234, 234–45.

³⁷⁷ Gyula Gál, *Space law* (A. W. Stijhoff and Akadémiai Kiadó 1969) 36.

³⁷⁸ Manfred Lachs, *The International Law of Outer Space: An Experience in Contemporary Law-Making* (Martinus Nijhoff, 1972 (2012 reprint) 33.

³⁷⁹ Tanja Masson-Zwaan and Mahulena Hofmann, *Introduction to Space Law* (5th edn, Wolters Kluwer 2024) 6.

international law but also the contributions of national legislation and soft law instruments to the protection of the orbital space environment. Nonetheless, rather than applying a treaty-by-treaty examination, this chapter adopts a thematic approach. Accordingly, the analysis begins by examining the current governance of two of the most commonly used orbital regions – LEO and GEO – and the associated legal challenges under the five international space law treaties and the relevant soft law instruments developed by UNCOPUOS. It then turns to the regulatory framework of the ITU, before concluding this chapter with an assessment of the question of non liquet.

A. Sources of space law

1. Binding sources of space law

It is widely recognized that the sources of general international law are articulated in Article 38 of the Statute of the International Court of Justice (ICJ).³⁸⁰ Despite its broad acceptance, Article 38 has also faced significant criticism from experts in international law.³⁸¹ Nonetheless, it undeniably serves as the essential starting point for any discussion on the sources of international law.³⁸² According to Article 38 paragraph 1, the traditional primary

³⁸⁰ The ICJ Statute was crafted mainly to outline the composition, function, and jurisdiction of the Court, with Article 38 guiding the Court on the sources it may use to determine the content of international law. Nevertheless, it has come to be recognized as a general guide for identifying the sources of international law. See: International Court of Justice (ICJ) Statute, 26 June 1945, 33 UNTS 993, entered into force: 24 October 1945 art 38.

³⁸¹ Article 38 of the ICJ Statute has been criticized for several reasons, some of them are: when listing the subsidiary sources of international law, it equates judicial decisions with the writings of publicists, despite the greater influence of judicial decisions in practice. Furthermore, there is a discrepancy between the English and French texts, with "subsidiary" in English and "auxiliary" in French having different connotations. Additionally, Article 38 of the ICJ Statute, apart from minor changes, is a verbatim repetition of Article 38 of the Statute of the Permanent Court of International Justice (PCIJ), the predecessor of the ICJ, adopted in 1920. Thus, not only the period between 1920 and 1945 but also the years since 1945 have witnessed significant changes in the structure, nature, and composition of the international legal community. For more on the topic, see for example: Alain Pellett and Daniel Müller, 'Article 38' in Zimmermann, Andreas, et al. (eds) *The Statute of the International Court of Justice: A Commentary* (3rd edn, Oxford Commentaries on International Law 2019) 819-962.

³⁸² The relevance of Article 38 has extended beyond the parameters of the ICJ and is viewed as the basis for the study of sources of international law. Accordingly, "each provision is essential to the understanding of international law". See: Imogen Saunders, *General Principles as a Source of International Law: Art 38(1)(c) of the Statute of the International Court of Justice* (Hart Publishing 2020) 1.

sources of international law are (a) international conventions [or treaties];³⁸³ (b) customary international law;³⁸⁴ and (c) general principles of law recognized by civilized nations.³⁸⁵ While Article 38 (1) of the ICJ Statute lists the sources without establishing a formal hierarchy, contemporary scholarship generally recognises that, although international treaties formally bind only their parties, they have nonetheless become the predominant sources of international law.³⁸⁶ This de facto primacy reflects their treaty-based nature, which, provides explicit state consent, offers greater specificity than customary international law, and can facilitate systematic development of legal regimes. The treaty predominance is equally evident in space law, where the five core space treaties form the foundational legal framework of outer space activities.³⁸⁷ Nevertheless, the enduring significance of customary international law remains

³⁸³ Under Article 2 of the Vienna Convention on the Law of Treaties ‘treaty’ means “an international agreement governed by international law and concluded in written form: (i) between one or more states and one or more international organizations; or (ii) between international organizations, whether that agreement is embodied in a single instrument or in two or more related instruments and whatever its particular designation”. See: Vienna convention on the law of treaties of 23 May 1969, entered into force 27 January 1980, 1155 UNTS 131 [hereinafter: Vienna Convention on the law of treaties] art 2.

³⁸⁴ Customary international law is binding on all states in the international community (with the exception of ‘persistent objector states’). A customary rule requires the presence of two sine qua non elements: 1) an objective element: a relatively uniform and constant state practice; and 2) a psychological or subjective element (or *opinio juris sive necessitates*): the belief that states behave in a certain way because they are convinced that it is binding upon them to do so. To learn more about customary international law, see for example: ILC, *Draft conclusion on identification of customary international Law* (Report of the International Law Commission on the Work of its Seventieth Session, UN Doc A/73/10, 2018) 118-122; ICJ, *Military and Paramilitary Activities in and against Nicaragua case* (Nicaragua v. United States of America) [1986] ICJ Reports 14 para 73; ICJ, *North Sea Continental Shelf case*, (Germany v. Denmark) (Merits) [1969] ICJ Rep 3, paras 70-77; Maurica H. Mendelson, *The Formation of Customary International Law* (1998) 272 The Hague Academy Collected Courses Online 155, 155-400; International Law Association, *Statement of Principles Applicable to the Formation of General Customary International Law*, Final Report of the Committee on the Formation of Customary (General) International Law (London Conference, 2000) 1-66 <https://www.ila-hq.org/en_GB/documents/conference-report-london-2000-2> accessed 20 October 2025.

³⁸⁵ General principles of international law are regarded as the most debated sources listed in the ICJ Statute. Even among those who acknowledge such principles, there is disagreement on whether they should be interpreted as principles of international law or as principles derived from domestic and particularly private procedural law (e.g., principle of good faith, or *res judicata*). To learn more: Herczegh, Géza, ‘Az általános jogelvek kérdése a Nemzetközi Bíróság Statutuma szerint’ [The question of general principles of law according to the Statute of the International Court of Justice] (1961) 4 (1-2) Állam- És Jogtudományi Intézet Értesítője 195; Giorgio Gaja, *General Principles in the Jurisprudence of the ICJ* in Mads Andenas, Malgosia Fitzmaurice, Attila Tanzi and Jan Wouters (eds.) *General Principles and the Coherence of International Law* (Brill 2019) 35, 35-43.

³⁸⁶ See for example: James Crawford, *Brownlie’s Principles of Public International Law* (9th edn, Oxford University Press 2019) 24; Malcolm N. Shaw, *International Law* (6th edn, Cambridge University Press 2008) 93; Anthony Aust, *Modern Treaty Law and Practice* (2nd edn, Cambridge University Press 2013) 12-14.

³⁸⁷ As Jakhu, Freeland and Chen argue, “the foundation of international space law is essentially conventional in nature, as it has been initiated and developed by international treaties primarily negotiated through the UN system”. See: Ram S. Jakhu, Steven Freeland and David Kuan-Wei Chen, ‘The Sources of International Space Law: Revisited’ (17 March 2021) 67(4) *German Journal of Air and Space Law (Zeitschrift für Luft- und Weltraumrecht)* 606, 612.

undeniable on both general international law and space law. The fundamental international space law treaty, the Outer Space Treaty (OST) is now widely regarded as reflecting principles of customary international law, particularly through several of its provisions that reiterate and codify norms established under earlier, consequential United Nations General Assembly resolutions.³⁸⁸ These principles are pivotal, binding not only States Parties to the OST and subsequent treaties but, in fact, all states, insofar as they are recognised as customary international law.³⁸⁹ Nevertheless, the extent to which certain OST provisions create obligations applicable to all states remains a matter of debate. Space lawyer, Setsuko Aoki calls for a careful assessment of whether customary international law rules truly exist since the beginning of the Space Age for example, particularly when many countries have remained silent or acquiescent.³⁹⁰ Indeed, Aoki asserts, “the safe conclusion seems to be that it is not clear whether the first few years of space activities by a few nations could be enough to establish a rule of customary international law”.³⁹¹ The expert concurs that her argument in fact underscores the significance of the Outer Space Treaty. Accordingly, by January 2025, 116 states, including nearly all spacefaring nations, had ratified or acceded to the OST.³⁹² As a result, the distinction between a rule being customary international law or treaty-based has little impact on the OST's application according to Aoki.

Over a period of just about a decade, the UN General Assembly successfully negotiated the five outer space treaties, establishing the basic principles and rules of today's international

³⁸⁸ The four main UNGA resolutions preceding the adoption of the OST are: UNGA, Recommendations concerning international respect for the right of peoples and nations to self-determination, UN Doc. A/RES/1314 (XIII) of 12 December 1958; UNGA, International co-operation in the peaceful uses of outer space, UN Doc. A/RES/1472 (XIV) of 12 December 1959; UNGA, International co-operation in the peaceful uses of outer space, UN Doc. A/RES/1721 (XVI) of 20 December 1966; and UNGA Resolution, Declaration of Legal Principles Governing the Activities of States in the Exploration and Use of Outer Space UN Doc. A/RES/1962 (XVIII) of 13 December 1963.

³⁸⁹ A great example of the creation of customary international law in space law, according to Manfred Lachs is related to the principle of free passage. As by not objecting to Sputnik I, Lachs contended, the United States began shaping customary international law of overflight of another state's territory in space. See: Manfred Lachs, *The International Law of Outer Space: An Experience in Contemporary Law-Making* (Martim Nijhoff, 1972 (2012 reprint) 15 and 131. For more on customary international law in space law, see: Stephan Hobe, and Kuan-Wei Chen, 'Legal status of outer space and celestial bodies' in Ram S. Jakhu and Paul Stephen Dempsey (eds.) *Routledge Handbook of Space Law* (Routledge 2016) 25, 26.

³⁹⁰ See: Setsuko Aoki, 'Outer Space Treaty and Fundamental Principles' in Sandeepa Bhat B., Dilip Ukey, and Adithya Variath (eds) *International Space Law in the New Space Era: Principles and Challenges* (Oxford University Press 2024) 66, 71.

³⁹¹ *Ibid.*, 71.

³⁹² UNCOPUOS, 'Status of International Agreements relating to activities in outer space' (1 January 2025) UN Doc. A/AC.105/C.2/2025/CRP.9.

space law.³⁹³ Among the five treaties, the first one, the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space Including the Moon and Other Celestial Bodies (commonly known as the Outer Space Treaty, or OST),³⁹⁴ drafted by the COPUOS and adopted by the UN General Assembly is widely regarded as the “constitution of outer space and the foundation of the international legal regime governing outer space activities”.³⁹⁵ The Outer Space Treaty does not only establish the fundamental principles but also the guiding philosophy for the governance of outer space. Later, within 12 years, the general principles of the Outer Space Treaty were further detailed in four binding instruments addressing rescue and return, liability, registration, and the use of the Moon and other celestial bodies.³⁹⁶ Similar to numerous other aspects of the Outer Space Treaty, the Rescue Agreement of 1968, the Liability Convention of 1972, the Registration Convention of 1975, and the Moon Agreement of 1978 have garnered widespread acceptance. These subsequent treaties contain specific provisions largely emanating from – but not always mirroring – the general principles of the OST. In case of inconsistency, the provisions of the subsequent treaties prevail over the ones in the OST, for those states that are parties to each of the treaties, due to the *lex specialis derogat legi generali*, as well as the *lex posterior derogat legi priori* legal doctrines.³⁹⁷

³⁹³ See for example: Manfred Lachs, *The International Law of Outer Space: An Experience in Contemporary Law-Making* (Martinus Nijhoff, 1972 (2012 reprint); Gyula Gál, *Space law* (A. W. Stijhoff and Akadémiai Kiadó 1969); Cheng, Bin, *Studies in International Space Law* (Oxford, 1997); George T Hackett, *Space Debris and the Corpus Iuris Spatialis* in Marietta Benkő (ed in cooperation with Willem de Graaff) *Forum for Air and Space Law* (Editions Frontieres 1994); Ram S Jakhu, and Joseph N Pelton, *Global Space Governance: An International Study* (Springer, 2017); Francis Lyall and Paul B Larsen, *Space Law: A Treatise* (3rd edn, Routledge 2025); Tanja Masson-Zwaan and Mahulena Hofmann, *Introduction to Space Law* (5th edn, Wolters Kluwer 2024); Martha Mejía-Kaiser, *The Geostationary Ring, Practice and Law* (Brill | Nijhoff 2020); Jonathan Verschuuren, *Principles of Environment Law* (Nomos 2003); and Frans Von der Dunk, *Advanced Introduction to Space Law* (Edward Elgar 2020).

³⁹⁴ Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, 27 January 1967, 610 UNTS 205, 18 UST 2410, TIAS No. 6347, 6 ILM 386 (entered into force on 10 October 1967) [hereinafter: Outer Space Treaty].

³⁹⁵ Ram S. Jakhu, ‘Legal Issues Relating to the Global Public Interest in Outer Space’ (2006) 32(1) *Journal of Space Law* 31, 31.

³⁹⁶ Agreement on The Rescue of Astronauts, The Return of Astronauts and The Return of Objects Launched into Outer Space of 22 April 1968 (entered into force 3 December 1968), 672 UNTS 119 [hereinafter: Rescue Agreement]; Convention on International Liability for Damage Caused by Space Objects of 29 March 1972 (entered into force 1 September 1972), 961 UNTS 187 [hereinafter: Liability Convention]; Convention on registration of Objects Launched into Outer Space of 14 January 1975 (entered into force 15 September 1976), 1023 UNTS 15 [hereinafter: Registration Convention]; and Agreement governing the Activities of States on the Moon and Other Celestial Bodies of 18 December 1979 (entered into force 11 July 1984) 1363 UNTS 21 [hereinafter: Moon Agreement].

³⁹⁷ Vienna Convention on the Law of Treaties, Art 31(3)(a).

As the third primary source of international law, two of the most widely recognized general principles of international law that have great relevance to the regulation of the exploration and use of outer space, are identified by the three space law experts, Jakhu, Freeland and Chen as good faith (*bona fides*) and of equity.³⁹⁸ Good faith obligations, including cooperation, information sharing, and the reciprocal nature of rights and freedoms (prohibition of abuse of rights, or harmful interference) also form the fundamental basis of the space regime.³⁹⁹ These obligations implicitly demand that the right to explore and use outer space be exercised in good faith and not in ways that impede or harm the rights of other states.⁴⁰⁰ Equity, on the other hand, often referred to as a general principle of law,⁴⁰¹ seeks to consider and balance the differing, and sometimes conflicting interests of states at various stages of economic development, while also addressing the needs of both present and future generations.⁴⁰² In the management of radio frequencies and orbits for example, the ITU Constitution emphasizes that such benefits derived from outer space's natural resources should be shared equitably.⁴⁰³ It mandates consideration of the "special needs" of certain countries in the use of outer space.⁴⁰⁴ This approach marks a significant departure from the traditional first-come, first-served mechanism that has long characterized space law, particularly in relation to the use of LEO. Nevertheless, the practical implications and scope of this potential divergence will be analysed later in this chapter, especially when addressing the ITU regulatory framework.

Alongside the three primary sources of international law identified in the ICJ Statute, *jus cogens* (peremptory norms) occupy a significant position, as they prevail over and may invalidate conflicting rules from the primary sources. Indeed, the Vienna Convention on the Law of Treaties of 1969 provides that an international treaty is to be void 'if at the time of its

³⁹⁸ See for example: Ram S. Jakhu, Steven Freeland and David Kuan-Wei Chen, 'The Sources of International Space Law: Revisited' (17 March 2021) 67(4) *German Journal of Air and Space Law (Zeitschrift für Luft- und Weltraumrecht)* 606, 631-635.

³⁹⁹ *Ibid.*, 632.

⁴⁰⁰ See for example Outer Space Treaty, art I, stipulating that exploration and use of outer space shall „be carried out for the benefit and in the interest of all countries”.

⁴⁰¹ ICJ, *Continental Shelf (Tunisia v. Libyan Arab Jamahiriya)* [1982] ICJ Rep 18, para 71.

⁴⁰² Ram S. Jakhu, Steven Freeland and David Kuan-Wei Chen, 'The Sources of International Space Law: Revisited' (17 March 2021) 67(4) *German Journal of Air and Space Law (Zeitschrift für Luft- und Weltraumrecht)* 606, 633.

⁴⁰³ ITU Constitution, art 44(2).

⁴⁰⁴ The allocation of radio frequencies and geostationary orbital slots based on the needs of ITU Member States is a prime example of equity in space law. See: International Telecommunication Union (ITU), *Radio Regulations* (rev WRC-19, ITU 2020) articles 11.1-11.8.

conclusion, it conflicts with a peremptory norm of general international law”.⁴⁰⁵ The International Law Commission (ILC), in drafting the Vienna Convention on the Law of Treaties, diplomatically avoided providing a comprehensive list of jus cogens norms. Instead, it highlighted examples such as the prohibitions on the use of force, the threat of force, genocide, and piracy.⁴⁰⁶ As international law experts observe, peremptory norms operate as a form of public order, safeguarding the integrity of the international legal system from laws, acts, or transactions that are fundamentally incompatible with its core values.⁴⁰⁷ Thus, jus cogens norms are indispensable precisely because they protect the legal interests shared by the international community and preserve the coherence and legitimacy of the international legal order.⁴⁰⁸ Space law scholars, such as Jakhu, Chepelka and Gilmour argue that space law, too, encompasses such peremptory norms, including the freedom principle and the non-appropriation principle.⁴⁰⁹ Following the introduction of relevant soft law instruments, both principles will be analysed in the subsequent sections.

⁴⁰⁵ Under Article 64, if a new peremptory norm of general international law emerges, any existing treaty which is in conflict with that norm becomes void and terminates. This rule of jus cogens also applies in the context of customary international law. See: Vienna convention on the law of treaties art 64; and Malcolm N. Shaw, *International Law* (6th edn, Cambridge University Press 2008) 123-128.

⁴⁰⁶ Yearbook of the International Law Commission 1966, Vol II (United Nations Publication) 20-23.

⁴⁰⁷ Alexander Orakhelashvili, *Peremptory Norms in International Law* (Oxford University Press 2008) 10.

⁴⁰⁸ Yevgeniya Oralova, ‘Jus Cogens Norms in international Space Law’ (2015) 6(6) *Mediterranean Journal of Social Sciences* 421, 422.

⁴⁰⁹ According to Jakhu, four key principles enshrined in the Outer Space Treaty — the principle of exploration and use of outer space for the benefit of all peoples (Article I, Para. 1); the principle of freedom of exploration and use of outer space (Article I, Para 2); the prohibition of national appropriation of outer space (Article II) and the obligation to consider the interests of all other states in outer space activities (Article IX) — embody elements of *global public interest* and constitute jus cogens norms. Similarly, in 1970, Cepelka and Gilmour suggested that two groups of jus cogens norms apply to outer space: one based on non-appropriation and the other on free access to outer space. See: Ram S. Jakhu, ‘Legal Issues Relating to the Global Public Interest in Outer Space’ (2006) 32(1) *Journal of Space Law* 31, 48; and Cestmir Cepelka and Jamie H. C Gilmour, ‘The application of general international law in outer space’ (1970) 36(1) *The Journal of Air Law and Commerce* 30, 46-49; Yevgeniya Oralova, ‘Jus Cogens Norms in international Space Law’ (2015) 6(6) *Mediterranean Journal of Social Sciences* 421, 423-426.

2. International soft law instruments

*“In any case, it [soft law] is very often the best method of rule-making available”.*⁴¹⁰

Although soft law instruments are not recognized as formal sources of international law under the ICJ Statute, they nevertheless play a significant role. In the context of space law, and particularly within the broader shift towards governance, soft law serves several vital functions.⁴¹¹ Soft law instruments help clarify how states should fulfil their core obligations under the *corpus juris spatialis* and provide guidance on the expected standards or responsible behaviour. Indeed, the evolution of international space law has been significantly shaped by the proliferation and broad acceptance of soft law instruments, particularly United Nations General Assembly (UNGA) resolutions.⁴¹² These include, for example, the resolutions on Direct Television Broadcasting, on Remote Sensing of the Earth from Space, and on the Use of Nuclear Power Sources in Outer Space. Although these UNGA Resolutions are not legally binding, they express *opinio juris* of states and can thus develop into customary rules.⁴¹³

Technical guidelines of non-binding norms, in particular, can offer practical direction and foster consensus. The UNCOPUOS LTS Guidelines, for example is a milestone document, as it codified, for the first time, an internationally accepted set of best practices for the protection of the Earth’s orbits as limited resources. Furthermore, the LTS Guidelines was adopted by 92 COPUOS States members – including the largest spacefaring nations – showing wide appreciation of the urgency of addressing the issue. Despite the non-binding nature of the LTS Guidelines under international law, space law and policy experts emphasize that: 1) the existing United Nations treaties and principles on outer space provide the fundamental legal framework within which the LTS Guidelines operate; and 2) the LTS Guidelines may acquire

⁴¹⁰ Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff, 2008) 245.

⁴¹¹ Beyond formal law, space governance increasingly relies on soft law, standards, and best practices. This shift reflects an effort to supplement treaty frameworks with more flexible mechanisms capable of addressing new technologies and activities not expressly covered by existing agreements. See: P.J. Blount, ‘A Network of Governance’, in P.J. Blount and Mahulena Hofmann (eds.) *Space Law in a Networked World* (Brill, 2023) 3, 9.

⁴¹² States may favour soft law instruments because they entail fewer legal consequences, bypass the need for domestic ratification, provide greater flexibility, and can be more easily amended or supplemented. See: Alan Boyle and Christine Chinkin, *The Making of International Law* (Oxford University Press 2007) 214.

⁴¹³ Stephan Hobe, ‘Article I’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns, 2009) 167, 172.

a legal character insofar as states choose to incorporate elements of them into national legislation. Whether this multilateral voluntary instrument – and its 21 guidelines – will be sufficient to incentivize the global space community, including COPUOS Member States, as well as governmental and non-governmental actors more broadly, in a timely manner, or whether a more “hard-law” approach will ultimately be required, remains an open question.

It is also important to highlight that even though the LTS Guidelines recognizes the current growing development relevant to large constellations in its preamble, it misses to seriously address the need for the overall consolidation of the rapid and uncontrolled exploitation of LEO by large constellations. Moreover, while the LTS Guidelines represent a significant step forward in addressing space sustainability and space debris, their development and adoption were protracted. Crucially, their non-binding, voluntary nature poses a challenge: it allows both operators and states to act as free riders – benefiting from the responsible conduct of others without making equivalent contributions themselves.⁴¹⁴

Another key non-binding instrument in the area of space debris mitigation is the Space Debris Mitigation Guidelines of the Inter-Agency Space Debris Coordination Committee (IADC), first published in 2002.⁴¹⁵ The IADC is an international governmental forum comprising national space agencies and one international intergovernmental organization, the European Space Agency (ESA) established to coordinate global efforts addressing both human-made and natural debris in space.⁴¹⁶ The Guidelines are the product of a multi-year consensus-building process among member agencies, aimed at establishing internationally accepted best practices for limiting the creation of debris in the space environment.

The IADC Guidelines organize mitigation measures into two broad categories: those aimed at reducing the near-term generation of debris, and those that seek to minimize long-term risks. The former includes practices to reduce mission-related debris and prevent accidental break-ups during operations. The latter focuses on end-of-life disposal procedures designed to remove inactive spacecraft and launch vehicle stages from densely populated

⁴¹⁴ The free rider dilemma will be addressed more in Chapter IV of this document.

⁴¹⁵ The IADC Guidelines have undergone minor updates, reflecting evolving technical understanding and operational experience. See the development: IADC, ‘Space Debris Mitigation Guidelines’ (Initial version, Mar 2002); (Revision 1, Sept 2007); (Revision 2, Mar 2020); (Revision 3, June 2021); UNCOPUOS, ‘Inter-Agency Space Debris Coordination Committee (IADC), Space Debris Mitigation Guidelines’ (Revision 4, January 2025) UN Doc. A/AC.105/C.1/2025/CRP.9 (2025) 2.

⁴¹⁶ Ibid., 4.

orbital regions, thereby preserving the viability of critical orbital environments. Despite their technical comprehensiveness, the IADC Guidelines are not legally binding, nor do they include any formal enforcement or compliance mechanism. Nonetheless, many states have voluntarily incorporated the IADC Guidelines into their national legal and regulatory frameworks, thereby elevating their practical relevance and influence on operational behaviour in space.

In response to emerging challenges, particularly the proliferation of large satellite constellations in low Earth orbit (LEO), the IADC published in September 2017 a dedicated Statement on Large Constellations, which was significantly revised and expanded in July 2021.⁴¹⁷ While not formally extending the IADC Guidelines, this Statement offers detailed technical guidance on how the existing mitigation framework should be applied to the design and operation of large-scale satellite systems. Together, the IADC Guidelines and related instruments such as the Large Constellations Statement represent key normative tools in the evolving architecture of space sustainability governance.

B. The freedom principle applicable to the Earth's orbits

The broadest and most fundamental principle of the outer space legal regime is often referred to as the 'freedom principle'. This principle is articulated in Article I of the Outer Space Treaty and derives from the notion of the 'province of all mankind', set out in Article I(1) OST, which will be examined further in the discussion of the limits of the freedom principle.

According to Aoki, Article I "establishes one of the most critical principles in the exploration and use of outer space",⁴¹⁸ furthermore, Hobe, Schmidt-Tedd and Schrogl in their Commentary characterizes Article I as the most important and the most disputed provisions of the OST.⁴¹⁹ Essentially, Article I is not only binding on parties to the Treaty but is also

⁴¹⁷ IADC, 'Statement on Large Constellations of Satellites in Low Earth Orbit' (2021).

⁴¹⁸ Setsuko Aoki, 'Outer Space Treaty and Fundamental Principles' in Sandeepa Bhat B., Dilip Ukey, and Adithya Variath (eds.) *International Space Law in the New Space Era: Principles and Challenges* (Oxford University Press 2024) 66, 72.

⁴¹⁹ Stephan Hobe, 'Article I' in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 167, 171.

considered customary international law⁴²⁰ (or to some, a general principle of international law).⁴²¹ Some scholars further contend that the freedom principle has achieved the status of a *jus cogens* norm in international space law.⁴²²

Article I of the OST provides:

“The exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind.

Outer space, including the moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind, on a basis of equality and in accordance with international law, and there shall be free access to all areas of celestial bodies.

There shall be freedom of scientific investigation in outer space, including the moon and other celestial bodies, and States shall facilitate and encourage international co-operation in such investigation.”

Article I of the Outer Space Treaty sets a permissive and enabling tone to the Treaty. It affirms the right of states – and other subjects of international law – to engage in space activities, guaranteeing the freedom to: i) explore outer space; ii) use of outer space; and iii) conduct scientific investigations in outer space.⁴²³ According to Hobe and Chen, the term

⁴²⁰ Jakhu, Ram S., ‘Legal Issues Relating to the Global Public Interest in Outer Space’ (2006) 32(1) *Journal of Space Law* 31, 48.

⁴²¹ According to Gál, freedom of outer space enjoys a constant recognition in international law theory as well as international practice. Consequently, the principle of the freedom of outer space appears as a universally accepted norm, a general principle of common international law with a binding force. See: Gyula Gál, *Space law* (A. W. Stijhoff and Akadémiai Kiadó 1969) 140.

⁴²² Tare Brisibe, ‘Customary International Law, Arms Control and the Environment in Outer Space’ (2009) 8(2) *Chinese Journal of International Law* 375, 375-393; Ruwantissa Abeyratne, *Space Security Law* (Springer, 2011) 56-57; Valérie Kayser, *Launching space objects: issues of liability and future prospects* (Kluwer, 2001) 25-26; Ricky J. Lee, *Law and regulation of commercial mining of minerals in outer space* (Springer 2012) 124-126; Ram S. Jakhu, ‘Legal Issues Relating to the Global Public Interest in Outer Space’ (2006) 32(1) *Journal of Space Law* 31, 48.

⁴²³ A fourth freedom can also be recognized, as highlighted in Article I, paragraph 2 of the Outer Space Treaty. Hobe, Schmidt-Tedd, and Schrogl describe this as a reaffirmation and strengthening of the three core freedoms,

"freedom" signifies that all entities addressed by these provisions have the right to conduct the above activities in outer space without needing permission from other states or international bodies.⁴²⁴ The separation of activities within the OST clearly indicates that the freedoms of exploration, use, and scientific investigation are distinct. One should also keep in mind when dealing with the "three freedoms of space" that emphasizing the distinction among them is not only relevant for categorizing and granting specific freedoms, but also for determining which activities may need to be limited in order to define the precise scope of those freedoms. Yet these freedoms are not explicitly defined; rather they are only broadly articulated in the Outer Space Treaty. As a result, numerous questions emerge concerning the granting of these freedoms, including, which activities fall within the scope of each freedom, and what legal consequences and limitations accompany them. Indeed, as the three space law experts highlight, "any evaluation of the freedoms of outer space can only be made if one has a careful look into the limitations of these rights",⁴²⁵ contained in the Outer Space Treaty and in general international law. This suggests the need for further examination and interpretation to clarify their meaning and to assess their potential legal implications.

1. Free exploration and scientific investigation

Article I paragraph 2 of the OST grants the freedom of exploration and use of outer space including celestial bodies. In the context of exploration and use, 'freedom' means that any entity benefiting from it does not need to seek permission from other governments, instead, they are free to explore and use outer space.⁴²⁶ In interpreting the concepts of use and exploration, one may emphasize Article 31 paragraph 1 of the Vienna Convention on the Law of Treaties (VCLT), which sets out the general principles for the interpretation of a treaty, and

as it extends to the free access to outer space and all areas of celestial bodies. A key aspect of this freedom of access is the ability to establish stations, installations, equipment, and space vehicles on celestial bodies. Under this freedom, however, such facilities must be accessible to everyone on the basis of reciprocity. See: Stephan Hobe, 'Article I' in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns, 2009) 167, 199.

⁴²⁴ Stephan Hobe and Kuan-Wei Chen, 'Legal Status of Outer Space, and Celestial Bodies' in Ram S. Jakhu and Paul Stephen Dempsey (eds.) *Routledge Handbook of Space Law* (Routledge 2016) 25, 31.

⁴²⁵ Stephan Hobe, 'Article I' in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 167, 200.

⁴²⁶ Ibid., 194.ß

has been confirmed to reflect customary international law on several occasions.⁴²⁷ In line with Article 31 of the VCLT,

“A treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose”.⁴²⁸ In line with the VCLT, one should firstly consider the ordinary meaning of the terms, followed by their codification in relevant space treaties.⁴²⁹ In the context of outer space exploration, after carefully considering the ordinary meaning of the term exploration, De Man for example proposes that it should be broadly interpreted to encompass all activities whose main objective is the discovery and understanding of outer space, such as studying celestial bodies like planets or moons.⁴³⁰ Furthermore, it should refer to acts of simple research of or in outer space “with the objective of gaining knowledge without explicitly stated goal of immediate practical application. In the view of Hobe, Schmidt-Tedd and Schrogl, exploration in outer space can be interpreted as the initial phase of use, or “as the activity, through which to find out whether use is possible”.⁴³¹ An additional aspect of exploration worth noting is the challenge in distinguishing between *scientific investigation*, as described in Article I, Paragraph 3 of the OST, and space exploration, as these activities often overlap. While it could be argued that every scientific investigation also involves an element of exploration, not all exploration activities are driven by scientific inquiry.⁴³² Thus, the Outer Space Treaty’s explicit mention of scientific investigation demonstrates the particular importance assigned to this activity within the broader concept of exploration.

The object and purpose of the OST, reflected in its Preamble, are essential to interpreting key terms such as “exploration, and “use”. The Preamble establishes that outer

⁴²⁷ See, for example, ICJ, *Territorial Dispute (Libyan Arab Jamahiriya v Chad)* [1994] ICJ Rep 6 para 41; ICJ, *Maritime Delimitation and Territorial Questions (Qatar v Bahrain)* [1995] ICJ Report 6, para 33; ICJ, *Legal Consequences of the Construction of a Wall in the Occupied Palestinian Territory (Advisory Opinion)* [2004] ICJ Rep 136, para 94.

⁴²⁸ Vienna convention on the law of treaties art 31 para 1.

⁴²⁹ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 78.

⁴³⁰ *Ibid.*, 78.

⁴³¹ Stephan Hobe, ‘Article I’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 167, 194.

⁴³² As per the Cologne Commentary, the two phrases, exploration and scientific investigation, determine different activities with respect to outer space activities. Exploration is the general finding out of something yet to be explored, which may or may not include scientific activity. See: Stephan Hobe, ‘Article I’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 167, 195.

space exploration and use must serve peaceful purposes, promote international cooperation, and must be carried out for the benefit of all nations regardless of their economic or scientific development. From this, it follows that the term “exploration” should not be understood narrowly as merely scientific discovery or physical travel through space. Instead, its interpretation must align with the broader goals of the Treaty. Exploration thus encompasses a range of activities – including research, observation, and technology development; that contribute to the common interest of humanity. A teleological interpretation of the OST therefore requires that all space activities, including commercial ventures such as satellite constellations, be assessed against the Treaty’s overarching aim to safeguard equitable access and peaceful use of outer space for the benefit of all.

2. Free use and exploitation

Turning to the next freedom, the free *use* of space, according to the Cologne Commentary, “all kinds of activities that purport to make use of space in one way or another, including (...) the usage of satellites may be covered by the legal regime of the use of outer space”.⁴³³ De Man explores the concept of “use” in outer space, describing it as activities that involve leveraging a particular segment of space with an actionable objective – whether economic, commercial, civil, or military – that extend beyond the segment itself.⁴³⁴ Thus, resources such as orbital slots represent a shift from exploration to utilization of outer space itself. Here, states exploit the unique physical properties of space, rather than investigating celestial bodies, to provide services and conduct commercial activities.

Indeed, legal scholarship establishes that “use” under the OST encompasses both non-economic and economic activities,⁴³⁵ including commercial exploitation of space resources. The Treaty therefore permits non-scientific use of natural resources. Moreover, according to De Man, this interpretation is further supported by the legislative history and preparatory works of the Outer Space Treaty. Delegates have emphasized that the term “use” should not be limited

⁴³³ Stephan Hobe, ‘Article I’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 167, 196.

⁴³⁴ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 80.

⁴³⁵ *Ibid.*, 82.

to “exploration” alone, but should also encompass “exploitation”, reflecting the established practices of utilizing outer space for meteorology, direct broadcasting, navigation, and telecommunication for instance.⁴³⁶ Indeed, the primary way states have engaged in outer space, both during the drafting of the Outer Space Treaty and today, is through the placement of artificial satellites in Earth's orbit. Prohibiting such activities would contradict established state practice and undermine the OST's functional purpose. Economic use of outer space (including the use of the orbits) may encompass the exploitation of outer space and celestial bodies with the aim of generating economic profit.⁴³⁷ This approach stands in stark contrast to the legal regime of governing Antarctica, for example. As another *area beyond national jurisdiction*, Antarctica permits limited economic activities such as tourism but strictly prohibits mining and resource extraction.⁴³⁸ Moreover, it is also viewed by the majority of space law experts that Article I of the OST grants states the freedom to utilize outer space – for both economic and non-economic purposes –, while Article VI extends this right to non-governmental entities (while ensuring their activities are conducted under the supervision of their respective governments).

Nevertheless, the term “exploitation” is not just a synonym for “use”.⁴³⁹ The question, whether *exploitation* of natural resources and commercial uses of outer space are part of the freedom to use outer space has been a topic of debate. By considering the ordinary meaning of “exploitation”, dictionaries typically distinguish between a positive (or neutral sense), and a pejorative sense. In the positive or neutral sense, “to exploit” means to make use of or derive

⁴³⁶ Not surprisingly, all these activities use frequency bands and orbital positions as limited natural resources. See for example, the Summary record of the sixty-third meeting of the Legal Subcommittee of the Committee on the Peaceful Uses of Outer Space, held on 20 July 1966, UN. Doc. A/AC.105/C.2/SR.63 (20 October 1966), 8; See also the delegate's remarks in Summary record of the sixty-ninth meeting of the Legal Subcommittee of the Committee on the Peaceful Uses of Outer Space, held on 27 July 1966, UN. Doc. A/AC.105/C.2/SR.69 (21 October 1966), 5–6.

⁴³⁷ See, for example, E. FASAN, “Basic principles regarding the celestial bodies”, 6 Proc. Coll. L. Outer Space 1963; C.Q. Christol, “The common heritage of mankind provision in the 1979 Agreement governing the activities of states on the Moon and other celestial bodies”, 14 Int'l Law. 1980; Jakhu, Ram S., ‘The legal regime of the geostationary orbit’ (Doctoral thesis, McGill University, 1983) 151

⟨<https://escholarship.mcgill.ca/concern/theses/bg257f82k>⟩ accessed 20 October 2025; Stephan Hobe, ‘Article I’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 167, 195.

⁴³⁸ Protocol on Environmental Protection to the Antarctic Treaty (Environmental Protocol) of 4 October 1991, entered into force 14 January 1998, 2941 UNTS 5778, art 7.

⁴³⁹ Interestingly, Tronchetti emphasizes the exploitative nature of space resource use in space, suggesting that the terms ‘use’ and ‘exploitation’ can be considered synonymous. See: Fabio Tronchetti, *The exploitation of natural resources of the Moon and other celestial bodies: a proposal for a legal regime* (Martinusoff, 2009) 223.

benefit from resources, assets, skills, or opportunities.⁴⁴⁰ In contrast, the pejorative sense of “to exploit” involves taking wrongful advantage of another person for one’s own gain at the unfair expense of others.⁴⁴¹ It specifically refers to using something in a way that extracts value, usually economic value. Exploitation of outer space therefore encompasses activities that yield material or economic benefit, such as commercial satellite services, telecommunications, and remote sensing. The fundamental tension thus emerges: “how do we account for the exploitation of natural resources in light of the non-appropriation provision?”⁴⁴² As De Man argues, “it is clear that, if Article I OST allows the use of natural resources while Article II OST proscribes their appropriation, the only solution can be found in the differentiation of exploitation from appropriation”.⁴⁴³

It is essential to point out, that the free use and exploitation of space resources – such as orbits and minerals – are only allowed when they comply with the limitations, particularly those outlined in Articles I, III, and IX of the Outer Space Treaty and international law. While Article I of the OST may suggest a broad interpretation of the rights it provides, granting considerable freedom in the use of outer space, this freedom is not without limits.⁴⁴⁴ According to some analysts, the well-known 1927 Lotus case established the so-called Lotus principle,⁴⁴⁵ which suggests that what is not expressly prohibited is permitted under international law.⁴⁴⁶ However, the broader space law community views this presumption of unrestricted freedom as inapplicable in space law. In this domain, the principle of freedom is fundamentally based on

⁴⁴⁰ Susan Marks, ‘Exploitation as an International Legal Concept’ in: Susan Marks (ed.) *International Law on the Left: Re-Examining Marxist Legacies* (Cambridge University Press 2008) 281, 283.

⁴⁴¹ *Ibid.*, 283.

⁴⁴² Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 180.

⁴⁴³ *Ibid.*, 180.

⁴⁴⁴ As Manfred Lachs emphasized, the freedom to use outer space “is neither absolute nor unqualified” but is limited by the right and interest of other states. See: Manfred Lachs, *The International Law of Outer Space: An Experience in Contemporary Law-Making* (Martinus Nijhoff, 1972 (2012 reprint) 117.

⁴⁴⁵ PCIJ, *SS ‘Lotus’ case (France v. Turkey)* [1927] PCIJ Rep 10, 18-20.

⁴⁴⁶ In accordance with the “principle of freedom” established in the Lotus judgement: “It is impossible to hold with the judgment that, over and above positive international law, there is a kind of international law which amounts to this: that the absence of a rule prohibiting an action suffices to render that action permissible (...).” See PCIJ, *SS ‘Lotus’ case (France v. Turkey)* [1927] PCIJ Rep 10, para 225. This argument can be traced back to the idea that states have sovereignty, which cannot be limited except when the state voluntarily agrees. Thus, in the absence of prohibitory rules, every state remains free to adopt the principles which it regards as best and most suitable. See: Mariano J Aznar-Gómez, ‘The 1996 Nuclear Weapons Advisory Opinion and Non Liquefaction in International Law’ (1999) 48(1) *International and Comparative Law Quarterly* 3, 8.

reciprocity.⁴⁴⁷ As is often emphasized, the actions of one spacefaring state or actor can significantly affect the rights and interests of others in using and exploring outer space, making limitations essential.⁴⁴⁸

The inherently lawful nature of exploitation activities in space, therefore, extends to the utilization of natural resources from celestial bodies, as well as from the surrounding space, including orbits and radio frequencies. Moreover, it can be reasoned that since orbits are acknowledged as natural resources and the OST grants a general freedom to use space, this creates an implicit legal foundation supporting the legitimacy of exploiting the orbits as limited natural resources. Furthermore, the widespread participation of many states, along with their non-governmental private entities, strongly supports the notion that such activities are generally permissible. This raises the important question: what are the limitations to these exploitations? Today, we see that several unilateral national policies and activities – particularly the launch of large satellite constellations in LEO – have adopted a first-come, first-served approach. In certain cases, concerns about monopolization also arise as seen in the previous chapter of this thesis. These actions, often justified under the principle of freedom of use, frequently disregard the interests of other states, thus conflicting with the broader global public interest in outer space. Thus, one might ask whether there are valid justifications for limiting or restricting the ongoing deployment and operation of large LEO constellations within the framework of space law and international law.

⁴⁴⁷ It is worth noting that the application of the Lotus principle is not only limited by specific legal restrictions in international law fields like space law, but there is also a broader reluctance to apply this outdated principle in international law, as the 1927 ruling in the Lotus case has been subsequently overturned by later conventions and ICJ judgments. See for example the UNCLOS art. 27, which contains provisions with respect to the exclusive criminal jurisdiction over a ship of the flag state, a rule contrary to that enunciated in the Lotus case. Furthermore, the reasoning of the ICJ held that the absence of an explicit rule in international law prohibiting the use of nuclear weapons does not imply their legality. Instead, the ICJ emphasized that other areas of international law, such as international humanitarian law and environmental law, should be considered to determine the existing legal framework (*lex lata*) regarding the legality or illegality of nuclear weapons in contemporary international society. See: ICJ, *Legality of the Threat or Use of Nuclear Weapons* case [1996] ICJ Rep 226 (Advisory Opinion) 243–44; Ram S. Jakhu, ‘Legal Issues Relating to the Global Public Interest in Outer Space’ (2006) 32(1) *Journal of Space Law* 31, 41; and in Setsuko Aoki, ‘Outer Space Treaty and Fundamental Principles’ in Sandeepa Bhat B., Dilip Ukey, and Adithya Variath (eds.) *International Space Law in the New Space Era: Principles and Challenges* (Oxford University Press 2024) 66, 78.

⁴⁴⁸ Ram S. Jakhu, Steven Freeland and David Kuan-Wei Chen, ‘The Sources of International Space Law: Revisited’ (17 March 2021) 67(4) *German Journal of Air and Space Law (Zeitschrift für Luft- und Weltraumrecht)* 606, 638.

C. Existing limits of the freedom principle

In the realm of space governance, a persistent tension exists between two competing principles, particularly as competition in LEO intensifies. On the one hand, the communitarian principle advocates for the equitable access to outer space, ensuring that all states – whether spacefaring or non-spacefaring – can benefit from its resources and opportunities. On the other hand, the entrepreneurial principle of *first come, first served* posits that those who first explore and exploit space resources should be entitled to the rewards of their efforts. Historically, spacefaring nations have prioritized optimizing the use and exploration of outer space, advancing their technological capabilities to maximize their advantages. In contrast, non-spacefaring states, wary of their potential exclusion from future benefits, have sought to influence space law rulemaking to constrain the activities of spacefaring states and protect their own interests.⁴⁴⁹

As the commercialization of outer space accelerates, private entities have emerged as significant stakeholders, seeking regulatory frameworks that enable their business ventures. These actors advocate for rules that expand their commercial opportunities with minimal governmental interference, while still benefiting from strong governmental support. This evolving dynamic adds complexity to the interplay between the principles of equitable access and commercial expansion, as both state and private actors attempt to shape the future trajectory of space exploration and resource exploitation.⁴⁵⁰

The above tensions are reflected in competing interpretations of the freedom principle and its associated limitations under international space law. While the freedom to explore and utilize outer space is a fundamental aspect of space law, it must be understood within the broader framework of the Outer Space Treaty and international law. The freedoms provided by the OST are not absolute; they are circumscribed by specific limitations, including the restrictions enshrined in Article I OST, other relevant treaty obligations, and general principles

⁴⁴⁹ Nina Tannenwald, 'Law versus power on the high frontier: The case for a rule-based regime for outer space' (2004) 29(9) *The Yale Journal of International Law* 363, 371.

⁴⁵⁰ Steven Freeland, 'Opinion: Reconciling Commercial Space Activities with the Foundational Principles of Space Law' (*Space Watch Global*, October 14, 2021) <<https://research.bond.edu.au/en/publications/spacewatchgl-opinion-reconciling-commercial-space-activities-with/>> accessed 20 October 2025.

of international law. Balancing these freedoms against their limitations remains central to outer space governance, particularly concerning the exploitation of finite LEO orbital capacity.

1. The province of all mankind principle

“Although the articles of the Outer Space Treaty that are designed to protect against the exploitation of resources by powerful states instruct states to share their gains equally, deeper analysis demonstrates that it does not provide a satisfactory safeguard”.⁴⁵¹

The freedom principle can be derived from the fact that outer space is considered the “province of all mankind” stating in Article 1 para 1 of the Outer Space Treaty with the legal regulation of human activities in areas beyond the jurisdiction of any state.⁴⁵² It is important to clarify, however, that it is not the physical domain of outer space itself – extending above national airspace and continuing infinitely outwards – that constitutes the province of all mankind as set out in Article I OST, but rather the activities of “exploration and use” addressed in the Outer Space Treaty. Scholars note that a common misconception frames outer space – whether understood as the void or as celestial bodies – as collectively owned by humanity.⁴⁵³ In reality, space is not owned by any state or entity. What, the OST guarantees is the freedom of exploration and use of outer space, including celestial bodies, for all States Parties. Although commentators sometimes characterise space as *res communis*, the legal reality is that outer space is not subject to appropriation but is instead freely accessible for peaceful purposes under international law. Indeed, even the full title of the OST – *Treaty on the Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies* – underscores this point. While the instrument is commonly referred to

⁴⁵¹ Henry Padden, ‘Does Space Law Prevent Patterns of Antarctic Imperialism in Outer Space?’ (2022) 13 *Global Policy* 346, 353.

⁴⁵² Stephan Hobe, ‘Article I’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 167, 173-178.

⁴⁵³ Henry Hertzfeld, Brian Weeden and Christopher Johnson, ‘How Simple Terms Mislead Us: The Pitfalls of Thinking about Outer Space as a Commons’ (International Astronautical Congress, Jerusalem, October 2015) IAC-15 - E7.5.2 x 29369, 3-4.

simply as the Outer Space Treaty, such shorthand can downplay a key aspect of the Treaty: its explicit emphasis on both exploration and use of outer space. These terms are deliberately included in the title to underscore that states are expressly entitled to engage in both activities under the Treaty's provisions.⁴⁵⁴

The province of all mankind principle further entails that activities in outer space and on celestial bodies cannot be pursued for the exclusive benefit of individual states. Fundamentally, this principle emphasizes placing certain limits on state freedoms to ensure that the advantages of outer space remains accessible to all humanity. This non-discrimination aspect is also present in paragraph 2 of Article I of the OST and highlights that exploration and use of outer space shall be undertaken without discrimination of any kind on a basis of equality. Hobe, Schmidt-Tedd, and Schrogl also suggest that the repeated emphasis on non-discrimination in paragraphs 1 and 2 of Article I underscores the principle that space exploration and use should benefit all nations. This means that every country should share in the advantages of these activities, aligning with the ultimate goal of the province of all mankind principle, which emphasizes the communal nature of space endeavours.⁴⁵⁵

In the context of space activities, the phrase province of all mankind remains undefined within the formal text of the OST and the other space law sources. While interpretations may be offered through broader international legal discourse or non-legal literature, such sources carry limited authority for treaty interpretation due to their absence from the treaty's own language or its preparatory works. For instance, Merriam-Webster describes "province" as an "administrative district or division of a country".⁴⁵⁶ Or Collis English Dictionary defines province as "a territory governed as a unit of a country or empire".⁴⁵⁷ These definitions, provide little clarity on the specific rights or obligations the phrase implies under space law. It therefore remains an open question whether province of all mankind principle imposes substantive legal duties or merely carries aspirational significance, akin to the descriptive phrase "envoys of all

⁴⁵⁴ Ibid., 3-4.

⁴⁵⁵ Stephan Hobe, 'Article I' in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 167, 207.

⁴⁵⁶ 'province' in Merriam-Webster Dictionary <https://www.merriam-webster.com/dictionary/province> accessed 20 October 2025.

⁴⁵⁷ 'province' in Collins English Dictionary, 2012 edn. <https://www.dictionary.com/browse/province> accessed 20 October 2025.

mankind” applied to astronauts.⁴⁵⁸ Nevertheless, its prominent placement – at the very beginning of Article I – suggests that the principle was intended to carry more than symbolic value. Considering the freedoms granted elsewhere in Article I and throughout the Treaty, the term, “province” appears to reflect a forward-looking vision: one that frames outer space exploration and use as a shared endeavour of all humankind, with benefits to be accessible to all states and their peoples.⁴⁵⁹ This interpretation aligns the phrase with the Treaty’s overarching objective of equitable access and peaceful cooperation.

Rights come with certain obligations and limitations. The province of all mankind theory, however, offers little guidance for what limits and to what extent of obligation may exist to the freedom principle – and especially of free use – of outer space. At the same time, despite its deficiencies and ambiguity, the language of the adopted space law provisions remains the most accurate representation of the principles – including the specific limitations of freedom of use – guiding the legal regime of outer space activities.⁴⁶⁰

2. The common interest clause

International space law establishes reciprocal rights and obligations for states, where the freedoms of one state are primarily limited by the corresponding freedoms of others, regardless of their current ability to participate in space activities.⁴⁶¹ States, thus expected to exercise their freedoms in space in a way that does not unduly interfere with the ability of other states to engage in similar activities even in the future. The foundational principles outlined in the OST reinforce this mutual interdependence, which sets the boundaries for lawful activities in space.⁴⁶²

Jakhu emphasizes the inclusive or "the global public interest" in outer space as a key objective of space law and governance, an understanding recognized by the international

⁴⁵⁸ Henry Hertzfeld, Brian Weeden and Christopher Johnson, ‘How Simple Terms Mislead Us: The Pitfalls of Thinking about Outer Space as a Commons’ (International Astronautical Congress, Jerusalem, October 2015) IAC-15 - E7.5.2 x 29369, 4.

⁴⁵⁹ Ibid., 4.

⁴⁶⁰ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 33.

⁴⁶¹ Manfred Lachs, *The International Law of Outer Space: An Experience in Contemporary Law-Making* (Martinus Nijhoff, 1972 (2012 reprint) 105.

⁴⁶² Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 77.

community through its adoption of the Outer Space Treaty. Accordingly, the OST and its legal framework guarantee that all nations have the right to access outer space freely and without discrimination.⁴⁶³ To preserve this right, states, along with their non-governmental entities and intergovernmental organizations, must exercise restraint and adhere to limitations applicable to their space activities. Furthermore, as Jakhu observes, the OST is not merely a collection of idealistic aspirations without legal implications; rather the intention of the drafters was to establish binding obligations. Jakhu argues that the Treaty's principles, including the common interest clause "must be interpreted as legally authoritative norms that govern international relations in all matters relating to outer space".⁴⁶⁴ It is even claimed by the expert that the equal benefit principle constitutes an *erga omnes* obligation.⁴⁶⁵

Additionally, under this provision, countries shall benefit "irrespective of their degree of economic or scientific development".⁴⁶⁶ The objective of Article I appears clear: by calling attention to the essential needs of mankind and emphasizing the importance of cooperation, it sought to require states to cooperate internationally in their space ventures. What remains unclear, however, is the extent of the obligation involved.⁴⁶⁷

The issue of *monopolization* is a fundamental matter in terms of limiting the freedom of use, especially in terms of (over)exploitation of LEO. One may even argue that monopolization can be regarded as the abuse of the freedom principle, as it fails to show due regard for the interests of other states.⁴⁶⁸ The concern about prolonged resource exploitation, such as the monopolistic or excessive use of valuable orbits by one country or entity, could potentially infringe on both the freedom principle and the common interest clause. Specifically,

⁴⁶³ Ram S. Jakhu, 'Legal Issues Relating to the Global Public Interest in Outer Space' (2006) 32(1) *Journal of Space Law* 31, 31-32.

⁴⁶⁴ *Ibid.*, 34.

⁴⁶⁵ In discussing space activities, distinguished space law scholars Jakhu, Freeland, and Chen emphasize that the practices of major spacefaring nations do not hold more weight than those of states without spacefaring capabilities. This is because the 1967 Outer Space Treaty, particularly under Articles I and II, establishes fundamental and binding principles that create *erga omnes* obligations. These principles ensure that the exploration and use of outer space must be conducted for the benefit and in the interest of all countries, regardless of their level of economic or scientific development. See: Ram S. Jakhu, Steven Freeland and David Kuan-Wei Chen, 'The Sources of International Space Law: Revisited' (17 March 2021) 67(4) *German Journal of Air and Space Law (Zeitschrift für Luft- und Weltraumrecht)* 606, 624.

⁴⁶⁶ Outer Space Treaty article I, paragraph 1.

⁴⁶⁷ Nandasiri Jasentuliyana, *International Space Law and The United Nations* (Brill | Nijhoff 1999) 174.

⁴⁶⁸ Jakhu, Ram S., 'The legal regime of the geostationary orbit' (Doctoral thesis, McGill University, 1983) 167 <<https://escholarship.mcgill.ca/concern/theses/bg257f82k>> accessed 20 October 2025.

if one party were to monopolize or heavily dominate key orbits or resources, it could undermine the idea that outer space is open and accessible to all.⁴⁶⁹ Although outer space and celestial bodies are not subject to national appropriation under Article II of the Outer Space Treaty (and under customary international law), irrespective of scale or intensity, it is not Article II that specifically prohibits monopolization of the use or exploitation of orbital space as a resource. Rather, such conduct is understood to violate Article I (2) of the OST.⁴⁷⁰ Article I OST asserts that space shall be free for exploration and use by all states and emphasizes that space activities must be conducted for the benefit of all countries. If the monopolistic or continuous use of space resources by one party were to effectively exclude others from accessing or utilizing these resources, it would contradict the inclusive freedom guaranteed by Article I. Therefore, proving such a violation would require demonstrating that the monopolistic behaviour impedes the fundamental principle of free and equal access to outer space for all states as set out in Article I. Determining the threshold of monopolization of orbital space and LEO, however, is especially challenging. Several factors contribute to this difficulty, including the lack of clear data and measurements regarding the *carrying capacity* of LEO, the constantly evolving nature of orbital space due to the ongoing deployment of new satellites and missions,⁴⁷¹ and the escalating risks to space operations as the use of LEO continues to expand.

To address, for instance, the persistent problem of *paper satellites*, De Man links potential violations of Article I with those of Article II.⁴⁷² According to De Man, one would need to demonstrate that such monopolistic and continual use violates Article I OST, which requires that space activities be conducted for the benefit of all states and not for the exclusive benefit of one (common interest clause). Furthermore, paper satellites diminish the availability of valuable orbital slots without contributing to their actual use, thus infringing on the

⁴⁶⁹ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 344.

⁴⁷⁰ Kai-Uwe Pritzsche, *Natürliche Ressourcen im Weltraum – das Recht ihrer wirtschaftlichen Nutzung* (Peter Lang, 1989) 106; Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 196-197.

⁴⁷¹ Here one may also consider the chaotic and cascading effect of just one accident in orbital space, that may change the whole orbital ecosphere.

⁴⁷² In addition to the concerns about violating Articles I and II of the Outer Space Treaty, De Man also argues that separating exclusion from actual use undermines the qualification of the orbit-frequency spectrum as a limited natural resource under Article 44(2) of the International Telecommunication Union Constitution. This qualification emphasizes the need for rational, efficient, and economical use of this resource. For further details, see Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 344. The ITU's regulatory framework is explored in greater depth later in this chapter.

prohibition of national appropriation and potentially violating the principle of equitable use of space resources (Article II OST).

The Outer Space Treaty itself contains a range of additional limitations beyond those in Article I, each addressing different aspects of space activities. When these are compared to Article I, they typically focus on the consequences of space activities (such as military use, liability for damage, or assistance to astronauts), rather than on ensuring that the benefits of space exploration and use are shared by all nations, which is the concentration of Article I. In other words, Article I's limitations can be argued to apply broadly to all space activities, including governmental and non-governmental actors, emphasize non-discrimination and equal access to space, and aim at inclusivity. While other Articles deal more with specific legal, safety, or cooperative issues arising from space activities. The challenge lies in interpreting how all these limitations relate to one another, as they serve different purposes.⁴⁷³

3. Non-appropriation principle

*“But it was more easy to take
Possession of Jurisdiction only,
over some Part of the Sea,
without any Right of Property”.*⁴⁷⁴

One of the defining limitations to the freedom principle can be found in Article II of the Outer Space Treaty. The “non-appropriation principle” reinforces the important concepts of freedom of exploration and use, by confirming that principles of territorial sovereignty, unlike on Earth, do not apply to outer space.⁴⁷⁵ Under Article II of the OST:

“Outer space, including the moon and other celestial bodies, is not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means.”

⁴⁷³ Stephan Hobe, ‘Article I’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 167, 209.

⁴⁷⁴ Hugo Grotius, *The Rights of War and Peace* (Jean Barbeyrac and Richard Tuck eds. Liberty Fund 2005) book II, chapter III, para. XIII.

⁴⁷⁵ Ram S. Jakhu and Steven Freeland, ‘Article II’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 221, 230.

Article II not only embodies the practices of states since the dawn of the space age but also plays a crucial role in preventing conflicts that could arise from territorial claims and ambitions in outer space.⁴⁷⁶ Moreover, given its declaratory nature and inclusion in unanimously adopted United Nations General Assembly Resolutions and the Outer Space Treaty, one could argue that Article II has attained the status of a *jus cogens* norm of international law.⁴⁷⁷

The application of the non-appropriation principle to orbital positions was not initially accepted universally. Developing states, in the 1976 Bogotá Declaration (as previously discussed), explicitly asserted that the geostationary orbit should not be regarded as part of outer space.⁴⁷⁸ They argued that Article II OST did not apply to this orbit. In 1977, Colombia further rejected the binding nature of Article II, denying its peremptory character under Article 53 of the Vienna Convention on the Law of Treaties, on the grounds that it had not been recognized as such by the international community. The stance of the equatorial states gradually evolved, as they progressively moved away from asserting sovereign claims over GEO in international forums.⁴⁷⁹ In 2000, Columbia acknowledged before COPUOS that access to the orbit should occur in an equitable manner and in accordance with the ITU Radio Regulations.⁴⁸⁰ Subsequently, in 2001, COPUOS reached consensus that GEO forms part of outer space.⁴⁸¹

By stipulating that countries and individuals cannot appropriate any area in outer space or on celestial bodies, these regions are designated as international (global) commons, or areas beyond the limits of national jurisdiction, akin to the high seas, the deep seabed, and, to some extent, Antarctica. Although the precise interpretation of these provisions remains contested, it

⁴⁷⁶ See, for example, discussion of the anti-colonial nature of Article II OST in: Thomas Cheney, Alessandra Marino, and Thomas Cheney, 'Centring Environmentalism in Space Governance: Interrogating Dominance and Authority Through a Critical Legal Geography of Outer Space' (2023) 63 *Space Policy* 1, 2.

⁴⁷⁷ Ram S. Jakhu and Steven Freeland, 'Article II' in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 221, 248-249; Laura Mac Garry, and Steven Freeland, 'What Place for Jus Cogens? How Manfred Lachs Foresaw New Thinking in International Space Law' (2022) 46(2) *Journal of Space Law* 260, 288.

⁴⁷⁸ UNCOPUOS, 'Verbatim Record of the 173rd Meeting' UN. Doc. A/AC.105/PV.173 (1977) 56 <https://www.unoosa.org/pdf/transcripts/copuos/AC105_PV173E.pdf> accessed 20 October 2025.

⁴⁷⁹ Martha Mejía-Kaiser, *The Geostationary Ring, Practice and Law* (Brill | Nijhoff 2020) 105.

⁴⁸⁰ UNCOPUOS, Report of the Legal Subcommittee on Its Thirty-Ninth Session, UN. Doc A/AC.105/738 (2020) Annex III para 8 <<https://www.unoosa.org/pdf/reports/ac105/LGLR00E.pdf>> accessed 20 October 2025.

⁴⁸¹ UNCOPUOS, Report on Its Forty-Fourth Session, UN. Doc. A/56/20 (2001) para 126 <https://www.unoosa.org/pdf/gadocs/A_56_20E.pdf> accessed 20 October 2025.

is unequivocally clear that any form of territorial claim – whether in outer space through the permanent positioning of satellites in particular orbital positions, or on celestial bodies – is invalid and prohibited.⁴⁸²

In terms of appropriation by way of “use”, the term, *use* must be understood in light of Article I OST, which extends the freedom principle to activities involving the use of outer space. Since Article II OST states that outer space is not subject to appropriation through use, no amount of usage can ever legally justify a claim of ownership over any part of outer space, including the orbits and the Moon and other celestial bodies. This means that, for instance, the exploitation of orbital positions and radio frequencies as natural resources qualifies as a *use* of outer space under the freedom principle outlined in the Outer Space Treaty, subject to the conditions set by other space treaties. However, in the context of Article II, such *use* can never be considered national appropriation that would grant ownership rights. However, drawing a clear line between “lawful use as exploitation” and “unlawful appropriation by use” remains a complex and challenging task. Temporary use or regulated extraction that does not infringe upon the core prohibition on sovereignty or permanent control may qualify as lawful utilization of space resources. Nevertheless, this complexity does not undermine the fundamental legal principle of non-appropriation. It may therefore be argued that the prolonged use of radio-frequency spectrum and orbital positions – where such use amounts to appropriation or *de facto* *occupation* resulting in exclusive control – would be considered unlawful.⁴⁸³

Another key issue concerning the non-appropriation principle and the exploitation of natural resources, particularly on celestial bodies, is the applicability of the Moon Agreement (MA). The limited ratification of the Moon Agreement has frequently been used as an excuse to overlook its provisions when addressing various issues in international space law, with discussions often defaulting to the general principles of the Outer Space Treaty – even in matters concerning the exploitation of celestial resources. The Agreement has faced such

⁴⁸² Stephan Hobe, *Space law* (Nomos/Beck/Hart 2019) 69-70.

⁴⁸³ According to De Man, resolving the interpretive tension between lawful and unlawful use does not depend on drawing legal distinctions between material and immaterial resources, nor on applying different standards to celestial bodies and outer space *sensu stricto* (the physical void beyond celestial bodies, such as the orbital regions). Rather, it is *inclusivity* that serves as the normative benchmark for distinguishing between these two forms of use. For De Man, inclusivity requires that access to outer space and its resources remain open to all states, and that no actor may use or manage space resources in a manner that excludes others or undermine equitable participation. See: Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 211.

criticism that some scholars have even argued it should not be considered part of international law.⁴⁸⁴ However, the Agreement was unanimously adopted on 18 December 1979 and entered into force on 11 July 1984, making it a valid and binding international treaty for over 40 years. Its provisions, therefore, must be respected, at least, *inter partes* (*res inter alios acta*) – by the states that have chosen to be bound by it. This recognition underscores the continued legal relevance of the Agreement for those signatory states, regardless of its broader lack of ratification. Moreover, the MA has been signed, though not yet ratified, by several influential spacefaring nations, including France and India. According to the Vienna Convention on the Law of Treaties, these signatory states are at least bound to refrain from actions that would undermine the object and purpose of the Agreement, unless they formally notify their intent to not proceed with ratification.⁴⁸⁵ This creates an obligation to act in good faith toward the principles outlined in the Moon Agreement, even if full ratification has not been completed. Thus, the Moon Agreement helps specify, explain and expand on the rules of the Outer Space Treaty, particularly for those states that have ratified or signed it. This underscores the need for careful and holistic interpretation of these treaties when examining space law and the management of natural resources.

There are two key points in the Moon Agreement that contributed to its lack of popularity – the declaration that the Moon and other celestial bodies are the “common heritage of mankind” (CHM),⁴⁸⁶ and the related proposal to establish an ‘international regime’ to manage these areas, especially relevant to the “equitable sharing by all States Parties in the benefits derived from those resources”.⁴⁸⁷ The CHM concept, apart from its articulation in the Moon Agreement, appears in only a limited number of fields of public international law, as

⁴⁸⁴ See for instance, in, Michelle LD Hanlon, ‘The Moon Agreement—A Swan Song’, in Sandeepa Bhat B., Dilip Ukey, and Adithya Variath (eds.) *International Space Law in the New Space Era: Principles and Challenges* (Oxford University Press 2024) 143, 143, where the Moon Agreement is being referred to as a “swan song”; or in David Johnson, ‘Limits on the giant leap for mankind: legal ambiguities of extraterrestrial resource extraction’ 26(5) *American University International Law Review* (2011) 1477, 1481, Johnson describes the Moon Agreement “practically useless due to its failure to gain significant backing from major spacefaring nations.”

⁴⁸⁵ Vienna Convention on the Law of Treaties, article 18.

⁴⁸⁶ The ‘common heritage of mankind’ (CHM) principle in the Moon Agreement and the ‘province of all mankind’ concept in the Outer Space Treaty both address areas beyond national jurisdiction. However, while the province of all mankind principle acknowledges the global significance of these areas and allows for diverse forms of governance, the CHM principle goes further. The latter stipulates that these areas should be managed for the benefit of all humanity, requiring international cooperation and regulation to ensure responsible use and preservation for future generations.

⁴⁸⁷ Moon Agreement, art. 11, para. 3-7.

previously discussed – most notably in relation to minerals in the deep seabed, under Part XI of the 1982 UN Convention on the Law of the Sea (UNCLOS), and the subsequent 1994 Agreement.⁴⁸⁸

Although the Moon Agreement specifically addresses the Moon and does not directly cover Earth's orbits,⁴⁸⁹ principles and goals could still shape the development of international norms and regulations for managing LEO. The MA's emphasis on cooperation, sustainability, and equitable access could guide efforts to promote a collaborative approach to orbit utilization and address issues such as space debris and space traffic management. However, it is important to recognize that states are likely to continue to be hesitant to commit to multilateral treaties, reluctant to adopt the common heritage of mankind principle in this context, and cautious about the international distribution of space resources.

4. Compliance with international law

According to Article III of the Outer Space Treaty, all activities in outer space must be carried out “in accordance with international law, including the Charter of the United Nations”.⁴⁹⁰ While international law generally applies to all state activities, including those conducted in outer space, the explicit affirmation of this principle in the space treaties removes any ambiguity regarding the obligation of states to comply with international law in their space operations. This clarity is important for upholding global legal norms and principles, which are essential for maintaining order and fostering cooperation, especially in the increasingly congested and competitive space environment. Additionally, such explicit references can provide a solid foundation for developing more specific space regulations and guidelines, ensuring they align with established international legal principles and contribute to a cohesive and comprehensive legal framework for space activities.

⁴⁸⁸ See: UNCLOS art 137 and UNGA Agreement relating to the implementation of Part XI of the United Nations Convention on the Law of the Sea, UN Doc A/RES/48/263 of 28 July 1994.

⁴⁸⁹ The Moon Agreement mentions the orbit from the perspective of the moon, when it states that “States Parties shall not place in orbit around or other trajectory to or around the moon objects carrying nuclear weapons or any other kinds of weapons of mass destruction or place or use such weapons on or in the moon.” See: Moon Agreement, article 3, para 3.

⁴⁹⁰ Outer Space Treaty, article III.

Regarding the sustainability of orbital space, obligations arising not only from space law but also from international environmental law may be applicable.⁴⁹¹ With the rapid increase in satellite launches, the environmental impact of both launch and re-entry activities on the Earth's atmosphere has become a growing concern. In this regard, the United Nations Framework Convention on Climate Change⁴⁹² and the Paris Agreement⁴⁹³ – sources of international environmental law, containing both binding and soft law provisions – are generally applicable.⁴⁹⁴ With respect to potential ozone depletion, the applicable treaty framework – namely, the Vienna Convention for the Protection of the Ozone Layer and its associated Montreal Protocol – currently does not regulate emissions resulting from launch and re-entry activities. As a result, states are not yet legally required to address such emissions through national regulatory measures. Nevertheless, the Montreal Protocol remains a dynamic legal instrument, regularly updated to reflect emerging emission sources. Increasingly, there are calls to expand its scope to include emissions from space activities that contribute to ozone layer degradation.

In addition, general principles of international environmental law, including sustainable development, equity, due diligence, precaution, common but differentiated responsibilities, the polluter-pays principle, and the prohibition of abuse of rights, also apply.⁴⁹⁵ Notably, Principle 21 of the 1972 Stockholm Declaration,⁴⁹⁶ and Principle 2 of the 1992 Rio Declaration⁴⁹⁷ establish that states must ensure that activities within their jurisdiction or control do not cause

⁴⁹¹ Lesley James Smith, and Susan-Gale Wintermuth, 'Ensuring space sustainability through national space legislation', in Lesley James Smith, Ingo Baumann, & Susan-Gale Wintermuth (eds.) *Routledge Handbook of Commercial Space Law* (Routledge 2023) 533, 534.

⁴⁹² United Nations Framework Convention on Climate Change, 9 May 1992, 31 ILM 849 (UNFCCC Framework Convention).

⁴⁹³ Paris Agreement to the United Nations Framework Convention on Climate Change, Dec. 12, 2015, TIAS. No. 16-1104 (Paris Agreement).

⁴⁹⁴ This framework establishes long-term objective to guide all nations in reducing global greenhouse gas emissions and limiting global warming. Each party is responsible for defining its own emission reduction targets, known as nationally determined contributions (NDCs). The extent to which a state includes measures to address emissions from the launch and re-entry of space objects within its NDCs remains at the discretion of the respective contracting party.

⁴⁹⁵ Sergio Marchisio, 'Article IX' in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 551, 574; Jonathan Verschuuren, *Principles of Environment Law* (Nomos 2003) 77.

⁴⁹⁶ 'Declaration of the United Nations Conference on the Human Environment' UNGA Res 2994 (15 December 1972) UN Doc. A/RES/2994 (Stockholm Declaration).

⁴⁹⁷ 'Rio Declaration on Environment and Development' in Report of the United Nations Conference on Environment and Development, Rio de Janeiro, Brazil, 3-14 June 1992, vol I, UN Doc. A/CONF.151/26 (12 August 1992) (Rio Declaration).

environmental harm to other states or to areas beyond national jurisdiction. While no specific international environmental treaties have yet been adopted to address the environmental risks associated with in-orbit operations, the “no-harm rule” has evolved into a norm of customary international law and is particularly relevant to outer space, which constitutes an area beyond national jurisdiction.

Furthermore, environmental degradation resulting from space activities, affecting both the Earth and outer space, may be interpreted as infringing upon certain human rights, including the right to life and the recently recognised right to a clean, healthy, and sustainable environment.⁴⁹⁸ In this context, Article III OST may also permit the application of human rights law – beyond the environmental obligations already mentioned – to space activities.

5. International responsibility and liability of states

a) Responsibility

Article VI of the Outer Space Treaty may be regarded as a pioneering provision, establishing a framework for addressing the space activities of non-governmental entities through the mechanism of state responsibility. Indeed, Article VI marks a notable departure from general international law, under which a state is typically held responsible only for its own conduct or the activities of agents acting on its behalf.⁴⁹⁹ It introduces a key constraint on the freedom principle by holding appropriate states – typically the state of incorporation –⁵⁰⁰ internationally responsible for national activities in outer space, whether conducted by

⁴⁹⁸ In 2022 the UN General Assembly recognized that a clean, healthy, and sustainable environment is a human right. This followed Res. 48/13 of the UN Human Rights Council, which acknowledged the right in October 2021. See: ‘The human right to a clean, healthy, and sustainable environment’ UNHRC Res 48/13 (8 October 2021) UN Doc. A/HRC/RES/48/13.

⁴⁹⁹ See for example: ILC, ‘Responsibility of States for Internationally Wrongful Acts’ (Report of the International Law Commission on the work of its Fifty-Third Session, UN Doc A/56/10, 2001) arts 4 – 11.

⁵⁰⁰ The obligation to authorize and supervise space activities rests with the “appropriate state”. While the term is not explicitly defined, it is generally understood that the state of incorporation is best positioned to fulfil this role. See for example: Bin Cheng, ‘Article VI of the 1967 Space Treaty Revisited: “International Responsibility”, “National Activity” and “The Appropriate State”’, (1998) 26(1) *Journal of Space Law* 7, 21-22; Tanja Masson-Zwaan and, Mahulena Hofmann, *Introduction to Space Law* (5th edn, Wolters Kluwer 2024) 22.

governmental or non-governmental entities, both prior to and throughout the duration of a mission.⁵⁰¹ Furthermore, this responsibility specifically entails a duty to authorize and continuously supervise such national activities, effectively conditioning the exercise of freedom on a state's capacity to ensure compliance with broader treaty obligations and international law. Accordingly, states are generally expected – and indeed encouraged – to establish a national regulatory framework that incorporates a licensing system to authorize and supervise the activities of non-governmental entities, particularly private actors, seeking to engage in space activities.⁵⁰² Detailed licensing requirements may encompass space debris mitigation or broader sustainability measures, such as incorporating specific design features, ensuring passivation procedures, on-board deorbiting mechanisms, and implementing effective information-sharing protocols to ensure sustainable space operations.

In practice, regulation and enforcement of space sustainability measures derived from interpretations of both binding and soft law instruments and incorporated into national legislation – may curtail or even prohibit certain space activities that invoke the freedom principle under Article I OST, particularly those involving the deployment of large satellite constellations. For example, if a proposed satellite constellation presents a credible risk of harmful interference with other existing space assets – contrary to the obligations under Article IX OST to avoid harmful contamination and interference – a state may lawfully deny the licensing request of a private entity.

⁵⁰¹ State responsibility under Article VI of the Outer Space Treaty can be considered a *lex specialis* to the general doctrine of state responsibility under public international law. The general rule states that every internationally wrongful act that is attributable to the state under international law and constitutes a breach of an international obligation of the state entails the international responsibility of the state, with consequences including cessation and reparations. This general rule is codified in ILC, 'Responsibility of States for Internationally Wrongful Acts' (Report of the International Law Commission on the work of its Fifty-Third Session, UN Doc A/56/10, 2001) and is also considered to reflect customary international law. To learn more, see: James Crawford, *Responsibility: The General Part* (Cambridge University Press 2013) 1-110. The *lex specialis* nature of the OST within the broader framework of state responsibility implies that States Parties bear direct international responsibility for any breaches of the OST by non-governmental entities under their jurisdiction and control. See: Hanhui Zha and Jinyuan Su, 'The "due regard" obligation in the deployment and operation of satellite mega-constellations' (2025) 73 *Space Policy* 1, 2-3 <<https://doi.org/10.1016/j.spacepol.2024.101674>>.

⁵⁰² Ram S. Jakhu and Steven Freeland, 'Article II' in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 221, 241.

b) International liability for damages

Article VII OST establishes international liability of launching states. The launching state⁵⁰³ is liable for damage to another state party or to its natural or juridical persons caused by its space object or its component parts on the Earth, in air or in outer space, including the Moon and other celestial bodies. The Liability Convention complements these provisions by setting out more detailed rules for cases of such damages involving different states.

Importantly, causation is a key factor in determining liability, meaning that there must be a direct connection between the damage and the space object responsible. This is essential for any compensation claims and is required for a state to be held liable for damage caused by its space object. Normally, a clear link between the object and the damage is needed. In some cases, like when a Soviet satellite crashed in Canada (Cosmos 954 Case), the damage being close to the object provides obvious proof, making it easier to show causation.⁵⁰⁴ However, in space, proving causation is more challenging, especially for damage in orbit, as it often requires proving fault, which needs stronger evidence. In cases of indirect damage, it becomes even harder to establish this connection, but it remains necessary to prove the damage is tied to the space object.

Indeed, not all damage caused by a space object happens immediately or in its vicinity. In certain situations, such as with space debris, damage might not manifest until some time has passed. However, as mentioned, for the damage to be attributed to the space object, it must stem – directly or indirectly – from the original event.⁵⁰⁵ If the causal link is broken, the damage can no longer be traced back to the space object. Legal concepts, such as foreseeability and the proximity of the damage, help determine whether indirect damage falls within the scope of the original incident. In principle, if a piece of space debris strikes a spacecraft belonging to another

⁵⁰³ Convention on international liability for damage caused by space objects of 29 March 1972, entered into force 1 September 1972, 961 UNTS 187 (Liability Convention) art. 1: “*The term "launching state" means: (i) A state which launches or procures the launching of a space object; (ii) A state from whose territory or facility a space object is launched*”.

⁵⁰⁴ ‘Settlement of Claim between Canada and the Union of Soviet Socialist Republics for Damage Caused by “Cosmos 954” (JAXA, April 2, 1981) See: https://www.jaxa.jp/library/space_law/chapter_3/3-2-2-1_e.html accessed 20 October 2025.

⁵⁰⁵ Armel Kerrest and Lesley Jane Smith, ‘Article VII’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 437, 480.

state and this results in additional damage to a third state, both the launching state of the debris (if it can be identified) and the state of the impacted (victim) spacecraft are jointly and severally liable for any resulting damage to other states.⁵⁰⁶ For incidents occurring in outer space, liability is based on fault,⁵⁰⁷ while for damage caused on Earth or to aircraft in flight, liability is absolute.⁵⁰⁸

Importantly, it is commonly known that damages caused by a space object to the space environment per se is not covered in any of the space treaties, whether such harm occurs in outer space or on Earth beyond areas under national jurisdiction.⁵⁰⁹ As a result, potential polluters face limited legal accountability for environmental harm – even when such damage is severe – provided that no injury is caused to foreign persons or property. The Liability Convention does not explicitly address environmental concerns such as pollution, focusing instead on direct harm suffered by states or natural or legal persons due to the space activities of others.

Only Article XXI of the Liability Convention offers a possible reference to environmental consequences, mentioning damage caused by space objects that pose “a large-scale danger to human life” or seriously disrupt “the living conditions of the population or the functioning of vital centres”.⁵¹⁰ However, this provision does not establish liability or responsibility; it merely provides for the possibility of “appropriate and rapid assistance” to the affected state upon request.⁵¹¹ Consequently, it has been advised, by some, that the Liability Convention should be revised to address environmental damages caused to outer space itself, irrespective of whether such harm directly affects human interests.⁵¹² Thus, states may be empowered to “exercise an ecological right” to protect outer space for future generations by using its jurisdiction to grant compensation for damages to the space environment. The liability mechanism under international space law operates differently from that applicable in environmental law. However, liability for environmental degradation of the orbital space

⁵⁰⁶ Liability Convention art. IV, para. 1.

⁵⁰⁷ Liability Convention art. IV, para. 1/b.

⁵⁰⁸ Liability Convention art. IV, para. 1/a.

⁵⁰⁹ Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff, 2008) 69.

⁵¹⁰ Liability Convention art. XXI.

⁵¹¹ Liability Convention art. XXI.

⁵¹² See for example: Ouarda Layachi, ‘International Liability for Pollution Damage in Outer Space Environment’ (2020) 16 *WSEAS Transactions On Environment and Development* 149, 156 <<https://www.wseas.com/journals/ead/2020/a305115-052.pdf>> accessed 20 October 2025.

environment (as such, for its own sake) remains unaddressed as it does not fall within the existing definitions of “damage” or an “international wrongful act” under international space law.

Moreover, the vague and ambiguous language of the Liability Convention raises concerns about whether damage caused by space debris is even covered under its provisions. The Convention attributes liability for damage “caused by a space object,” yet Article I(d) merely defines a space object as including “component parts of a space object as well as its launch vehicle and parts thereof.” If space debris were not considered a “space object” within the meaning of the Convention, then the most frequent and dangerous form of harm associated with space activities would be excluded from the scope of international liability, rendering the Convention largely ineffective.⁵¹³ In response to this interpretive gap, some scholars have argued that “anything which has been launched into outer space, whatever its size,” should be regarded as a space object.⁵¹⁴ Others contend that space debris may reasonably be considered a “component part” of a space object. Such interpretations, which prioritize safety and environmental concerns, offer a more practical and contemporary reading of the Convention. In light of the growing threats posed by space debris, treating it as either a space object or part thereof appears to be the only viable approach to ensure that liability mechanisms remain relevant and enforceable.

Another notable factor in the context of liability and the growing use of orbital space is the increasing number of states that require their commercial space operators to carry third-party liability insurance as a condition for operating their space objects.⁵¹⁵ This requirement allows governments to partially recover costs if held liable under the Liability Convention and Article VII OST. However, as the number of satellites in LEO continues to increase, the

⁵¹³ Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff, 2008) 70-71.

⁵¹⁴ See for instance the European Code of Conduct for Space Debris Mitigation which defines space debris as “[a]ny man made space object including fragments and elements thereof, in Earth orbit or re-entering the Earth’s atmosphere, that is non-functional”, and space object as “[a]ny man-made space system and any of its components or fragments” See: European Space Agency, ‘European Code of Conduct for Space Debris Mitigation’ (28 June 2004) 13-14 <https://www.unoosa.org/documents/pdf/spacelaw/sd/2004-B5-10.pdf> accessed 20 October 2025; Also, the UNCOPUOS, Space Debris Mitigation Guidelines, and the IADC Guidelines define space debris as: “all man-made objects, including fragments and elements thereof, in Earth orbit or re-entering the atmosphere, that are non-functional”.

⁵¹⁵ Mathieu Luinaud and Virgile Salmon, ‘The contribution of space objects insurance regulations to space object management’ (2023) 10(1) *Journal of Space Safety Engineering* 112, 115.

associated risks and insurance premiums rise accordingly.⁵¹⁶ With growing probabilities of collisions and other anomalies, there is increasing concern that insurers become more cautious or reduce their exposure in the space market.⁵¹⁷ Consequently, the insurance sector underscores the importance of establishing a renewed cooperative framework of space traffic management, as discussed in the first chapter of this dissertation, and within this context the role of insurance mechanisms as a key component of the incentive structure for commercial space actors.⁵¹⁸

6. Registration and other sharing of information of space objects

The obligation to register space objects, as set out in Article VIII of the Outer Space Treaty and further elaborated in the Registration Convention of 1976,⁵¹⁹ imposes a regulatory framework that conditions access to and use of orbital slots. Furthermore, Article VIII OST stipulates that the state of registry retains jurisdiction and control over any space object and its personnel. Accordingly, jurisdiction and state authority in outer space, similar to the regime applicable on the high seas, are exercised over persons and objects and not territories.⁵²⁰

By mandating that states provide information on the trajectory, function, and ownership of satellites, the registration regime contributes to transparency, coordination, and the avoidance of harmful interference in orbital zones. It thus acts as a safeguard against unregulated activity, helping to prevent and manage congestion, mitigate collision risks, and ensure accountability. In this way, registration serves not merely as an administrative formality, but as a substantive legal mechanism that tempers the open-ended nature of the freedom principle in favour of a more orderly and equitable use of orbital resources.

⁵¹⁶ Hanhui Zha and Jinyuan Su, 'The "due regard" obligation in the deployment and operation of satellite mega-constellations' (2025) 73 *Space Policy* 1, 5 <<https://doi.org/10.1016/j.spacepol.2024.101674>>.

⁵¹⁷ Mathieu Luinaud and Virgile Salmon, 'The contribution of space objects insurance regulations to space object management' (2023) 10(1) *Journal of Space Safety Engineering* 112, 116.

⁵¹⁸ *Ibid.*, 119.

⁵¹⁹ Convention on registration of objects launched into outer space of 14 January 1975, entered into force 15 September 1976, 1023 UNTS 15 (Registration Convention)

⁵²⁰ According to the *legal geography theory*, this can be considered as a thrusting of state power into areas beyond national jurisdiction. The legal geography theory will be discussed more in Chapter IV of this dissertation. See for example: Alessandra Marino and Thomas Cheney, 'Centring Environmentalism in Space Governance: Interrogating Dominance and Authority Through a Critical Legal Geography of Outer Space' (2023) 63 *Space Policy* 1, 5.

Additionally, all rights and obligations that apply to space objects under international space law also extend to small satellites. Nonetheless, the unique characteristics of small satellite operations have prompted the development and interpretation of specific provisions tailored to their use, addressing practical and regulatory challenges within the broader legal framework, such as relevant to registration obligations.⁵²¹

Furthermore, in addressing international environmental challenges, meaningful reassessment requires comprehensive monitoring efforts and close international cooperation in evaluating the resulting data. Consequently, effective information exchange and ongoing, direct communication between scientists and the various national entities responsible for implementing international environmental commitments are indispensable.⁵²² In light of the free rider problem, a key factor influencing states' willingness to comply with collective decisions on the environmental protection of outer space is the assurance that others are equally committed to those efforts.⁵²³ Often, only scientific experts possess the technical capacity to verify such compliance, making transparency and information sharing essential. While, organizing basic transparency mechanisms can be relatively straightforward if there is sufficient political will, addressing more complex environmental challenges may require the establishment of new cooperative frameworks, potentially including entirely new international institutions.⁵²⁴

⁵²¹ There have been initiatives led by organizations such as the ITU and UNOOSA aimed at assisting small satellite developers and operators by providing guidance on matters including registration, authorization, debris mitigation, and frequency management for small and very small satellites. See: UNOOSA & ITU, 'Guidance on Space Object Registration and Frequency Management for Small and Very Small Satellites' (2015) https://www.unoosa.org/documents/pdf/psa/bsti/2015_Handout-on-Small-SatellitesE.pdf accessed 20 October 2025.

⁵²² The IADC exemplifies effective collaboration at the level of space agencies, where participants generally share aligned interests, a mutual understanding of the challenges, and a common technical language. This shared foundation significantly enhances the efficiency of information exchange and consensus-building. Moreover, the IADC Space Debris Mitigation Guidelines stand as a key testament to the success of this cooperative framework. See: IADC Guidelines; See also: Steven A Mirmina, 'Reducing the Proliferation of Orbital Debris: alternatives to a legally binding instrument' (2005) 99(3) *The American Journal of International Law* 649, 660.

⁵²³ Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff 2008) 260.

⁵²⁴ One notable proposal involves creating an international consultative expert body composed of representatives from major space agencies, the private sector, and small-scale operators. This body would serve to examine pressing environmental issues in outer space and promote global awareness. In addition, broader interdisciplinary cooperation has been advocated – bringing together scientists, legal experts, and even ethics committees – to develop a more holistic approach to space pollution. Regardless of the specific institutional form, such cooperative efforts would likely foster mutual trust among stakeholders, laying the groundwork for deeper collaboration and contributing positively to the progressive development of international space law. See: Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff 2008) 260.

7. Due regard principle

*“Due regard is optimal regard; an optimized standard to allow the overall maximal use and exploration of space by all parties”.*⁵²⁵

A particularly important limitation on the freedom to exploration and use of territories – especially those beyond national jurisdiction – and their resources under international law is the principle of *due regard*. The due regard obligation first emerged in the 1944 Convention on International Civil Aviation, also known as the Chicago Convention, or ICAO.⁵²⁶ This treaty stipulates that States Parties must ensure that “state aircrafts” give due regard to the safety of navigation of civil aviation.⁵²⁷ When one considers the ordinary meaning from Marrian Webster Dictionary definition for the expression, “with due regard to”,⁵²⁸ Article 3(d) ICAO can be interpreted as state aircraft shall take “the proper care and concern for” the safety of navigation of civil aircraft. The way this duty of care is exercised depends on the specific circumstances and is assessed on a case-by-case basis.⁵²⁹

The due regard principle has a particular past in the law of the sea context as well. In 1974, the ICJ noted in the Fisheries Jurisdiction cases (United Kingdom v. Iceland, and Federal Republic of Germany v. Iceland)⁵³⁰ that, in response to the intensification of fishing activities,

⁵²⁵ Andrea J Harrington, ‘Due regard as the Prime Directive for Responsible Behaviour in Space’ (2023) 20(1) *University Chicago International Law Review* 57, 69.

⁵²⁶ Sergio Marchisio, ‘Article IX’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 551, 569.

⁵²⁷ Although Article 3 of the ICAO exempts “state aircrafts” (“aircraft used in military, customs and police services”) from the ICAO’s jurisdiction, it requires such aircrafts to fly with due regard for the safety of civil aviation. See: Convention on International Civil Aviation, 7 December 1944, 15 UNTS 295, UN Doc. 7300/9 (ICAO) article 3(d).

⁵²⁸ ‘with due regard to’ in Merriam-Webster.com Dictionary <https://www.merriam-webster.com/dictionary/with%20due%20regard%20to>, accessed 20 October 2020.

⁵²⁹ For example, when a “state aircraft” requests an airways clearance and complies with a controller’s clearances/instructions, it is giving the proper care and concern for the safety of civil aircraft by complying with civil aviation rules. When operating contrary to the ICAO rules, however, using special procedures established by the contracting state (e.g., maintaining a distance from civil aircraft that is less than the separation minimum that controllers apply in the same airspace, as “state aircrafts” may be easier to manoeuvre), the contracting state must still ensure the safety of civil aircraft navigation under to the due regard principle. See: International Federation of Air Traffic Controllers’ Associations (IFATCA), ‘State Aircraft and “Due regard” Operations’ (57th Annual Conference, Accra, Ghana, 19-23 March 2018) Working Paper No 92 <https://ifatca.wiki/kb/working-paper/2018/wp-2018-92/>, accessed 20 October 2025.

⁵³⁰ ICJ, *Fisheries Jurisdiction (UK. v. Iceland)* [1974] ICJ Rep 3, para 72; ICJ, *Fisheries Jurisdiction (Federal Republic of Germany v Iceland)* [1974] ICJ Rep 175, para 64.

a “duty to have due regard to the rights of other states and the needs of conservation for the benefit of all” had replaced the previous “laissez-faire” approach to managing the living resources of the high seas.⁵³¹ With the adoption of the United Nations Convention on the Law of the Sea (UNCLOS) in 1982, the principle of due regard was expressly incorporated into several provisions,⁵³² requiring states to take into account the rights and interests of other states when exercising their own freedoms – thereby imposing a limitation on those freedoms.

The due regard principle is equally pertinent in the context of space activities and serves as an important limitation to the freedom principle contained in Article I OST. The purpose of this limitation is to preserve outer space as a domain of free use for *all*, requiring each state to consider the potential adverse impacts its space activities may have on those of other states. The first sentence of Article IX of the Outer Space Treaty provides that “*States Parties to the Treaty shall be guided by the principle of cooperation and mutual assistance and shall conduct all their activities in outer space, including the Moon and other celestial bodies, with due regard to the corresponding interests of all other States Parties to the Treaty*”.⁵³³ Article IX OST also includes three additional provisions: (1) an obligation to prevent harmful contamination of outer space and detrimental changes to Earth's environment, (2) a requirement for states to seek prior international consultations if their activities might cause potentially harmful interference with other states' activities (active consultation), and (3) the right for a state to request consultations with another state that may interfere with its space activities (passive consultation).⁵³⁴ Besides the duty to respect the freedom of other states to conduct their own space activities without suffering harmful interference, a combined reading of Art

⁵³¹ Caroline E Foster, *Due Regard and Due Diligence, Global Regulatory Standards in Environmental and Health Disputes: Regulatory Coherence* (Oxford University Press 2021) 89.

⁵³² “Due regard” is mentioned 17 times in the UNCLOS. The Montego Bay Convention requires for example that coastal states exercising their rights and performing their duties in the exclusive economic zone have due regard to the rights and duties of other states, see: UNCLOS art 56(2); UNCLOS also stipulates that flag states have due regard to coastal state rights and duties See: UNCLOS art 56(2), 58(3). Equally on the high seas, under UNCLOS, states are to exercise their freedoms with due regard for the interests of other states in their exercise of the freedom of the high seas, and with due regard for rights with respect to activities in the Area. See: UNCLOS art 87(2).

⁵³³ Outer Space Treaty article IX

⁵³⁴ Although Article IX OST, is broadly worded, it nonetheless establishes a consultation framework that includes both an “active” obligation to consult, when a state plans a space activity that may cause harmful interference, and a “passive” right to request consultations if a state believes its own activities may be adversely affected. See: Hanhui Zha and Jinyuan Su, ‘The “due regard” obligation in the deployment and operation of satellite mega-constellations’ (2025) 73 *Space Policy* 1, 2 <<https://doi.org/10.1016/j.spacepol.2024.101674>> accessed 20 October 2025.

IX OST also reveals a further interest that states should take into consideration when undertaking space activities: the obligation to protect the outer space environment.⁵³⁵ Accordingly, Article IX imposes an obligation of due regard, which – depending on the nature of the interest at stake – is owed either to a specific state or collectively to all States Parties to the Treaty.

While Article IX is widely regarded as the foundational provision for environmental protection in the space domain,⁵³⁶ – particularly as it underpins the subject of planetary protection –⁵³⁷ commentators have remarked that it may lack the strong language and specificity necessary to establish binding legal obligations for addressing orbital congestion and pollution.⁵³⁸ While the obligation of due regard is separate from the three additional obligations and right outlined in Article IX, this section focuses primarily on due regard, as it is the mostly relevant to the limitation of the freedom of use of LEO from an environmental approach.⁵³⁹ Nonetheless, it is important to recognize the link between the principles of due regard and the duty to consult, since engaging in consultations can demonstrate that a state has taken the interests of others into account.⁵⁴⁰ Furthermore, one may take into consideration the

⁵³⁵ Elena Carpanelli, ‘Unweaving the Tangled Web: The Due Regard Obligation Under Article IX of the Outer Space Treaty’ (2024) 49(1) *Air & Space Law* 35, 41.

⁵³⁶ Sergio Marchisio, ‘Article IX’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 551, 571.

⁵³⁷ The subject of harmful contamination is widely connected to the topic of planetary protection. According to the Planetary Protection Policy of the Committee on Space Research (COSPAR), the simple act of sending a spacecraft to explore in-situ (directly on its original location) solar system objects can potentially compromise their pristine environment and cause harmful contamination when spacecraft and/or samples are returned to Earth. Avoiding such biological contamination of planetary bodies (forward contamination) is essential in the scientific exploration of our solar system, as is protecting Earth’s environment from the introduction of extraterrestrial matter (backward contamination) from planetary missions. The protection is confined to environmental risks resulting from the introduction of extraterrestrial matter. Space debris, however, does not apply as ‘extraterrestrial matter’, so the prohibition of back contamination is not applicable to it. See: Committee on Space Research (COSPAR), ‘Planetary Protection Policy, For sustainable space exploration and to safeguard our biosphere’ (2024), Available: <https://cosparhq.cnes.fr/cospar-policy-on-planetary-protection/>.

⁵³⁸ Tanja Masson-Zwaan and Mahulena Hofmann, *Introduction to Space Law* (5th edn, Wolters Kluwer 2024) 23

⁵³⁹ “An environmental approach recognizes that (...), having ‘due regard’ for the interests of other states and their nationals requires considering the impact of proposed activities on the environment. See: Alessandra Marino and Thomas Cheney, ‘Centring Environmentalism in Space Governance: Interrogating Dominance and Authority Through a Critical Legal Geography of Outer Space’ (2023) 63 *Space Policy* 1, 5.

⁵⁴⁰ Andrea J Harrington, ‘Due regard as the Prime Directive for Responsible Behaviour in Space’ (2023) 20(1) *University Chicago International Law Review* 57, 60; The general obligation of cooperation in public international law has been operationalized through specific measures, such as information sharing and environmental impact assessment through international law. The ITU coordination procedure for the allocation of GEO frequencies and orbital slots can be regarded as one of the most developed expressions of the general consultation requirement in international space law, aimed at avoiding harmful interference. See: Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff, 2008) 61-62.

general obligation of cooperation in public international law that has been operationalized through specific measures, such as information sharing and environmental impact assessment.⁵⁴¹

The content of the due regard obligation remains difficult to ascertain, leading some to regard it as largely aspirational.⁵⁴² Needless to say, Article IX of the Outer Space Treaty does not define the terms *due regard* or *corresponding interests*. Likewise, other provisions within the broader corpus juris spatialis that invoke the due regard requirement also fail to provide a clear definition.⁵⁴³ It is widely recognized across the space community, however, that due regard remains a limitation to the freedom principle, and the obligation of due regard entails *self-restraint* by States Parties to the OST in their space activities, grounded in the principles of reciprocity and equality of states.⁵⁴⁴ This interpretation may be seen as complementary to the common interest clause articulated in Article I OST, which provides that space activities shall be carried out for the benefit and in the interests of all countries. Taken together, Article I and IX can be understood to require that the exploration and use of outer space be conducted in a sustainable manner – one that avoids causing harmful interference with the present and future activities of all states.⁵⁴⁵ To that end, states are expected to uphold a certain *standard of care* in the conduct of space activities – an obligation which, as argued by Chen, Freeland, and

⁵⁴¹ Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff, 2008) 154.

⁵⁴² Elena Carpanelli, ‘Unweaving the Tangled Web: The Due Regard Obligation Under Article IX of the Outer Space Treaty’ (2024) 49(1) *Air & Space Law* 35, 38.

⁵⁴³ The Moon Agreement for example refers to the expressions due regard in Articles 2, 4, and 15. Furthermore, soft law instruments, such as the Declaration on Legal Principles Governing the Activities of states in the Exploration and Use of Outer Space and the Principles Relating to Remote Sensing of the Earth from Outer Space, both articulate an obligation of due regard, without any definition of the term.

⁵⁴⁴ “States have to tolerate proportionate interference deriving from other states’ use of their respective rights; again, it is a matter of balancing legitimate but colliding interests”. Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff 2008) 154; See also: Setsuko Aoki, ‘How can the principle of due regard be applied to address threats arising from state behaviours with respect to outer space?’ (Presentation to OEWG on Topic 1: Existing international law concerning threats arising from state behaviours with respect to outer space, Agenda item 6(a), First session, Geneva, 9 May 2022) 1 <https://documents.unoda.org/wp-content/uploads/2022/05/Panel1-Setsuko-Aoki_09052022-final.pdf> accessed 20 October 2025; Manfred Lachs, *The International Law of Outer Space: An Experience in Contemporary Law-Making* (Martinus Nijhoff 1972 (2012 reprint) 43-45; Sergio Marchisio, ‘Article IX’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schögl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 551, 568; Andrea J Harrington, ‘Due regard as the Prime Directive for Responsible Behaviour in Space’ (2023) 20(1) *University Chicago International Law Review* 57, 60.

⁵⁴⁵ Ram S. Jakhu & Upsana Dasgupta and Ujwala Raghavan Iyengar, ‘Exploration and Use of Outer Space for the Benefit and in the Interests of all Countries’ (2024) in Marcia Alvarenga dos Santos et al, 1, 21 <<https://ssrn.com/abstract=4741041>> accessed 20 October 2025.

Jakhu, may have risen to the level of an *erga omnes* norm, the violation of which entails state responsibility.⁵⁴⁶ Although no precise threshold or established test exists to determine the appropriate standard of care, and thus the limits of the freedom principle, in contexts such as the orbital space environment, states are nevertheless expected to demonstrate *beyond a reasonable doubt* that they have taken all possible measures to prevent harmful interference.⁵⁴⁷ Additionally, the obligation of due regard is to be interpreted in a holistic manner, taking into account the particular facts and circumstances of the case.⁵⁴⁸

An additional element worth highlighting is that, when the obligation of due regard under Article IX is interpreted in light of *intergenerational equity* – an emerging norm in international law – it implies that States Parties must consider the long-term impacts of their space activities on the outer space environment, including their implications for the rights and interests of future generations. The Moon Agreement even highlights the importance of intergenerational equity, stating that due regard shall be paid to the interests of present and future generations.⁵⁴⁹ Indeed from the idea of intergenerational equity one can argue that degrading outer space would breach the Outer Space Treaty, as it compromises fairness and the rights of other states by reducing their opportunity to utilize space. According to Hackett for example, use of outer space that causes “negative ecological effects directed against the benefit and interests of other States” constitutes a violation of the common interest clause set out in Art. I (1) of the Outer Space Treaty.⁵⁵⁰ The same author even argues that Article I (1) OST in essence “asserts that newcomers to outer space shall face the same environment as the space powers did in 1957”.⁵⁵¹ While such a view may appear somewhat severe, it underscores the clear tension between the escalating accumulation of space debris – alongside the first-come,

⁵⁴⁶ Any state, whether it has suffered any injury due to such violation, can invoke such responsibility as the “obligation breached is owed to the international community as a whole”. See: ILC, ‘Responsibility of States for Internationally Wrongful Acts’ (Report of the International Law Commission on the work of its Fifty-Third Session, UN Doc A/56/10, 2001) art 48; and Ram S. Jakhu, Steven Freeland and David Kuan-Wei Chen, ‘The Sources of International Space Law: Revisited’ (17 March 2021) 67(4) *German Journal of Air and Space Law (Zeitschrift für Luft- und Weltraumrecht)* 606, 648.

⁵⁴⁷ Sergio Marchisio, ‘Article IX’ in Stephan Hobe & Bernhard Schmidt-Tedd and Kai-Uwe Schrogl (eds.) *Cologne Commentary on Space Law Volume I: Outer Space Treaty* (Carl Heymanns 2009) 551, 570.

⁵⁴⁸ *Ibid.*, 570.

⁵⁴⁹ Moon Agreement, art 4 para 1.

⁵⁵⁰ George T Hackett, *Space Debris and the Corpus Iuris Spatialis* in Marietta Benkö (ed in cooperation with Willem de Graaff) *Forum for Air and Space Law* (Editions Frontieres 1994) 72-74.

⁵⁵¹ *Ibid.*, 99-103.

first-served competition for orbital positions and frequencies in LEO – and the principle of inter intergenerational equity, entailing reciprocity and equality among states, and promotes the need for long-term stewardship. A similar tension is evident in the context of climate change, where arguments concerning the rights of future generations are increasingly being raised in judicial fora.⁵⁵²

Regarding the sea and oceans, but in the context of climate change, on 21 May 2024, the International Tribunal for the Law of the Sea (ITLOS) unanimously delivered its first advisory opinion addressing the obligations of states to protect and preserve the marine environment from the effects of climate change, including ocean warming, sea level, and acidification.⁵⁵³ This made ITLOS the first international judicial body to issue a climate-focused advisory opinion.⁵⁵⁴ While not legally binding, advisory opinions offer an authoritative interpretation and clarification of the scope and content of state's obligations addressing persistent uncertainties within international law. This approach is particularly valuable in the context of climate change and environmental protection and may likewise serve as an important tool for advancing the protection of the orbital space environment.⁵⁵⁵ According to ITLOS,

⁵⁵² Courts and tribunals are increasingly affirming that future generations possess enforceable rights in the context of environmental protection and climate change. This evolution is grounded in constitutional interpretations, human rights law, and international environmental law. See cases for example, ECtHR, *Verein KlimaSeniorinnen Schweiz and Others v. Switzerland* [GC] App no 53600/20 (ECtHR, 9 April 2024); or see the 'Maastricht Principles on the Human Rights of Future Generations' (July 2023) <https://www.rightsoffuturegenerations.org/the-principles/english> accessed 20 October 2025.

⁵⁵³ Regarding the advisory opinion competence of ITLOS, the UNCLOS, Article 191 of UNCLOS provides that the Tribunal "shall give advisory opinions at the request of the Assembly or the Council on legal questions arising within the scope of the activities". See: UNCLOS, article 191.

⁵⁵⁴ Since the decision by ITLOS in 2024, there has been to additional advisory opinions of international courts on the subject of climate change. The second advisory opinion was issued on July 2025 by the Inter-American Court of Human Rights (IACHR) clarifying the specific obligations of states to address the climate crisis through a human rights lens. See: IACHR, *Climate Emergency and Human Rights* (Advisory Opinion) Oc-32/25 (IACHR, 29 May 2025). https://climatecasechart.com/wp-content/uploads/non-us-case-documents/2025/20250703_18528_decision-1.pdf accessed 20 October 2025. Thirdly, the ICJ issued its advisory opinion on Obligations of States in respect of Climate Change on 23 July 2025, which is discussed below in this dissertation.

⁵⁵⁵ Advisory opinions on climate change provide important benefits by reinforcing the view that climate change is not solely a political or ethical issue, but one that entails binding legal obligations for states. They also enable international courts and tribunals to articulate such obligations in a general, authoritative manner – independent of specific disputes – thus shaping broader state practice. Furthermore, advisory opinions can establish critical legal foundations for future contentious proceedings in which states may be held accountable for climate-related harm. Advisory opinions serve to complement and enhance the normative force of the Paris Agreement by

UNCLOS expressly establishes an obligation of conduct under article 194 (1), requiring states to act with *due diligence*. Under this provision, “States Parties to the Convention have the specific obligations to take all necessary measures to prevent, reduce and control marine pollution from anthropogenic greenhouse gas (GHG) emissions (...)”.⁵⁵⁶ ITLOS, by referencing relevant provisions of UNCLOS, affirms that the obligation to reduce GHG emissions – and thereby protect the marine environment – extends beyond ocean-based sources,⁵⁵⁷ to include emissions originating from land- and air-based activities.⁵⁵⁸ This allows ITLOS to interpret states’ obligations more broadly, enriching the text of UNCLOS with greater meaning to encompass climate-related responsibilities.

To understand the relationship between the due regard obligation in Article IX OST and the concept of due diligence in international environmental law, the International Law Commissions’ Report on Due Diligence offers valuable guidance.⁵⁵⁹ Accordingly, due regard and due diligence can be regarded as closely connected. When acting in *due regard*, one must act carefully and reasonably with due regard for the rights and duties *of other states*.⁵⁶⁰ Accordingly, due regard can be considered as a relational duty focusing on the prevention of one actor from dominating or excluding others. At the same time, *due diligence* is an obligation of conduct that emphasizes the *prevention of significant harm to the environment* or to the rights of other states, functioning in space law as an extension of the liability mechanism

embedding its commitments within the broader architecture of international law, including human rights and environmental protection. Finally, it can be argued that advisory proceedings are particularly useful tool for small, developing states or non-state entities, as they help counterbalance structural power asymmetries in international negotiations by injecting the authoritative voice of the ICJ into global legal discourse. See for example: Myrto Stavridi, ‘The Advisory Function of the International Court of Justice: States Resorting to Advisory Proceedings as a “Soft” Litigation Strategy?’ (22 April 2024) *Journal of Public and International Affairs of the Princeton University* <<https://jpia.princeton.edu/news/advisory-function-international-court-justice-are-states-resorting-advisory-proceedings-“soft”>> accessed 20 October 2025.

⁵⁵⁶ ITLOS, Obligations of states to prevent, reduce and control marine pollution and to protect and preserve the marine ecosystem from the impacts of climate change (Advisory Opinion) (ITLOS, 21 May 2024) [hereafter ITLOS Advisory Opinion (2024)] para. 234.

⁵⁵⁷ See: Pollution from seabed activities subject to national jurisdiction (UNCLOS article 208), pollution from activities in the Area (UNCLOS article 209), pollution by dumping (UNCLOS article 201), pollution from vessels (UNCLOS article 211).

⁵⁵⁸ For land-based sources, see: UNCLOS, para 207; and ITLOS Advisory Opinion (2024) paras 265-273. For pollution from or through the atmosphere, see: UNCLOS para 212; and ITLOS Advisory Opinion (2024) paras. 274-277.

⁵⁵⁹ Duncan French (Chair) and Tim Stephens (Rapporteur), ‘International Law Association Study Group on Due Diligence in International Law, First Report’ (7 March 2014)

⁵⁶⁰ Duncan French (Chair) and Tim Stephens (Rapporteur), ‘International Law Association Study Group on Due Diligence in International Law, First Report’ (7 March 2014) 30; and UNCLOS, article 56(2).

discussed above. One may draw a linkage between due regard and due diligence, as both are about ensuring responsible behaviour in shared or overlapping spaces, where one state's actions can affect other's rights. This linkage may be particularly relevant to the orbital space, as Article IX OST requires states to show due regard to the interests of other states when carrying out space activities – a principle that can be understood as a manifestation of the broader due diligence standard.

As part of its *due diligence* analysis, the Tribunal interpreted the *precautionary principle* and affirmed that the due diligence obligation is intrinsically linked to the precautionary approach – a widely recognized principle of international environmental law – requiring states to act with precaution even in the absence of scientific certainty regarding the likelihood and severity of harm.⁵⁶¹ Accordingly, states must apply the precautionary approach in their exercise of due diligence to prevent, reduce and control GHG emissions.⁵⁶² Drawing on the well-known Pulp Mills case,⁵⁶³ ITLOS further emphasized the positive obligation of states to adopt and implement appropriate legislative and regulatory measures necessary to prevent, reduce, and control marine pollution.⁵⁶⁴ This duty becomes especially significant where the activities at issue, such as GHG emissions, are primarily undertaken by private individuals or entities. In such circumstances, the principle departs from the general notion of state responsibility by recognizing that a state may incur responsibility indirectly for the acts of individuals, private or non-state actors if those acts cause injury to the property or other legally protected interests of another state.⁵⁶⁵ The Tribunal highlighted that the standard of due diligence is a stringent one given the high risk of serious and irreversible harm to the marine environment from such emissions.

Additionally, the principle of *common but differentiated responsibilities* was also underlined in the advisory opinion of ITLOS, arguing that the implementation of the obligation of due diligence may vary according to states' capabilities and available resources.⁵⁶⁶

⁵⁶¹ ITLOS Advisory Opinion (2024) paras 235 and 236.

⁵⁶² ITLOS Advisory Opinion (2024) para. 242.

⁵⁶³ ICJ, Pulp Mills case on the River Uruguay (Argentina v. Uruguay) [2010] ICJ Rep 18, 79 para. 197.

⁵⁶⁴ The ICJ, in the Pulp Mills case, further affirmed that the obligation of due diligence is intrinsically linked to the precautionary approach – a principle widely recognized in international environmental law – with required states to apply precaution even in the absence of scientific certainty regarding the likelihood and severity of harm. See: Pulp Mills case (2010) paras 203-206.

⁵⁶⁵ ITLOS Advisory Opinion (2024) para. 236; and Pulp Mills case (2010) para. 197.

⁵⁶⁶ ITLOS Advisory Opinion (2024) para. 243.

Furthermore, the Tribunal also acknowledged that the content of the due diligence obligation varies according to the particular circumstances in which it applies – an approach similar to that taken with respect to the due regard principle. ITLOS identified several factors that shape the content of the due diligence obligation, including available scientific and technological information, relevant international rules and standards, the degree of risk of harm, and the urgency of the situation (e.g., the riskier activities may require a more stringent standard of due diligence).⁵⁶⁷ Nonetheless, the standard of due diligence may change over time, given that those factors constantly evolve.

Due diligence has been further clarified in the International Court of Justice’s recent groundbreaking advisory opinion on climate change.⁵⁶⁸ The Court characterised due diligence not as an obligation of result but as a standard of conduct, requiring states to take all reasonable, good-faith measures within their capacity to prevent significant environmental harm arising from activities under their jurisdiction or control – even where full scientific certainty is lacking.⁵⁶⁹ Exercising due diligence thus includes adopting appropriate legislation and regulatory mechanisms to ensure that domestic systems operate effectively in addressing environmental risks.⁵⁷⁰ Importantly, the Court emphasized that due diligence obligations extend not only to the acts of state organs but also to activities of non-governmental (e.g., private) entities under their jurisdiction, and that they apply both to harm occurring within national territory, cross-border, as well as on areas beyond national jurisdiction.⁵⁷¹ Furthermore, the ICJ did not limit the applicability of due diligence to GHG alone. Rather, it confirmed that the no-harm principle and the duty of due diligence apply to all significant environmental harm, including harm to areas beyond national jurisdiction.⁵⁷² This is a general

⁵⁶⁷ “Such measures should be determined objectively, taking into account, inter alia, the best available science and relevant international rules and standards contained in climate change treaties, such as the UNFCCC and the Paris Agreement (...), [where] the scope and content of necessary measures may vary in accordance with the means available to States Parties and their capabilities [common but differentiated responsibilities]. See: ITLOS Advisory Opinion (2024) para 441.

⁵⁶⁸ The ICJ characterised due diligence as a standard of conduct, which is taking all reasonably good-faith measures within their capacity which take place in its territory, or in any area under its jurisdiction, causing significant damage to the environment of another state to prevent serious harm, even when scientific certainty is lacking. See: ICJ, *Obligations of States In Respect of Climate Change*, Advisory Opinion of 23 July 2025, para 280.

⁵⁶⁹ ICJ Advisory Opinion (2025) para 293.

⁵⁷⁰ Ibid., para 281.

⁵⁷¹ Ibid., para 353.

⁵⁷² Ibid., para 134.

formulation that extends beyond the context of climate change.⁵⁷³ Although the ICJ does not explicitly address the space environment, its reasoning can be understood as directly applicable to state responsibility for causing significant harm, such as space debris, to the orbital space environment. One way to act with due diligence is to legislate to make sure that domestic systems work efficiently on the topic.⁵⁷⁴ Including, the application of the precautionary principle, explained above.⁵⁷⁵ Although a detailed analysis of the principles of international environmental law lies beyond the scope of this dissertation, it is nevertheless essential to affirm that existing international environment obligations extend to the space environment and are binding upon both states and their private entities.

D. National legislation and enforcement

*“The advantage of national legal norms is that they are directly applicable and enforceable, which is not necessarily the case with obligations of a public international law nature. The disadvantage is that they do not exist in all countries”.*⁵⁷⁶

The growing involvement of private actors in the exploration and use of outer space has prompted the need for the development and implementation of national space laws and regulatory frameworks. As earlier noted, to fulfil their obligations under Article VI of the OST, states may adopt national space legislations to ensure that the activities of their non-governmental entities align with requirements for the protection and preservation of both the Earth and the outer space environment. Recognizing that sustainable space practices may lower the chances of causing damage, and thus minimize exposure to liability, states may also employ legislative mechanisms to incentivize such practices, for instance by imposing specific

⁵⁷³ Ibid., para 134.

⁵⁷⁴ ITLOS Advisory Opinion (2024) para 235.

⁵⁷⁵ ICJ Advisory Opinion (2025) paras 293-294.

⁵⁷⁶ Irmgard Marboe, ‘National Space Law’ in Frans von der Dunk, and Fabio Tronchetti (eds.) *Handbook of Space Law* (Edward Elgar Publishing 2015) 127, 128.

conditions related to liability and insurance.⁵⁷⁷ Such legislation not only serves to enforce binding international obligations but may transpose international guidelines and non-binding recommendations – thereby making them mandatory for commercial operators. Moreover, national legislation can contribute to the progressive development of space and environmental law by imposing more ambitious sustainability standards than those currently found at the international level. Additionally, national space legislation enables states to safeguard their national security, uphold foreign policy objectives, and promote socio-economic interests.⁵⁷⁸

One of the principal United Nations soft law instruments on space sustainability, the LTS Guidelines, is most effectively implemented through national legislation.⁵⁷⁹ By integrating the voluntary guidelines into domestic law, states can create licensing systems requiring private operators to adhere to core safety and sustainability standards. These include end-of-life disposal plans (e.g. controlled deorbiting or transfer to graveyard orbits), passivation to prevent explosions, maneuverability for collision avoidance, sustainable satellite design, real-time sharing of orbital data, coordination protocols, controlled re-entry procedures, and mandatory liability insurance – aligning with both the LTS Guidelines and Article VI of the OST.

E. The International Telecommunication Union regime

If orbits are understood to constitute natural resources, then determining how those resources can be allocated equitably and sustainably among users becomes essential. The extension of the International Telecommunication Union's (ITU) regulatory framework to

⁵⁷⁷ Lesley James Smith, and Susan-Gale Wintermuth, 'Ensuring space sustainability through national space legislation', in Lesley James Smith, Ingo Baumann, & Susan-Gale Wintermuth (eds.) *Routledge Handbook of Commercial Space Law* (Routledge 2023) 533, 533.

⁵⁷⁸ Irmgard Marboe, 'National Space Law' in Frans von der Dunk, and Fabio Tronchetti (eds.) *Handbook of Space Law* (Edward Elgar Publishing 2015) 127, 134.

⁵⁷⁹ Under the LTS Guidelines, when adopting and revising their national regulatory frameworks, "States should consider not only existing space projects and activities but also, to the extent practicable, the potential development of their national space sector, and envisage appropriate, timely regulation in order to avoid legal lacunae". Furthermore, it is recommended in the same soft law instrument that, "Traditionally, national regulations have been concerned with issues such as safety, liability, reliability and cost. As new regulations are developed, States should consider regulations that enhance the long-term sustainability of outer space activities. At the same time, regulations should not be so prescriptive as to prevent initiatives addressing the long-term sustainability of outer space activities". See: LTS Guidelines, guideline A.1.

include orbital positions – despite its initial focus on radio frequencies – is justified both practically and conceptually by the fact that orbital positions and frequencies are inseparably connected in the operation of satellite systems. Satellites require both access to radio frequencies and placement in specific orbital slots or positions to function effectively, rendering the two technically inseparable. This interdependence has grounded the ITU’s role in orbit regulation, even though its founding instruments – the ITU Constitution and Convention – do not explicitly confer such authority. As a result, the ITU’s involvement in orbit allocation can be understood through the doctrine of *implied powers*: the idea that certain competencies, while not expressly stated, are necessarily inferred from an organization’s primary functions. This functional necessity has led to the emergence of the term “orbit-spectrum resource” in both academic commentary and the proceedings of UNCOPUOS, reflecting the practice of treating orbits and frequencies as a unified regulatory domain.⁵⁸⁰ This development may seem to underscore a broader trend in international space law, whereby regulatory authority evolves to meet the operational demands of space activities, even in the absence of explicit treaty language. The ITU’s regime thus exemplifies how legal governance can adapt to technological interdependence, offering a model of functional integration between space law and telecommunications regulation.⁵⁸¹

An orbit is not a physical object – it is a functional resource that comes into being only when a satellite is placed in it. This makes it the perfect example of a “resource-by-use,” reinforcing the idea that exploitation in space is activity-dependent. Consequently, the ITU regime on satellite orbits shows how a legal system can manage the tension between use and ownership without allowing appropriation, through coordinated rules and international cooperation.⁵⁸² It demonstrates, according to De Man, that resources can be exploited functionally, equitably, and sustainably without conferring rights or property claims – offering a concrete model for other areas of resource governance, such as asteroid mining or lunar extraction.⁵⁸³

⁵⁸⁰ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 62-64.

⁵⁸¹ *Ibid.*, 62-64.

⁵⁸² De jure, it is the use of orbital positions that is mentioned once the satellites are deployed; de facto, however, the question of appropriation arises from their prolonged occupation. This issue will be addressed in greater detail below.

⁵⁸³ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 216-217.

The purpose of the ITU is to ensure the rational, efficient, and economic use of the orbit-spectrum resources, regarded as limited natural resources, to promote equitable access for all countries. This mission is codified in Article 44 (2) of the ITU Constitution, requiring that frequencies and associated orbital slots be used “efficiently and economically, [...] so that countries or groups of countries [especially those without current capabilities] may have equitable access to those orbits”.⁵⁸⁴ Indeed, the wording of this paragraph shows that efficiency and economical use are preconditions for achieving equity. In contrast, it can be argued that prioritizing equity without requiring efficient and economical use could lead to wasted or underutilized orbital slots, which undermines both equity and efficiency. In other words, fulfilling one or two of the three required use is not enough, but legitimate use must account for all three elements. It is important to note, however, that sustainability, or the environmental protection dimension, is not incorporated into this equitation, as the ITU framework emphasizes due regard without integrating the due diligence obligations associated with environmental protection.

While orbits are an integral part of outer space and are directly governed by space law, the frequency spectrum, though essential for space operations, remains primarily within the domain of telecommunications regulation. As geostationary (GEO) satellites maintain fixed positions in the sky over the equator relative to the ground stations they serve, frequency bands and orbital positions must be carefully planned through the ITU to prevent interference between systems. However, the narrow orbital spacing between adjacent satellites operating on the same frequencies increases the risk of interference, limiting the ability to deploy additional satellites.⁵⁸⁵ While using different frequencies across systems could mitigate this, the number of frequency bands allocated for space radiocommunications under the ITU Radio Regulations (RR) is limited. As a result, the orbit-spectrum is considered a finite and shared resource. In contrast, non-GEO (or in ITU terms, non-GSO) satellites follow dynamic trajectories, causing the geometry of each system – and their relative positions – to vary continuously. This

⁵⁸⁴ ITU Constitution art 44 para 2.

⁵⁸⁵ Gérard Maral, Michel Bousquet and Zhili Sun, *Satellite Communications Systems: Systems, Techniques and Technology* (6th edn, John Wiley & Sons Ltd, 2020) 15-16.

variability significantly complicates coordination efforts and increases the risk of radio frequency interference.⁵⁸⁶

As a result, the international community has yet to establish a viable governance mechanism for non-GSO, and in particular for low Earth orbit. This impasse is largely attributable to the reluctance of technologically advanced states, which dominate satellite deployment in LEO, to endorse equitable management schemes. Many of these actors benefit from the current first-come, first-served practice, which continues to shape orbital access, particularly in densely populated regions like LEO.⁵⁸⁷ This approach reflects a pragmatic but inequitable mode of allocation, privileging early and well-resourced actors without ensuring sustainable or fair access. While not explicitly economic in its legal origin, it nevertheless echoes market-like logic and raises concerns of distributive justice, including potential violations of the common benefit principle under Art I OST.

Besides the ITU's Constitution and Convention, the technical complexity of the ITU Radio Regulations (a multi-volume, intricate and binding legal and engineering framework) has made the regulatory system of the ITU hard to access and understand. The principal purpose of the modern ITU is to govern how radio frequencies and GEO slots are allocated and used. In more details, it administers the allocation of bands of the radio-frequency spectrum, the allotment of radio frequencies, as well as the registration of radio frequency assignments. Moreover, geostationary orbital slots and radio frequencies across all orbits must be coordinated or registered through the International Telecommunication Union (ITU), which holds authoritative oversight in these areas of space activity.⁵⁸⁸ However, there is currently no international body responsible for assigning or regulating orbital positions for satellites operating in LEO and other non-geostationary systems. Instead, LEO operators must apply for spectrum allocations through the national regulatory authorities of the country or countries where they intend to operate, specifying their planned orbital parameters and frequency usage

⁵⁸⁶ Ibid., 15-16.

⁵⁸⁷ See for example, Rob Frieden, Balancing Equity and Efficiency Issues in Global Spectrum Management in William Drake and Ernest Wilson (eds.) *Governing Global Electronic Networks: International Perspectives on Policy and Power* (The MIT Press 2008) 127, 127-148.

⁵⁸⁸ For space services, the ITU registers orbital positions in the GSO. To see more: Ram S. Jakhu and Joseph N Pelton, *Global Space Governance: An International Study* (Springer, 2017) 125.

within their applications.⁵⁸⁹ Important to emphasize that the ITU does not monitor the orbital positions of non-GSO satellites as such; it uses the submitted orbital parameters solely to assess how satellite movements may affect frequency use and potential interference. An important change on this regard is the outcome of the World Radio Conference 2023 (WRC-23), when the first time the ITU imposed binding positional tolerances on non-GSO satellite systems.⁵⁹⁰ Accordingly, non-GSO system satellites are required to remain within ± 70 km during deployment, shrinking to ± 30 km once operational.⁵⁹¹ This reflects the increasing pressure of orbital congestion and the spillover of spectrum regulation into de facto orbital governance.⁵⁹²

The phenomenon of paper satellites has emerged as a systemic challenge in LEO within the framework of the ITU where over 1 million satellite filings have been registered between 2017 and 2022.⁵⁹³ These filings, many of which represent satellites that are never launched, reflect strategic behaviour by both state and private actors. A distinction is sometimes drawn between filings regarded as legitimate cases of temporary overuse of the filing system and those as potentially abusive attempts to reserve orbital slots or frequencies without any real intention to deploy satellites, thereby exploiting gaps in the ITU procedures.⁵⁹⁴ However, this distinction is often difficult to draw in practice, as it heavily relies on subjective judgements regarding the legality and intent behind evolving filing strategies. Some entities may file for orbital slots and radio frequency bands without the capability, political support, or genuine intent to use them, but to reserve scarce orbital resources for future use, trade them for financial investment, lease

⁵⁸⁹ Internet Society, ‘Perspectives in LEO Satellites – Using Low Earth Orbit Satellites for Internet Access’, (November 2022) 1 <<https://www.internetsociety.org/resources/doc/2022/perspectives-on-leo-satellites/>> accessed 20 October 2025.

⁵⁹⁰ Non-GSO tolerance refers to the extent to which non-GSO satellites must remain within the orbital parameters registered by their national regulators. Although non-GSO satellites have been operational for decades, they were not previously subject to clearly defined orbital tolerance limits comparable to those imposed on GSO satellites, which must remain within 0.5° of their assigned slot. See: European Space Policy Institute (ESPI) ‘From WRC-23 to the Next Cycle: How to Make Everyone Happy? (Hint: You Can’t)’ 66 (Mach 2024) 3 <<https://www.espi.or.at/wp-content/uploads/2024/03/ESPI-Brief-66-RA-23-WRC-23-2.pdf>>.

⁵⁹¹ Ibid., 3.

⁵⁹² At the same conference, as mentioned in the previous chapter, debates also emerged over Equivalent Power Flux Density (EPFD) limits, which are designed to protect geostationary satellite systems from interference caused by the aggregated emissions of non-GSO constellations. While non-GSO operators sought to reopen EPFD rules at WRC-27, strong opposition from GSO operators and some states resulted in only technical studies being mandated, with no regulatory change. Ibid., 3.

⁵⁹³ Andrew Falle et al., ‘One million (paper) satellites’ (12 October 2023) 382(6667) *Science* 150, 151.

⁵⁹⁴ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 216.

them to foreign operators, or block access by competitors.⁵⁹⁵ This practice effectively undermines the equitable access principle enshrined in space law and fosters inefficient and monopolistic behaviours in orbital and spectrum management. When assessed against the ITU's three key criteria – efficiency, economy, and equity – such conduct clearly fails on all counts, rendering it an illegitimate practice under the organization's framework.⁵⁹⁶ The efficiency test is failed because nothing is being done with the slot; it fails the economy test as a scarce resource is being wasted – it reduces market output, increases price, and diminishes social welfare –;⁵⁹⁷ and finally, it fails the equity test, because it blocks others from accessing the slot and radio frequency, which are often states with real needs or capabilities. Consequently, it can be argued that slot warehousing violates the formal legal standards as well as ethical objectives and “spirit” of the ITU rules.⁵⁹⁸

Despite this legal clarity surrounding the issue, slot warehousing and speculative filing often persist with minimal consequence. The international community has only sporadically condemned slot warehousing, leading to a gap between the established legal framework and its practical enforcement.⁵⁹⁹ Despite the ITU's regulatory mechanisms, enforcement remains weak.⁶⁰⁰ The ITU has occasionally taken action to revoke filings for non-compliance – such as missing the Bringing into Use (BIU) deadline – but these actions have limited long-term effect. The Bringing into Use regulation was introduced to counter the paper satellite phenomenon by requiring operators to place a satellite or a satellite constellation within a defined period after filing with the ITU. Accordingly, operators of large constellations must deploy 10% of the constellation within two years after the end of the current regulatory period for bringing into use (seven years), 50% within five years, and they must complete the deployment within seven years (fourteen years altogether).⁶⁰¹ If they do not comply with these requirements, their spectrum rights will be limited proportionally to the number of stations launched before the

⁵⁹⁵ Ram S. Jakhu and Joseph N Pelton, *Global Space Governance: An International Study* (Springer, 2017) p 151; or see: Andrew Falle et al., ‘One million (paper) satellites’ (12 October 2023) 382(6667) *Science* 150, 151.

⁵⁹⁶ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 221-223.

⁵⁹⁷ Nodir Adilov, Brendan Cunningham, Peter Alexander, Jerry Duvall and Daniel Shiman, ‘Left for Dead: Anti-Competitive Behavior in Orbital Space’ (2019) 57(3) *Economic Inquiry* 1497, 1498.

⁵⁹⁸ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 223.

⁵⁹⁹ Andrew Falle et al., ‘One million (paper) satellites’ (12 October 2023) 382(6667) *Science* 150, 152.

⁶⁰⁰ Ram S. Jakhu and Joseph N Pelton, *Global Space Governance: An International Study* (Springer, 2017) 151.

⁶⁰¹ ITU Radio Regulations (rev WRC-19 ITU 2020) art 11; Tanja Masson-Zwaan and Mahulena Hofmann, *Introduction to Space Law* (5th edn, Wolters Kluwer 2024) 164.

deadline.⁶⁰² Ultimately, it can be argued that the persistence of paper satellites reflects a deeper tension in the ITU's current governance model: the reliance on a first-come, first-served framework in an environment of growing demand and limited resources. Without stronger regulatory safeguards, mechanisms for transparency, and equitable enforcement, the issue of paper satellites will continue to distort access to orbital resources and frustrate efforts to ensure their long-term sustainability.

Another key challenge that the ITU faces in ensuring the equitable and sustainable use of orbital positions is their prolonged and repeated occupation, especially by operators of large satellite constellations. Such sustained use can result in quasi-permanent control, effectively limiting future access for states that have not yet secured their own coordinated assignments. The current ITU Radio Regulations impose no fixed, universal expiry date for assignments. Instead, guidance derives primarily from Resolution 2 (1971) and Resolution 4 (1979, revised multiple times) annexed to the Radio Regulations, both aimed at curbing first-come, first-served monopolisation.⁶⁰³ In practice, however, administrations can prolong use indefinitely by replacing satellites with ones of identical technical characteristics (thereby retaining the original data and status in the Master International Frequency Register), by extending a satellite's operational period, or by deploying upgraded satellites provided they comply with coordination requirements and do not increase harmful interference.⁶⁰⁴ The result is that, rather than imposing a temporal restriction, Resolutions 2 and 4 establish conditional safeguards: under current ITU practice, international protection from harmful interference may be maintained indefinitely, provided that the slot and frequency remain in continuous use and in full conformity with the Radio Regulations. It is relinquished only if such use ceases altogether or if the technical parameters are altered to an extent that triggers a new coordination and

⁶⁰² Ibid., 164.

⁶⁰³ According to ITU Resolution 2 (WRC-03) registration and use do not grant permanent priority and urges states to facilitate access for new entrants, especially developing states. See: ITU Resolution 2 (Rev. WRC-03) 'Equitable use, by all countries, with equal rights, of the geostationary-satellite and other satellite orbits and of frequency bands for space radiocommunication services' (Geneva, 2003) para 1. Moreover, ITU Resolution 4 of the same World Radio Conference reiterates that frequency assignments are not perpetual, tying validity to the operational period specified in the notification, after which the Bureau may cancel the assignment – unless extended. See: ITU Resolution 4 (Rev. WRC-03) 'Period of validity of frequency assignments to space stations using the geostationary-satellite and other satellite orbits' (Geneva, 2003) para 1.

⁶⁰⁴ Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 252.

registration process.⁶⁰⁵ This operational conditionality creates a form of functional perpetuity that can sustain long-term, exclusive occupation, potentially violating the common interest clause (Art I OST).

Last but not least, we must keep in mind that the ITU regime was designed with equity of access in mind, but not with sustainability of use. ITU coordination for non-GSO systems is designed to prevent harmful interference between different networks and constellations, but it does not place any restriction on how many satellites a single operator may deploy, provided they conform to the technical parameters of their filings and their frequency assignments do not cause harmful interference with those already recorded in the Master International Frequency Register (MIFR).⁶⁰⁶ Consequently, a single ITU filing can authorize tens of thousands of satellites as part of one network under a single frequency assignment, often to the disproportionate advantage of early entrants. With advancing technologies and novel operational methods, operators are able to accommodate ever larger constellations, while recently introduced positional tolerances for non-GSO satellites and existing EPFD limits do little to constrain this expansion. As in other resource systems, increases in technological capability and extraction efficiency can accelerate the depletion of the resource base. Although interference may eventually impose practical limits, under the current framework spectrum management alone remains an inadequate tool for ensuring the equitable and sustainable governance of non-GSO orbital use.

Both the issue of paper satellites and the prolonged occupation of high-value orbital positions, and the missing rules relevant to orbital positions, underscore critical challenges in the governance of orbital resources. These practices highlight not only systemic weaknesses in regulating access and use but also the difficulty in defining clear legal and operational boundaries, especially when the precise limits of orbital capacity remain uncertain amid rapidly evolving demands and technologies. The flexible yet binding nature of the Radio Regulations,

⁶⁰⁵ Rapid technological progress in satellite development ensures that generations of satellites are regularly replaced with more advanced models, each subject to renewed registration obligation. Thus, as De Man suggests, a provision initially intended merely to promote efficient utilisation of frequencies and orbital slots may, in practice, function as an important safeguard of equitable access to these scarce natural resources. Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 253.

⁶⁰⁶ This stands in sharp contrast to GEO satellite systems, where the inseparability of orbital slots and frequency assignments imposes a functional ceiling: only one satellite can occupy a given slot on a given frequency without causing interference. As a result, ITU regulation in GEO has evolved into a de facto orbital allocation regime, but without guaranteeing equitable access among states.

combined with the potential engagement of the private sector,⁶⁰⁷ could provide the ITU with a practical avenue to address the mounting challenges posed by the proliferation of large satellite constellations in LEO.⁶⁰⁸ However, the extent to which the private sector is genuinely committed to active and responsible participation in this process remains uncertain.

F. The question of non liquet

Since the first normative question of this dissertation states whether a *legal lacunae* exists in space law regarding the overexploitation of orbital space, it is essential to touch upon the theoretical foundation of *non liquet* (commonly known as a legal lacunae) and the question of the completeness of international law, to provide a clear answer. There has been a great deal of debate among international law scholars, whether a non liquet is at all possible, and “whether either in practice or in principle, any gaps actually exist in the fabric of international law”.⁶⁰⁹ In everyday terms, it is clear that legal gaps can arise; situations may emerge for which no specific, pre-existing legal rule is available within a legal system, whether national or

⁶⁰⁷ The main actors in all ITU activities are its 194 Member States. Only the representatives of Member States have full voting rights in all plenipotentiary or world conferences. This number is higher than the total number of UN members, which illustrates the universal character of the ITU. In addition to the Member States and in order to involve partners from the public and private sectors, ITU includes in its activities around one thousand Sector Members and Associates from industry, international and regional organizations, and academia. They have to pay a yearly membership fee from 32000- to 20000 Swiss francs, depending on whether the company is from a developing country, and whether it is from academia, of the private sector etc. These members are entitled to participate in all activities of the Sector of which they are members and are involved in the adoption of recommendations and procedural decisions of that Sector. Also, industry players can directly shape ITU policies by becoming members, engaging in technical groups, and lobbying national delegations. See: ITU, ‘ITU Membership: Member States, Sector Members, Associates and Academia’ (2024) <<https://www.itu.int/en/about/Pages/membership.aspx>> accessed 20 October 2025; and Joseph N Pelton, ‘Satellite Communications Overview’ in Scott Madry, Joseph N Pelton and Sergio Camacho-Lara (eds.) *Handbook of Satellite Applications* (2nd edn, Springer, 2017) 21, 21-26.

⁶⁰⁸ At the ITU’s Plenipotentiary in 2023, Member States adopted a new resolution, instructing the ITU Radiocommunication Sector (ITU-R) to undertake studies around spectrum and orbit usage by non-GSO systems and further encouraged Member States to develop the appropriate regulatory frameworks for non-GSO systems. The ITU-R Director was asked to report back on this at the World Radio Conference (WRC) 2023. See: ITU, Resolution ITU-R 74, ‘Activities related to the sustainable use of radio-frequency spectrum and associated satellite-orbit resources used by space services’ (2023) 1-4 <https://www.itu.int/dms_pub/itu-r/opb/res/R-RES-R.74-2023-PDF-E.pdf> accessed 20 October 2025.

⁶⁰⁹ Stephen C Neff, ‘In Search of Clarity: *Non Liquet* and International Law’, in Kaiyan Homi Kaikobad and Michael Bohlander (eds.) *International Law and Power: Perspectives on Legal Order and Justice. Essays in Honour of Colin Warbrick* (Koninklijke Brill, 2009) 63, 63; Hersch Lauterpacht, ‘Some Observations on the Prohibition of ‘Non Liquet’ and the Completeness of the Law’ (*Symbolae Verzijl* 1956) 196, 196-221.

international, to deal with them. This reflects the reality that lawmakers cannot anticipate every possible future scenario and craft precise rules for each case in advance. However, this type of legal gap does not constitute a “true non liquet” as understood in legal scholarship. A genuine non liquet occurs when a competent court or tribunal fails to decide the merits of an admissible case due to the character of the underlying legal system – be it the absence of suitable law, the vagueness or ambiguity of rules, inconsistencies in law, or the injustice of the legal consequences. In other words, there is no possible way to resolve the deficiency. The core question surrounding non liquet, therefore, is whether a consistent method can be identified to fill legal gaps as they arise – thereby refuting the existence of true legal lacunae.

Most international law scholars have rejected the possibility of non liquet in international law.⁶¹⁰ The famous legal theorist Hans Kelsen, for instance, argues that international law always contains either a specific rule (derived from treaty law or customary international law) governing a given subject, or, in the absence of such a norm, a general rule, often described in scholarly discourse as the “residual negative principle”.⁶¹¹ This residual negative principle, which Kelsen traced to the Lotus case’s freedom principle,⁶¹² applies automatically and immediately according to the expert, when no specific rule exists on the issue. By using this argument, Kelsen also denies any use of analogy to address perceived gaps in the law.⁶¹³ Hersch Lauterpacht, a distinguished legal philosopher and former ICJ judge also rejected the notion of non liquet in international law. Unlike Kelsen, however, he embraced a more pluralistic approach to addressing legal gaps. He argued that any legal lacunae in international law could be adequately addressed through the application of three principal

⁶¹⁰ Julius Stone, ‘Non Liquet and the Function of Law in the International Community’ (1960) 35 *British Year Book of International Law* 124, 124-161.

⁶¹¹ Hans Kelsen, *Principles of International Law* (2nd edn, revised by R.W. Tucker, 1966) 438-439; and Hugh Handeyside, ‘The Lotus Principle in ICJ jurisprudence: Was the Ship Ever Afloat?’ (2007) 29(1) *Michigan Journal of International Law* 71, 79-80.

⁶¹² It is worth noting that the “principle of freedom” articulated in the Lotus case is also invoked by Hans Kelsen to support his theory on the non-existence of legal lacunae (non liquet) in international law. Kelsen characterizes this norm as a “residual negative principle” – an ultimate method capable of resolving any legal question in the absence of a specific rule. See: PCIJ, *SS ‘Lotus’ case (France v. Turkey)* [1927] PCIJ Rep 10.

⁶¹³ Stephen C Neff, ‘In Search of Clarity: Non Liquet and International Law’, in Kaiyan Homi Kaikobad and Michael Bohlander (eds.) *International Law and Power: Perspectives on Legal Order and Justice. Essays in Honour of Colin Warbrick* (Koninklijke Brill, 2009) 63, 69.

methods: analogy, general principles, and equity.⁶¹⁴ Furthermore, as a last resort, Lauterpacht argued that whenever still a provisional gap in the law occurs, the judge must employ whatever degree of creativity is necessary to fill it.⁶¹⁵ By encouraging judges to exercise discretion as a last resort to non liquets, Lauterpacht's approach is notably more open-ended and adaptable than Kelsen's residual negative principle. However, this openness also introduces the potential for a higher degree of judicial activism.⁶¹⁶

The existence of non liquet has also been affirmed in scholarly discourse. Julius Stone, for instance, regarded gaps in the law not as a cause of concern, but as an inevitable feature of any legal system.⁶¹⁷ In fact, Stone argued that in cases where no specific legal provision exists, it is preferable to leave such gaps open to be gradually filled through the development of state practice and future treaty-making.⁶¹⁸ This approach, the expert maintained, ensures that substantive international law evolves organically through time, and reflects the actual conduct of states, which is, after all, the foundational source of international law.

The issue of legal lacunae has also featured in international space policy discussions. Since 2005, the most frequently discussed legal lacunae in space law have concerned the definition and delimitation of outer space, the prevention of arms race in space, space traffic management, resources and commercial mining, or generally the status of the five United Nations treaties on outer space.⁶¹⁹ Notably, the most recent instance in which the term "legal lacunae" or "legal gap" appeared in a final report of the Legal Subcommittee was in 2019, in reference to a statement asserting that the provisions of the five United Nations treaties on outer space were clearly and unequivocally formulated. The statement further argued that characterizing international space law as containing gaps or attempting to address such

⁶¹⁴ Hersch Lauterpacht, 'Some Observations on the Prohibition of 'Non Liquet' and the Completeness of the Law' (*Symbolae Verzijl* 1956) 196, 196; and Iain Scobbie, 'The Theorist as Judge: Hersch Lauterpacht's Concept of the International Judicial Function' (1997) 8(2) *European Journal of International Law* 264, 272.

⁶¹⁵ *Ibid.*, 272.

⁶¹⁶ Julius Stone, 'Non Liquet and the Function of Law in the International Community' (1960) 35 *British Year Book of International Law* 124, 159.

⁶¹⁷ Stephen C Neff, 'In Search of Clarity: Non Liquet and International Law', in Kaiyan Homi Kaikobad and Michael Bohlander (eds.) *International Law and Power: Perspectives on Legal Order and Justice. Essays in Honour of Colin Warbrick* (Koninklijke Brill, 2009) 63, 74-75.

⁶¹⁸ Julius Stone, 'Non Liquet and the Function of Law in the International Community' (1960) 35 *British Year Book of International Law* 124, 160-161.

⁶¹⁹ See the conference room papers of the Legal Subcommittee, discussing legal gaps and lacunae, including UN Docs A/AC.105/917; A/AC.105/1067; A/AC.105/1113; A/AC.105/1122 and A/AC.105/1203 (2008-2023).

perceived gaps through national legislation was counterproductive.⁶²⁰ Indeed, the reasoning above reflects a functionalist perspective that prioritizes practical applicability.⁶²¹ From this standpoint, one could argue that the foundational principles enshrined in the five core space law treaties – intended collectively to regulate all space activities – effectively negate the existence of legal lacunae.

Ultimately, this thesis does not seek to resolve the long-standing scholarly debate over the existence of non liquet in international law. Instead, it adopts a functionalist approach to advocate for the implementation of practical measures, aimed at ensuring the effective application of the fundamental principles enshrined in the sources of space law.⁶²² As previously noted in this chapter, while Article I OST affirms the principle of freedom in space activities; this freedom must be interpreted in conjunction with the obligation to ensure that such activities benefit all humankind.⁶²³ From a practical standpoint, however, if continued launches – particularly into LEO – result in cumulative harm (such as increased collision risks, orbital debris, spectrum congestion, light pollution, and atmospheric damage), then this freedom is functionally constrained by the duty to safeguard the outer space environment for present and future users and the duty to avoid harmful interference established in Article I and Art IX of the Outer Space Treaty. The general principles enshrined in the five space law

⁶²⁰ See: UNCOPUOS, ‘Report of the Legal Subcommittee on its fifty-eighth session, held in Vienna from 1 to 12 April 2019’ (2019) UN Doc. A/AC.105/1203 para 79.

⁶²¹ The duality between functionalist and spatialist approaches plays a significant role in interpreting and shaping space law. A key example is the long-standing debate over the demarcation between airspace and outer space, which reflects the broader divide between these two perspectives. Spatialists argue for a clearly defined boundary, while functionalists focus on the nature and purpose of an activity (e.g., “space activities” and the involvement of a “space object”), rather than its location. In other words, functionalists ask what the actor is doing, rather than where they are doing it. Until today states have been unwilling to declare a specific upper limit to their sovereignty (between air space and outer space), nor a specific lower border to an area to which they have free access. Although the functionalist approach has generally gained wider acceptance within the international space community, it is crucial to recognize that even this framework ultimately relies on a spatial reference (e.g., defining space activity and/or space object) for its application. To learn more on the dichotomy between the two systems, see for example: Gyula Gál, Space law (A. W. Stijhoff and Akadémiai Kiadó 1969) 59-105; Paul Stephen Dempsey and Maria Manoli, ‘Suborbital Flights and the Delimitation of Air Space Vis-à-Vis Outer Space: Functionalism, Spatialism and state Sovereignty’, (2017) 42 *Annals of Air & Space Law* 197, 197-219; Bin Cheng, *Studies in International Space Law* (Oxford, 1997) 425, 425-456; Mahulena Hofmann and P J Blount, ‘Space Law Disputes’ (*Max Plank Encyclopaedias of International Law*, October 2019) <<https://opil.ouplaw.com/display/10.1093/law-mpeipro/e2812.013.2812/law-mpeipro-e2812>> accessed 20 October 2025.

⁶²² On the one hand, it is clear that general principles can consistently be applied to space law cases from a judicial standpoint, especially considering Art III OST. On the other hand, this does not imply that broad and ambiguous norms are sufficient – from a forward-looking and proactive perspective – to effectively guide states’ conduct in response to emerging challenges.

⁶²³ Outer Space Treaty, art I.

treaties, together with the ITU regime, provide a broad framework for guiding satellite activities; however, evolving challenges, especially with respect to the governance of the LEO environment, call for more concrete decisions and specific, practical legal measures that effectively safeguard long-term and equal access to orbital space.

G. Chapter Conclusion

The legal status of Earth's orbits under space law reveals the complexities and evolving dynamics of an environment that is foundational to modern space activities and socio-economic development of humans. Earth's orbital regions, while not subject to sovereignty or appropriation under Article II of the Outer Space Treaty are nonetheless regulated by a layered framework of international legal norms comprising both binding sources and non-binding instruments. These include the five core space treaties, relevant UN General Assembly resolutions, the ITU Constitution and Convention, and a variety of soft law instruments such as the UNCOPUOS Long-Term Sustainability (LTS) Guidelines, the UNCOPUOS Space Debris Mitigation Guidelines, and the IADC Space Debris Mitigation Guidelines. The interplay between these sources reflects the growing need for legal mechanisms that balance permissiveness with limits and responsibility.

At the heart of this framework lies the freedom principle: freedom of exploration, access, and use (as well as exploitation) of outer space, including orbits. Yet this freedom is not and cannot be absolute. Its viability depends on built-in limitations, particularly those anchored in the principles of reciprocity and the common interest of all humanity, as emphasized in the OST. The reciprocal nature of compliance – where each actor's restraint encourages restraint in others – is central to sustaining orbital use. Similarly, the common interest clause affirms that orbital space, like outer space *sensu stricto*, is a shared environment that must be governed collectively and remain inclusive.

Despite this, the regulatory system remains underdeveloped in its environmental dimension, particularly with respect to orbital space, where space debris continues to accumulate and LEO is becoming increasingly and alarmingly congested. While a number of relatively new soft law measures exist to address the environmental risks posed by orbital congestion and debris, their legal influence depends almost entirely on domestic

implementation. Without transformation into binding national legislation, these guidelines cannot ensure consistent or enforceable behaviour across the international community.

The International Telecommunication Union has emerged as an indispensable institutional actor, not by governing outer space directly, but through its regulatory authority over the radio-frequency spectrum and associated orbital positions. Due to the technical and operational inseparability of orbits and spectrum, the ITU's role in orbital coordination, particularly in geostationary orbit, is now effectively central to orbital governance. However, beyond spectrum coordination, there is no comprehensive international mechanism for managing the physical use of non-geostationary orbits, particularly LEO, which currently bears the brunt of commercial expansion and increasing operational congestion. Two challenges remain particularly relevant to the ITU regime: the persistence of slot warehousing (or the paper satellite problem) and the monopolization resulting from the prolonged and repeated occupation of orbital positions by major constellation operators. Such practices risk creating quasi-permanent control over parts of the orbital environment, thereby constraining future access for other states and potentially infringing principles of inclusivity, the common interest clause (Art I OST) and the due regard obligation (Art. IX OST). Furthermore, although the ITU regime was established to promote equitable access for states, it was not designed with environmental sustainability in mind. Its focus on preventing harmful interference means that spectrum coordination alone – without complementary governance of orbital positions – remains insufficient to protect the LEO environment.

Although qualitative measures – such as responsible design, enhanced maneuverability, and end-of-life disposal protocols – have been incorporated into national regulations, regional norms, and international soft law instruments, they remain necessary but manifestly insufficient to offer a timely and effective response to the increasingly congested LEO environment. While the legal framework for orbital space has grown in scope and sophistication, it remains incomplete and imbalanced. The continued reliance on voluntary compliance, coupled with the absence of binding environmental protections, underscores the urgent need for a coordinated regulatory response that treats Earth's orbits not merely as conduits of technological ambition, but as finite and fragile resources essential to the future of space exploration and human development.

It is the incorporation of the due diligence principle; well established in international environmental law and reinforced through its interpretation in the most recent advisory opinions of established international tribunals on climate change, that may help to identify a balancing act between the freedom of use (including exploitation, Art. I OST) and the

prohibition of appropriation (Art. II OST) in space law as applied to LEO. Its integration into space governance may emphasize the need to protect the orbital environment while ensuring that the exercise of the freedom of use does not drift into de facto appropriation or generate significant environmental harm that may jeopardise continued access to outer space. To identify more practical ways of incorporating due diligence into the governance of LEO, the following chapter applies insights from economic analysis of law as well as relevant critical theories.

Chapter IV. Economic analysis and critical approaches to governing the orbital commons – de lege ferenda

*“As environmental harm caused by space activities is particularly difficult to remedy after the fact, the focus should clearly be on prevention”.*⁶²⁴

A. Economic analysis of law

Low Earth orbit (LEO) has become the backbone of contemporary space activities, yet it is also the domain most threatened by overexploitation by now. The proliferation of large constellations, combined with the persistent problem of space debris, exposes the structural limits of the orbital environment. The challenge is not simply technical but systemic: it arises from the interaction of physical limits, economic incentives, human behaviour, and legal frameworks. Addressing it therefore requires an integrated, interdisciplinary framework. Although this dissertation is situated within the field of international law, it recognises that the governance of orbital space cannot be fully understood without engaging particularly with economics. Law does not operate in a vacuum; it structures incentives, allocates rights, and contains behaviour, but the effectiveness of these legal norms also depends on the economic realities in which they function. The overexploitation of orbital space is, at its core, not only a legal problem but also an economic one – it arises from scarcity, competition, and externalities that law alone cannot resolve without reference to economic dynamics. This reflects the broader definition of economics from a behavioural approach as the “study of human behaviour in a world where resources are scarce in relation to human desires”.⁶²⁵ Against this backdrop, this final chapter turns to *economic analysis of law*, not as a departure from the legal analysis, but as a complementary methodology that helps to capture these dynamics and thereby enrich and sharpen the legal discussion, as economic analysis of law seeks to explain how legal rules

⁶²⁴ Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff, 2008) 157.

⁶²⁵ Eyal Zamir and Doron Teichman, *Behavioral Law and Economics* (Oxford University Press 2018) 8.

influence the behaviour of relevant actors and to assess whether the resulting outcomes are socially and environmentally desirable.

In this dissertation, *Law and Economics* and *economic analysis of law* are used interchangeably, in line with their common usage in the literature.⁶²⁶ At the same time, the terms are understood in a pluralist manner, extending beyond Chicago-style and narrowly efficiency-based neoclassical approaches.⁶²⁷ Accordingly, the economic analysis of law employed here draws on a range of economic traditions that have, to varying degrees, informed legal scholarship and governance debates. These include, inter alia, the old Institutional tradition, public choice theory; Keynesian and Post-Keynesian economics; Marxian and political economy; Austrian economics; behavioural economics; and ecological economics. Given the limited scope of this dissertation, only selected strands are addressed. Particular emphasis is placed on insights from Law and Economics in its narrower, neoclassical formulation,⁶²⁸ as well as from institutional, behavioural and ecological economic perspectives, where these offer specific explanatory or normative value for international space law and the governance of orbital space, as the chapter develops.

Applying economic analysis, particularly behavioural economics to *international law* presents distinct challenges when contrasted with domestic legal contexts, as states and international organizations (the primary actors of international law) are collective actors characterised by complex internal decision-making processes. Yet, there is a growing tendency

⁶²⁶ See for example Richard Posner, *Economic Analysis of Law* (3rd edn, Wolters Kluwer 1986) 19, defining Law and Economics, as “the application of the theories and empirical methods of economics to the legal system across the board” (e.g., to contracts, property; the theory and practice of punishment; civil, criminal, and administrative procedure; etc).

⁶²⁷ Critics of Law and Economics often equate the field with the Chicago School of Law and Economics and neoclassical economics. As a result, their objection, particularly to the use of efficiency as a normative criterion, are largely directed at Chicago-style approaches, rather than at the broader and more diverse body of economic analysis that has developed within legal scholarship. See: Nicholas Mercuro and Steven G. Medema, *Economics and the Law* (2nd edn, Princeton University Press, 2020) 49.

⁶²⁸ An important divide within Law and Economics lies between its narrower, neoclassical formulation and broader forms of economic analysis of law, particularly with respect to the *normative criteria* employed. In much neoclassical Law and Economics scholarship, *efficiency* operates as the dominant evaluative standard and is often presented as a technical or objective benchmark rather than as an explicit normative choice. This tendency can be linked to the historical development of Law and Economics within capitalist market systems, where existing distributions of wealth and power are frequently treated as given rather than as subjects of legal or economic critique. See, in particular, the old Institutional economics tradition, which emphasizes that efficiency-based analysis is inseparable from underlying distribution of power and from legally constructed market relations: Warren J Samuels, ‘The economy as a system of power and its legal bases: the legal economics of Robert Lee Hale’ (1973) 27(3-4) *University of Miami Law Review* 261; and Karl Polanyi, *The Great Transformation – The Political and Economic Origins of Our Times* (3rd edn, Beacon Press, 2001) (first published 1944).

to apply these approaches in public international law, from climate change to human rights, and they offer equally valuable insights for orbital space governance.

In addition to engaging with the above perspectives, this dissertation also turns to complementary critical frameworks that shed light on the deeper systemic challenges inherent in environmental resource governance, particularly in relation to climate change and the use of orbital space, as common pool resources. The chapter concludes by bringing all insights together to highlight the need for a paradigm shift in how global commons are conceptualized and preserved, while also outlining legal avenues through which such a transformation could be realised in the context of LEO.

1. Law and Economics and the neoclassical tradition

*“In a free society (...) there is one and only one social responsibility of business – to use its resources and engage in activities designed to increase its profits so long as it stays within the rules of the game (...)”.*⁶²⁹

The origins of the economic analysis of law can be traced back to Jeremy Bentham, who “systematically examined how actors would behave in the face of legal incentives (especially criminal sanctions) and who evaluated outcomes with respect to a clearly stated measure of social welfare (utilitarianism)”.⁶³⁰ The fundamental assumption of Law and Economics follows the *classical economic* thought and the rational choice theory, developed

⁶²⁹ Milton Friedman, ‘A Friedman doctrine – The Social Responsibility of Business is to Increase Its Profits’ *The New York Times* (New York, 13 September 1970) 125.

⁶³⁰ Mitchell Polinsky and Steven Shavell, ‘Economic Analysis of Law’ in: Matias Vernengo, Esteban Perez Caldentey, Jayati Ghosh (eds.) *The New Palgrave Dictionary of Economics* (Palgrave Macmillan 2008) https://doi.org/10.1057/978-1-349-95121-5_2440-1 accessed 20 October 2025; see also: Jeremy Bentham, ‘An Introduction to the Principles of Morals and Legislation’ in Monika Class, Cian Duffy (eds.) *Literature and Philosophy in Nineteenth Century British Culture* (Routledge 2024) 263, 263-267.

from the work of Adam Smith.⁶³¹ The theory rests on two central premises. First, the human being as *homo economicus* acts with perfect rationality on the basis of complete information, making decisions by weighing costs and benefits in order to maximise individual utility.⁶³² Second, when many individuals behave in this way, their actions, guided by an “invisible hand” under ideal conditions, collectively add up to the best possible outcome for society.⁶³³ A key contribution of classical political economy was the recognition that economic growth is driven by the accumulation and productive investment of a portion of the social surplus – under capitalism, primarily through the reinvestment of profits.⁶³⁴

Moreover, within the classical economic theory, the role of law is conceived as minimal and largely corrective, resting on the belief that markets are self-regulating and that state intervention would be limited to exceptional cases.⁶³⁵ This reflects the broader *laissez-faire* ethos that dominated early economic thought. At the same time, the rationalist law-and-economics tradition recognizes that markets cannot function in a vacuum: they require a baseline of legal infrastructure, such as property rights, contract enforcement, and dispute resolution, to operate effectively.⁶³⁶ Furthermore, within this framework, profit maximisation is often assumed to align, at least in the aggregate, with broader social welfare. Economic

⁶³¹ Most history of economics texts divide the history of economics into periods of pre-classical, classical, neoclassical, and modern. The term, *classical economics* was coined by Karl Marx in 1847 to describe David Ricardo’s formal economics, in contrast to what he called “vulgar or popular” economics. Over time, the label came to refer broadly to economic thought from roughly 1776 to 1870. Although Joseph Schumpeter, the famous Austrian political economist followed Marx in beginning the classical period with Ricardo, placing Adam Smith among the mercantilists, most histories of economic thought include Smith as a classical economist. See: David Colander, ‘The Death of Neoclassical Economics’ (2000) 22(2) *Journal of the History of Economic Thought* 127, 130-132.

⁶³² Even classical economists recognise that preferences change, and people do not always act as rational maximisers, but they assume such deviations are small and random enough that the rationality model remains useful, and that more realistic alternatives add excessive complexity. See: Milton Friedman, ‘The Methodology of Positive Economics’ in Daniel M. Hausman (ed.) *The Philosophy of Economics* (3rd eds, Cambridge University Press 2007) 145, 145-178.

⁶³³ Adam Smith, *An Inquiry into the Nature and Causes of the Wealth of Nations* (Edwin Cannan ed, University of Chicago Press 1977) 477-478.

⁶³⁴ Donald J Harris, ‘Classical Growth Model’ in Matias Vernengo, Esteban Perez Caldentey, Jayati Ghosh (eds.) *The New Palgrave Dictionary of Economics* (Palgrave Macmillan, 2008) 1, 1-2 <https://link.springer.com/rwe/10.1057/978-1-349-95121-5_3037-2> accessed 20 October 2025.

⁶³⁵ Besides Adam Smith, other classical political economic thinkers reflected on the relationship between law and markets. See for example: David Ricardo, *On the Principles of Political Economy and Taxation* (Piero Sraffa ed, Liberty Fund, 2004); Stuart John Mill, *Principles of Political Economy* (Sir William James Ashley ed, Liberty Fund, 1909); or Jeremy Bentham, *An Introduction to the Principles of Morals and Legislation* in Monika Class, Cian Duffy (eds.) *Literature and Philosophy in Nineteenth Century British Culture* (Routledge 2024).

⁶³⁶ See for example: Richard Nelson, ‘The Economic System Question Revisited’ (2022) 31(3) *Industrial and Corporate Change* 591, 596.

analysis of law therefore employs reasoning not only to explain and predict behaviour, but also to evaluate the efficiency of legal rules and institutions.

In the second part of the nineteenth century, the so-called *neoclassical school of economics* emerged, which marked a decisive shift from classical economics through the work of Jevons, Menger, and Walras.⁶³⁷ Neoclassical economics explain economic outcomes through individual choice and market mechanisms, treating law primarily as a corrective instrument. Although scholars may differ on the degree of human rationality, neoclassical economic theory generally assumes that individuals consistently weigh the pros and cons of their actions through cost-benefit analysis and choose the option with the highest net utility. In this logic, a person will exercise diligence only if the benefits of doing so outweigh the costs; breach a contract, when breaking it is less costly than compliance; and refrain from crime only when the expected penalty exceeds the anticipated gain.⁶³⁸ These calculations are typically expressed in monetary terms, allowing choices to be compared on a common scale. Two related expressions to note here, thus are the *willingness to pay*, and *cost-benefit-analysis*. Accordingly, preferences are measured by individuals' willingness to pay for a given outcome, forming the basis of cost-benefit analysis.⁶³⁹

Against this theoretical backdrop, the *Chicago School of Law and Economics* emerged as the most influential attempt to operationalise neoclassical insights within legal analysis.

⁶³⁷ It is widely recognised that there is considerable inconsistency in how the term *neoclassical* is defined and applied. Nonetheless, it is generally understood that the neoclassical movement began in the second half of the nineteenth century and concluded around the 1930s, with the emergence of modern economic theory. See: David Colander, 'The Death of Neoclassical Economics' (2000) 22(2) *Journal of the History of Economic Thought* 127, 132-135. While classical economics was primarily concerned with production, distribution, and social classes and emphasized objective cost and long-run dynamics, neoclassical economics marked a shift toward subjective value theory and formal models of resource allocation under scarcity. This new approach focused on individual analysis, choice, marginal analysis, price formation and equilibrium, thereby reorienting economic analysis from structural and historical questions to micro-level decision-making and market conditions. Despite these differences, both traditions share a commitment to market-based capitalism, efficiency, and the search for general economic laws.

⁶³⁸ Andrea Bianchi, *International Law Theories, An Inquiry into Different Ways of Thinking* (Oxford University Press 2016) 263, 264. This is also related to the *price theory* of neoclassical economics, according to which prices arise from the interaction of supply and demand and serve as a coordinating mechanism for the allocation of scarce resources. See: Alfred Marshall, *Principles of Economics* (8th ed. London: Macmillan and Co. 1920) Book VI, Ch 1.

⁶³⁹ Cass Sunstein, 'Lives, Life-Years, and Willingness to Pay' (2004) 104 *Columbia Law Review* 205, 205-251; Elizabeth Hoffman & Matthew L. Spitzer, 'Willingness to Pay vs. Willingness to Accept: Legal and Economic Implications' (1993) 71(1) *Washington University Law Quarterly* 59, 59-114. "Cost-benefit analysis assumes that willingness to pay is "an adequate representation of the difference in his or her utility arising from the change from the status quo and a given alternative state". See: Eyal Zamir and Doron Teichman, *Behavioral Law and Economics* (Oxford University Press 2018) 16.

Drawing on three main strands of neoclassical economics, particularly relevant for the development of Law and Economics – welfare economics; market failure theory; and new institutional economics – Chicago scholars apply microeconomic reasoning to legal rules in order to assess how law structures incentives, allocates resources, and promotes efficiency.

The Chicago School, associated with scholars such as Richard Posner, Ronald Coase, Gary Becker,⁶⁴⁰ and influenced by economists like Milton Friedman, emphasizes rational choice, efficiency, and the self-correcting capacity of markets. Rather than advocating extensive market regulation, this approach generally emphasizes correcting institutional and incentive structures through property rights, liability rules, and market-based mechanisms. Within this framework, law is viewed primarily as a mechanism (legal institution) for structuring incentives and correcting inefficiencies when markets fail due to transaction costs or poorly defined property rights. *Richard Posner*, one of the most influential figures in the Law and Economics movement, for instance, argued that the primary function of law is to maximize society's wealth, with *efficiency* serving as the principal criterion for evaluating legal rules.⁶⁴¹ In Posner's view, legal doctrines should be assessed according to how effectively they allocate resources rather than according to moral or distributive considerations.⁶⁴² This perspective builds on the foundational insights of *Ronald Coase*, who demonstrated that the allocation of legal rights determines how parties bargain in the presence of transaction costs.⁶⁴³

⁶⁴⁰ Gary Becker, 'Crime and punishment: An economic approach' (1968) 76 *Journal of Political Economy* 169, 169–217. Coase and Becker have been awarded the Nobel Prize in economics. See also: Nicholas Mercuro and Steven G. Medema, *Economics and the Law* (2nd edn, Princeton University Press, 2020) 101.

⁶⁴¹ Richard Posner, *Economic Analysis of Law* (3rd edn, Wolters Kluwer 1986) 11–15. Many critics argue especially in the old Institutional law and economics tradition – and even Posner himself has acknowledged – that the wealth-maximization criterion tends to reify existing distributions of wealth. In this sense, wealth maximisation disproportionately favours those who already possess economic resources and, as a result, the invocation of efficiency as a normative benchmark risks reinforcing existing power relations within the economic system, effectively allowing market outcomes to function as arbiters of legal rights. See: Nicholas Mercuro and Steven G. Medema, *Economics and the Law* (2nd edn, Princeton University Press, 2020) 48.

⁶⁴² According to Posner, a rule is efficient if those who gain from it could compensate those who lose and still come out ahead. This contrasts with the *Pareto efficiency*, which requires that no one be made worse off. See: Eric A Posner and Alan O Sykes, *Economic Foundations of International Law* (Harvard University Press, 2013) 3–4.

⁶⁴³ An important element of Law and Economics can be connected to Ronald Coase, who in 1960 published his landmark article, titled, *The Problem of Social Cost*, which became foundational for the law and economics movement. Coase introduced the concept of *transaction costs* and formulated what is now known as the *Coase*

Coase's analysis shifted the focus from correcting market failures through taxation or regulation, to designing legal rules that minimise transaction costs and facilitate private ordering. Complementing this view, *Milton Friedman* argued that businesses cannot be expected to assume social responsibilities on their own. In his view, the primary responsibility of firms is profit maximization within the framework of the law and rules established by the state ("the rules of the game").⁶⁴⁴ Indeed, in competitive markets, firms that neglect profit may be outcompeted, even if individual managers are ethically motivated. Thus, Friedman rejected the doctrine of corporate social responsibility,⁶⁴⁵ aligning with Adam Smith in maintaining that profit-driven behaviour by firms is legitimate. He argued that if citizens wish to pursue redistributive goals, these should be achieved through indirect democratic processes – by changing the "rules of the game" through taxation and legislation – rather than imposed directly on firms.⁶⁴⁶ Accordingly, Friedman reinforced the Chicago School's emphasis on incentives and market mechanisms as the primary drivers of economic behaviour, while largely treating legal and institutional frameworks as given background constraints.

Welfare economics rooted in the work of Vilfredo Pigou, Arthur Cecil Pareto and Kaldor-Hicks, who played a central role in shaping legal thought. In economics, the notion of the "good" derives largely from welfare economics, where it reflects the benefits accruing to consumers and producers as measured by individual utility.⁶⁴⁷ Welfare economics serves to connect theoretical economic analysis with practical policymaking by informing public authorities about when and how intervention may be warranted to address socially significant

theorem. In its simplest form, the theorem states that if transaction costs are absent, parties will negotiate toward an economically efficient outcome regardless of how legal entitlements are initially allocated. Transaction costs can be understood, for example, as those incurred for "identifying and bringing the parties together, having them negotiate, as well as the costs of the bargaining process, and those related to its enforcement". Ronald H. Coase, 'The problem of social cost' (1960) 3 *Journal of Law and Economics* 1, 1.

⁶⁴⁴ See: Milton Friedman, 'A Friedman doctrine – The Social Responsibility of Business is to Increase Its Profits' *The New York Times* (New York, 13 September 1970) 124.

⁶⁴⁵ Under the social responsibility doctrine, related to environmental protection for example, a company executive should make expenditures on reducing pollution beyond the amount that is in the best interests of their corporation or required by law. See: *Ibid.*, 124.

⁶⁴⁶ *Ibid.*, 124.

⁶⁴⁷ Mariana Mazzucato, 'Governing the economics of the common good: from correcting market failures to shaping collective goals' (2024) 27(1) *Journal of Economic Policy Reform* 1, 1.

problems.⁶⁴⁸ It views law as a tool for improving social outcomes by internalizing externalities and promoting efficiency, subject to equity considerations. Although not unified around a single normative framework, welfare economics generally evaluates social states in terms of individual well-being, using concepts such as utility, preferences, and willingness to pay. In its classical utilitarian variant, the public good, or efficient allocation of goods, is understood as the aggregation of private interests, meaning that when individuals pursue their own self-interest in a perfectly competitive markets,⁶⁴⁹ the result is assumed to generate the most efficient overall welfare.⁶⁵⁰ Accordingly, trade-offs are allowed – some may be made worse off if total welfare or utility increases. By contrast, *Pareto efficiency*, named after Italian economist, Vilfred Pareto, avoids interpersonal welfare comparison and defines a resource allocation as efficient if no further changes can make someone better off without harming anyone else. Since, however, most policies benefit some while harming others, strict Pareto efficiency is rarely achievable.⁶⁵¹ Instead, in practice, governance often rely on the so-called *Kaldor-Hicks efficiency*, which asserts that a legal rule is desirable or efficient if, as a result, the total gains are larger than the total losses, measured in monetary terms. In other words, an outcome is considered an improvement if the winner could hypothetically compensate the

⁶⁴⁸ Welfare economics confines the scope of morally relevant factors to consequences, and within those consequences, it focuses narrowly on human welfare. What constitutes human well-fare are in general three options: subjective happiness or pleasure, satisfaction of preferences, and objective good. See: Eyal Zamir and Doron Teichman, *Behavioral Law and Economics* (Oxford University Press 2018) 14.

⁶⁴⁹ Welfare economics is grounded in the *first optimality theorem*, which establishes that a perfectly competitive economy – absent major frictions such as information asymmetries, enforcement problems, public goods, or externalities – generates an efficient allocation of society’s scarce resources. “The purely competitive, perfectly functioning market has the following characteristics: (i) a large number of buyers motivated by self-interest and making the choices they expect will maximize their utility; (ii) many sellers, also motivated by self-interest, and acting to maximize their profits; (iii) individual buyers and sellers are unable to exert any control over market prices and are thus price takers; (iv) prices serve as the guideposts for decision-makers in the market to (among other things) communicate scarcity; (v) products are standardized (i.e., homogeneous); (vi) there are no barriers to entry or exit, which means that consumers and producers are free to enter or leave all product and factor markets; (vii) all buyers and sellers are fully in-formed as to the terms of all market transactions; (viii) resources are held in private property with all rights defined and assigned; and (ix) prevailing laws and property rights are fully enforced through the state. (...) If all factors of production and all goods and services are bought and sold in perfectly competitive markets, the outcome can be shown to be efficient. See: Nicholas Mercuro and Steven G. Medema, *Economics and the Law* (2nd edn, Princeton University Press, 2020) 20-21.

⁶⁵⁰ First articulated by Bentham (1789), this utilitarian perspective later became influential in economic analyses of social welfare, particularly in the works of Marshall (1890), Pigou (1920), and Robertson (1952). See: Amartya Sen, ‘Welfare Economics, Utilitarianism, and Equity’ in Amartya Sen and James Foster, *On Economic Inequality* (1973, Oxford University Press) 1, 16.

⁶⁵¹ Eric A Posner and Alan O Sykes, *Economic Foundations of International Law* (Harvard University Press, 2013) 3-4; and Mariana Mazzucato, ‘Governing the economics of the common good: from correcting market failures to shaping collective goals’ (2024) 27(1) *Journal of Economic Policy Reform* 1, 4.

losers and still retain a net benefit. This approach allows welfare trade-offs and is therefore more closely aligned with utilitarian reasoning, while avoiding the need for actual compensation. From a Law and Economics perspective, the Kaldor-Hicks efficiency criterion justifies legal rules when their aggregate benefits, such as reduced debris risk, preserved orbital capacity, and more equitable access for future generations, exceed the costs imposed on particular operators, even where those costs are not directly compensated.

Market failure theory emerged from neoclassical welfare economics, especially through the work of scholars such as Pigou,⁶⁵² Samuelson,⁶⁵³ and Arrow,⁶⁵⁴ who demonstrated that unregulated markets may fail to allocate resources efficiently in the presence of externalities, public goods, or information asymmetries. As previously discussed, neoclassical economics treats perfect competition as an ideal benchmark for market performance; deviations from these ideals, according to welfare economics, are viewed as forms of *market failure*. Welfare economics systematically identified circumstances in which ideal market conditions break down, giving rise to allocative inefficiencies and providing a normative justification for legal and governmental intervention. Specifically, neoclassical economics identifies three types of market failures: monopolies, externalities and public goods, and asymmetric information.⁶⁵⁵ Because of these market failures, this strand of welfare economics provides a foundational justification for legal and governmental intervention.⁶⁵⁶ This framework is widely used in environmental economics, a topic that will be discussed in greater detail later in this chapter.

New institutional economics builds on mainly two foundational principles. First, individuals are assumed to pursue their self-interest rationally, but within a framework of

⁶⁵² See: Arthur Cecil Pigou, *The Economics of Welfare* (4th edn, Macmillan 1932) <https://oll-resources.s3.us-east-2.amazonaws.com/oll3/store/titles/1410/Pigou_0316_EBk_v6.0.pdf> accessed 20 October 2025, where Pigou introduces the divergence between private and social costs and benefits, and explains why markets fail in the presence of externalities, justifying corrective intervention (such as taxes and regulation).

⁶⁵³ Paul A. Samuelson, 'The Pure Theory of Public Expenditure, *The Review of Economics and Statistics*' (1954) 36(4) *MIT Press* 387-389, Where Samuelson establishes the theory of public good and demonstrates why markets cannot efficiently provide them.

⁶⁵⁴ See: Kenneth J. Arrow, 'Uncertainty and the Welfare Economics of Medical Care' (1963) 53(5) *The American Economic Review* 941, 946-947, shows how information asymmetries and uncertainty undermine market efficiency.

⁶⁵⁵ Weiyang Zhang, 'A paradigmatic change is needed for understanding the real market' (2021) 66 *China Economic Review* 1, 4.

⁶⁵⁶ Brian Dollery and Joe Wallis, *The Theory of Market Failure and Policy Making in Contemporary Local Government* (2001) University of New England School of Economics 2, 5 <<https://www.une.edu.au/about-une/faculty-of-science-agriculture-business-and-law/unebs/research/occasional-paper-series/economics/1999-2007/pdfs-economics-1999-2007/econwp01-6.pdf>> accessed 20 October 2025.

constraints that are more numerous and restrictive than those assumed in standard neoclassical theory.⁶⁵⁷ These constraints include the existence and specification of property rights, the presence of transaction costs, and the recognition of *bounded rationality* arising from the limited cognitive capacity of individuals.⁶⁵⁸ Second, the emphasis on wealth maximisation, through institutional design states that the value of resources depends on how clearly property rights are defined: the more precise and secure these rights are, the lower the uncertainty and transaction cost, and the more efficient the use of resources.⁶⁵⁹ As a result, much of new institutional economics concentrates on analysing how different institutional arrangements affect economic performance over time.

2. Economic analysis of international law

From the 1990s onwards, economic analysis gained momentum in international law, accelerating exponentially to become one of the most influential theories of international law.⁶⁶⁰ Economic analysis in international law often draws an analogy between individual markets and the “market” of international relations. In this view, states, like rational market participants, are assumed to pursue stable interest, negotiate agreements, and cooperate through international institutions to maximise their own interests.⁶⁶¹ It also follows from the rational

⁶⁵⁷ Nicholas Mercuro and Steven G. Medema, *Economics and the Law* (2nd edn, Princeton University Press, 2020) 244.

⁶⁵⁸ Although both new institutional economics and behavioural economics draw on Herbert Simon’s concept of *bounded rationality*, they employ the idea in different ways. In new institutional economics, bounded rationality serves to explain the existence of transaction costs and the need for institutions, while behavioural economics uses it to identify systematic deviations from rational choice arising from cognitive biases. See: Herbert Simon, ‘Theories of Bounded Rationality’, in R. Radner and C. B. McGuire (eds.) *Decision and Organization* (North Holland Publishing Company 1972) 161, 161-176.

⁶⁵⁹ Nicholas Mercuro and Steven G. Medema, *Economics and the Law* (2nd edn, Princeton University Press, 2020) 245.

⁶⁶⁰ See for example: Kenneth Abbott, ‘Modern International Relations Theory: A Prospectus for International Lawyers’ (1989) 14 *Yale Journal of International Law* 335; Jeffrey L. Dunoff & Joel P. Trachtman, ‘Economic Analysis of International Law’ (1999) 24 *Yale Journal of International Law* 1; Jack L. Goldsmith & Eric A. Posner, *The Limits of International Law* (Oxford University Press 2005); and Anne van Aaken, ‘To Do Away with International Law? Some Limits to ‘The Limits of International Law’ (2006) 17 *European Journal of International Law* 289.

⁶⁶¹ Importantly, as Aaken and Stradner note, rational actors are not assumed to focus solely on short-term gains. Rather, they operate within repeated interactions and long-term relationships, where the consequences of

choice theory, that actors are assumed to make strategic decisions aimed at maximising their own interest.⁶⁶² This assumption rests on three subsidiary claims in international law: (i) states are treated as rational actors, (ii) their preferences or interests are stable and at least to some degree, knowable to others, and (iii) they act in ways that maximise those interests.⁶⁶³ Each of these promises, however, has been subject to significant critique and challenge.⁶⁶⁴ Unlike private actors who exchange goods, services, or money, states bargain with forms of power – military, economic, political, technological, and strategic advantages.⁶⁶⁵ The result is a system closer to barter than to a monetary economy. This barter-like structure significantly raises transaction costs, following the Coase theorem: coordinating numerous actors with divergent interests, and without a central enforcing authority, is inherently more complex than ordinary market exchange.⁶⁶⁶ Nonetheless, it is worth adding that both in “international law and economics” and in International Relations the rational choice approach assumes the condition of *anarchy*.⁶⁶⁷ In international law and economics, however, this does not mean chaos, but

lawmaking and compliance with international law are calculated part of their broader strategic reasoning. Rational choice theory focuses on strategic interactions, where each actor is defined by two attributes: *preferences* (the ability to rank outcomes) and *beliefs* (expectations about the preferences of others). “Because rational actors want to form an expectation of how other players will behave, they need to have some belief about what preferences other actors possess” See: Anne van Aaken and Ivana Stradner, ‘Economic analysis of international law’ in Rossana Deplano and Nicholas Tsagourias (eds) *Research Methods in International Law* (Edward Elgar Publishing 2021) 366, 367; and Jeffrey Dunoff and Joel Trachtman, ‘Economic Analysis of International Law’ (1999) 24(1) *The Yale Journal of International Law* 1, 13.

⁶⁶² Richard Posner, ‘Rational Choice, Behavioral Economics, and the Law’ (1998) 50(5) *Stanford Law Review* 1551, 1551; Kenneth W Abbott, ‘Enriching Rational Choice Institutionalism for the Study of International Law’ (2007) 1 *University of Illinois Law Review* 5, 6; Jeffrey Dunoff and Joel Trachtman, ‘Economic Analysis of International Law’ (1999) 24(1) *The Yale Journal of International Law* 1, 2; Jack L Goldsmith and Eric A Posner, ‘A Theory of Customary International Law’ (1999) 66(4) *The University of Chicago Law Review* 1113, 1113-1177.

⁶⁶³ Robert O Keohane, ‘Rational Choice Theory and International Law: Insights and Limitations’ (2002) 31(1) *The Journal of Legal Studies* 307, 307-309.

⁶⁶⁴ See for example: Zheng Tang, ‘International Judicial Cooperation in Game Theory’ (2021) *Journal of International Dispute Settlement* 1, 1-33.

⁶⁶⁵ Andrea Bianchi, *International Law Theories, An Inquiry into Different Ways of Thinking* (Oxford University Press 2016) 263, 270.

⁶⁶⁶ The Coase theorem applied in international law suggests that if transaction (bargaining) costs are zero or small, states will always negotiate and trade to use resources efficiently, no matter who has the formal right to them.

⁶⁶⁷ The realist school, which laid the foundations of International Relations (IR) in the 1940s within a Hobbesian tradition, also drew on rational choice theory by emphasizing the primacy of national interest and the sensitivity of states to incentives shaped by power relations. Neoliberal institutionalist theory, by contrast, built on the same rationalist assumption about states as self-interested actors, but added a further layer of strategic interaction,

rather the absence of a central international authority with the power to create and enforce laws.⁶⁶⁸

International law and economics scholarship centres on two core dimensions: 1) the processes through which international law is *made*, and 2) the mechanisms that sustain state *compliance* in the absence of centralized enforcement.⁶⁶⁹ In pursuing both inquiries, international law and economics draws on a wide range of analytical tools – among them, game theory, contract theory, price theory, principal-agent models, and collective-action approaches such as public choice and political economy – together with foundational concepts like externalities and common goods. Given the limited scope of this dissertation, only several of these techniques will be discussed in the further sections.

With respect to *lawmaking*, international treaties – one of the primary sources of international law – are often analysed through the lens of *contract theory*. This approach shifts attention from an *ex post* focus on breaches and remedies toward *ex ante* questions: why states choose to enter agreements at all, and how such treaties can be designed to maximize efficiency and ensure stability. In the language of contract theory, a state will consent to a treaty only if the anticipated costs of constraining its sovereignty are outweighed by the expected net benefits of cooperation.⁶⁷⁰ Alan Sykes, a leading figure of the Chicago School, argues that simply identifying common international problems or externalities is not sufficient to explain why treaties emerge in some areas but not in others.⁶⁷¹ What matters equally is whether the transaction costs of negotiating, monitoring, and maintaining an agreement are low enough to make cooperation realistic. In practice, international agreements take shape only when they fall within the “core” of the bargaining game – that is, when every participating state expects to be better off by joining than by staying out or defecting to a smaller coalition or partnership. In

employing game-theoretic models to explain how competition can emerge among states. See: Hans J Morgenthau, *Politics among Nations: The Struggle for Power and Peace* (6th edn, Alfred A. Knopf, 1985) 3-17; Duncan Snidal, ‘The Game Theory of International Politics’ (1985) 38(1) *World Politics* 25, 25-57; In terms of anarchy and international relations, see for example: Kenneth N Waltz, ‘The Anarchic Structure of World Politics’ in Robert Art and Robert Jervis (eds.) *International Politics: Enduring Concepts and Contemporary Issues* (13th edn, Pearson Education, Inc, 2017) 48, 48-69.

⁶⁶⁸ Anne van Aaken and Ivana Stradner, ‘Economic analysis of international law’ in Rossana Deplano and Nicholas Tsagourias (eds) *Research Methods in International Law* (Edward Elgar Publishing 2021) 366, 367.

⁶⁶⁹ *Ibid.*, 369.

⁶⁷⁰ *Ibid.*, 371.

⁶⁷¹ Alan O Sykes, ‘The Economics of Public International Law’ (2004) (John M. Olin Program in Law and Economics Working Paper No. 216) 14-15.

such cases, cooperation becomes a form of *Pareto improvement*, where no state is made worse off and at least one benefits.⁶⁷² Additionally, the transaction costs of reaching, monitoring, and enforcing international agreements can be very high – especially when many actors with divergent interests are involved and no central authority exists. In such cases, even when everyone would benefit from cooperation, the costs of negotiation or enforcing an agreement may block progress.

The *Coase theorem* from an international law perspective suggests that if transaction (bargaining) costs are zero or small, states will always negotiate and trade to use resources efficiently, no matter who has the formal right to them.⁶⁷³ This idea has been challenged on practical grounds. For example, from a behavioural economics perspective applied to international law, the so-called endowment effect means that states (much like individuals), tend to overvalue what they already possess simply because they own it.⁶⁷⁴ Furthermore, in practice, transaction costs are never zero – least of all in multilateral negotiations. International bargaining is typically slow, costly, and plagued by informational asymmetries and uncertainty. To address these obstacles, scholars in the institutionalist tradition argue that international organizations and regimes can play a vital role in mitigating “anarchy” by lowering transaction costs, streamlining negotiations, and reducing uncertainty, thereby making cooperation more

⁶⁷² Ibid., 14-15. It is important to distinguish between Pareto efficiency and Pareto improvement. A state of affairs is *Pareto efficient* when no actor can be made better off without making another worse off. By contrast, a *Pareto improvement* refers to a change that makes at least one actor better off without harming others. Multilateral treaties typically require all States Parties to perceive at least a Pareto improvement in order to consent, since no external authority exists to impose or enforce redistribution (Kaldor-Hicks element). Achieving full Pareto efficiency, as previously discussed, is far more difficult, as distributional conflicts in global commons governance mean that almost any new rule creates winners and losers.

⁶⁷³ Anne van Aaken and Ivana Stradner, ‘Economic analysis of international law’ in Rossana Deplano and Nicholas Tsagourias (eds) *Research Methods in International Law* (Edward Elgar Publishing 2021) 366, 374.

⁶⁷⁴ This helps understanding, for example, why territorial swaps are so rare, even when both parties might gain. In such cases, the Coase theorem breaks down: preferences are not neutral but systematically distorted by ownership. See: Daniel Kahneman, Jack L. Knetsch and Richard H Thaler, ‘Experimental Test of the Endowment Effect and the Coase Theorem’ (1991) 98(6) *Journal of Political Economy* 1325, 1326-1329.

feasible.⁶⁷⁵ Additionally, a central challenge in contract theory lies in managing *uncertainty*:⁶⁷⁶ in multilateral negotiations, parties must strike a balance between ensuring stability to encourage mutually beneficial investment and preserving enough flexibility to adapt to changing conditions.

Within *game-theoretic analysis*, which models strategic interactions under “anarchy”, two principal families of models are frequently applied in international law: *coordination games* and the *Prisoner’s Dilemma*. While coordination games are especially relevant to contracting and treaty formation and design, Prisoner’s Dilemma is more applicable to treaty compliance and enforcement. In coordination games the central challenge is not the temptation to defect, but the ambiguity of choosing among multiple possible equilibria.⁶⁷⁷ The key question is how states overcome this ambiguity without a central authority to enforce alignment. Repeated interactions, shared expectations, and communication can generate self-enforcing solutions: not perfect or uniquely optimal outcomes, but workable and adaptive equilibria. Such mechanisms are particularly relevant in dynamic domains like technology law (such as space law), where rules must evolve with changing conditions, and where the absence of global enforcement institutions makes spontaneous coordination indispensable. Some of the

⁶⁷⁵ See for example: Robert O. Keohane, *After Hegemony: Cooperation and Discord in the World Political Economy* (Princeton University Press 1984) 88; and Joel Trachtman, *The Economic Structure of International Law* (Harvard University Press 2008) 150-196.

⁶⁷⁶ Contract theory distinguishes between three types of uncertainty: 1. unforeseeable future developments (particularly relevant to fields like environmental law and law dealing with the regulation of rapidly evolving technologies such as space activities, or artificial intelligence); 2. information asymmetries about other actors’ behaviour; and 3. ambiguity on the meaning or scope of treaty provisions. Of these, information asymmetries pose the greatest risk, as each party holds private knowledge that others lack, creating opportunities for opportunism. As a result, international law is inherently incomplete, relying heavily on implicit understanding and expectations to fill gap in treaties that are difficult to enforce. See: Anne van Aaken and Ivana Stradner, ‘Economic analysis of international law’ in Rossana Deplano and Nicholas Tsagourias (eds) *Research Methods in International Law* (Edward Elgar Publishing 2021) 366, 371.

⁶⁷⁷ Zheng Tang, ‘International Judicial Cooperation in Game Theory’ (2021) *Journal of International Dispute Settlement* 1,18.

main coordination games applicable to international law are the Stag Hunt (or the Assurance Game);⁶⁷⁸ the Battle of Sexes;⁶⁷⁹ and the Chicken.⁶⁸⁰

When discussing *compliance*, from the perspective of rational economic analysis, the central question for compliance with international law is how cooperation can be sustained in the absence of a central authority capable of creating and enforcing obligation. The key question is: what is the price of breaching? A party may be tempted to break an agreement if the gains from breach exceed the expected benefits of performance. If these gains also surpass the expected benefits the other party would have received from compliance, and if the costs of breach (such as damages or reputational loss) are limited to covering that shortfall, the rational choice may be to breach.⁶⁸¹ In addressing questions of enforcement, the Prisoner's Dilemma is frequently used to illustrate the inherent limits of cooperation under conditions of anarchy. According to this approach, although mutual cooperation yields the best collective outcome, each actor has an incentive to defect, making defection the dominant strategy.⁶⁸² Avoiding the pessimistic outcomes predicted by the Prisoner's Dilemma requires conditions that make cooperation self-sustaining – most notably through mechanisms of retaliation, reciprocity,

⁶⁷⁸ The *Stag Hunt* illustrates the tension between cooperation and mistrust. Two hunters can either cooperate to hunt a stag (a high payoff for both) or go alone and catch a rabbit (a smaller, but guaranteed payoff). The best outcome is mutual cooperation, but if one hunter doubts the other's commitment, she may defect early to secure a rabbit rather than risk getting nothing. This dynamic explains why states hesitate to cooperate. If they fear others will not follow through, they may defect and choose minimal action. Experimental work, however, shows that communication and trust-building mechanisms increase the likelihood of cooperation. See: Brian Skyrms, *The Stag Hunt and the Evolution of Social Structure* (Cambridge University Press 2012) 1-14.

⁶⁷⁹ According to the *Battle of the Sexes*, a couple is deciding what to do together. They both prefer to be together rather than apart, but they disagree on the preferred activity. Applied in international law, states often agree that cooperation is necessary, but they disagree about how to distribute the burdens and benefits. Thus, the challenge here is not the cooperation itself, but to find a common framework to settle on. See for example: Zheng Tang, 'International Judicial Cooperation in Game Theory' (2021) *Journal of International Dispute Settlement* 1, 20.

⁶⁸⁰ The *Chicken game* has two players, who drive directly to each other, each hoping that the other swerve out of the way. If both swerve, they avoid disaster, but neither "wins" outright. If neither swerves, they crash – the worst possible outcome for both. If only one swerves, she will be seen as the "loser" while the other "wins". This is especially relevant to the free-riding dynamics in global commons, where all sides hope that the others will swerve (take the costly cooperative step), while they themselves keep going straight (free-ride). If all refuse to yield, the result is catastrophic, such as climate change. See: Joel Trachtman, *The Economic Structure of International Law* (Harvard University Press 2008) 134.

⁶⁸¹ Robert Birmingham, 'Breach of Contract, Damage Measures, and Economic Efficiency' (1970) 24 *Rutgers Law Review* 273, 273 and 284.

⁶⁸² In *Prisoner's Dilemma* interaction, two actors face a choice to cooperate or defect. If both cooperate, they achieve a good outcome (better than if both defect). But if one defects while the other cooperates, the defector gets the bigger gain while the cooperator suffers the worst loss. Because each actor fears being exploited, both tend to defect – even though mutual cooperation would leave them both better off. See: Joel Trachtman, *The Economic Structure of International Law* (Harvard University Press 2008) 81-84.

reputation and the “shadow of the future”, where long-term relationships make short-term defection less attractive.⁶⁸³

Before applying international law and economics to the governance of the orbital space as global commons, it is essential to first frame this larger systemic problem through the lens of neoclassical and welfare economics – particularly its specialized branch of environmental and resource economics, and to examine these perspectives through a legal lens.

B. Environmental and resource economics and the global commons

*“[The] essence of the environmental problem is the economy – producer behaviour and consumer desires”.*⁶⁸⁴

1. Environmental and resource economics

Adam Smith’s notion of the “invisible hand” suggests that individual pursuit of self-interest naturally translates into collective welfare. Were this assumption to hold universally, material self-interest could be regarded as a social virtue, and economic models could be constructed on simplified premises of rationality and equilibrium. Such a framework would render unnecessary the consideration of systemic externalities, distributive inequities, and the complex feedback dynamics that characterize real-world systems. The “elegance” of this vision explains its enduring practical influence for more than two centuries.⁶⁸⁵ Yet, its simplicity also reveals its limits: by overlooking externalities, distributive inequities, and the feedback

⁶⁸³ “Because states interact with each other over a long period of time, a reputation for abiding by cooperative arrangements is valuable to states”. See: Andrew T Guzman and Timothy L Meyer, ‘Customary International Law in the 21st Century’ in Russell A. Miller and Rebecca M. Bratspies (eds) *Progress in International Law* (Brill | Nijhoff 2008) 197, 201; Andrew Guzman, *How International Law Works: A Rational Choice Theory* (Oxford University Press 2008) 25-70; Anne van Aaken and Ivana Stradner, ‘Economic analysis of international law’ in Rossana Deplano and Nicholas Tsagourias (eds) *Research Methods in International Law* (Edward Elgar Publishing 2021) 366, 378-379.

⁶⁸⁴ Charles Kolstad, *Environmental economics* (Oxford University Press 1998) 1.

⁶⁸⁵ Donella H Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 105-106.

dynamics of shared and finite resources, it provides little guidance for managing global commons, such as the global climate and the Earth's orbital environment.

From a welfare economics perspective, the core dilemma lies in reconciling the drive for profit maximization with the demands of broader social and environmental responsibility. Classical market logic, particularly when applied in global settings, prioritises efficiency and the pursuit of self-interest, yet it often fails to safeguard common resources or ensure long-term sustainability. Environmental and resource economics, as a branch of neoclassical welfare economics, emerged precisely to address these shortcomings, reframing resources such as forests, fisheries, and the climate as finite, fragile, and prone to overexploitation. While this field has traditionally focused on market failures within domestic economies and firms, international law and economics extends the analysis to the interactions of sovereign states in global governance. This also makes environmental and resource economics highly relevant to orbital space, where limited capacity and debris generation create similar risks of scarcity, externalities, and systemic overuse. The challenge here lies in designing governance arrangements and identifying efficient distribution mechanisms capable of managing an international commons in the absence of a central authority, yet still operating within the narrow, neoclassical Law and Economics framework.

2. Market failures

As previously discussed, classical economic theory assumes that markets, left to themselves, balance supply and demand to generate optimal outcomes for society. In practice, however, this mechanism frequently breaks down, producing inefficiencies or harmful consequences. Environmental and resource economics highlights that many environmental issues stem from such breakdowns, described as market failures – a concept first articulated by Francis Bator, a key figure in welfare economics, to capture situations in which markets fail to allocate resources efficiently.⁶⁸⁶ Building on this insight, much of neoclassical economic

⁶⁸⁶ Francis Bator, 'The anatomy of market failure' (1958) 72(3) *The Quarterly Journal of Economics* 351, 351-379.

analysis has centred on identifying and addressing the conditions under which markets fail to generate efficient or socially desirable outcomes.⁶⁸⁷ Scholars typically highlight four recurring forms of market failure that are especially relevant to environmental challenges: negative externalities, the problems of information asymmetry, the exercise of market power, and the insufficient provision of public goods.⁶⁸⁸

As outlined in the first chapter of this dissertation, all major categories of market failures – externalities, monopolization, information asymmetries, uncertainty, and the common-pool resources dilemma – are deeply embedded in the governance challenges of the orbital space environment. Each manifests in distinct ways: satellite launches create negative externalities in the form of collision risks and long-lived debris, often blurring the boundary between public and private control; information asymmetries and scientific uncertainty complicate monitoring and verification; and the non-excludable yet rivalrous nature of orbital capacity generates classic common pool resources pressures, including the tragedy of the commons and widespread free-riding leading to the overexploitation of LEO. Taken together, these dynamics make orbital space particularly prone to inefficiency, overuse, and inequitable outcomes if left solely to market forces. The following sections therefore turn to the legal-economic toolkit – regulatory, economic, and voluntary instruments – as potential means to internalize externalities, distribute responsibilities, and build governance arrangements that might reconcile efficiency with sustainability and equity in the management of the orbital commons.

a) Externalities

*“(…) turning our attention to environmental treaties,
we notice that their core objective is
not the protection of the environment,
but the efficient management and
commodification of industrial externalities”.*⁶⁸⁹

⁶⁸⁷ Eyal Zamir and Doron Teichman, *Behavioral Law and Economics* (Oxford University Press 2018) 11.

⁶⁸⁸ Kentaka Aruga, *Environmental and Natural Resource Economics* (Springer 2022) 19.

⁶⁸⁹ Olivier Barsalou and Michael Hennessy Picard, ‘International Environmental Law in an Era of Globalized Waste’ (2018) 17(3) *Chinese Journal of International Law* 887, 897.

In welfare economics, externalities are understood as spillover effects of economic activities whose costs or benefits are not captured by market prices.⁶⁹⁰ Accordingly, we can differentiate between positive and negative externalities. A positive externality arises when the economic activity of one agent benefits others without directly compensating for it, while negative externality arises when an activity imposes costs or harms on others that are not reflected in market transactions or prices.⁶⁹¹ In other words, externalities distort market signals by concealing the true social costs of resource and environmental use, thereby encouraging overexploitation and resulting in long-term welfare losses. When externalities are not accounted for in economic decision-making, natural resources tend to be either over-supplied or over-consumed, leading to their overexploitation.⁶⁹² Consequently, externalities are recognized as a key cause of market failure, preventing the market from achieving socially efficient outcomes. This recognition has long driven economists to focus on environmental

⁶⁹⁰ In his seminal work, *The Economics of Welfare*, Pigou argued that markets (and market prices) often fail to account for costs or benefits imposed on others – in other words, markets fail to achieve the socially optimal outcome –, which idea later became known as *externalities*, the foundation of environmental economics and the modern concept of market failure. See: Arthur Cecil Pigou, *The Economics of Welfare* (4th edn, Macmillan 1932) Part II, Chapter IX §10 <https://oll-resources.s3.us-east-2.amazonaws.com/oll3/store/titles/1410/Pigou_0316_EBk_v6.0.pdf> accessed 20 October 2025.

⁶⁹¹ A common example for a *positive externality* is planting trees: besides providing shade and fruit for the owner, trees absorb carbon dioxide, improve air quality, and contribute to climate mitigation – benefits that spill over to society at large. Environmental harms, such as noise, air pollution, and ecosystem degradation are classical examples of *negative externalities*, since they shift costs onto others without their consent and without adequate compensation. It is also notable that negative externalities, from welfare economics perspective, can be further classified between pecuniary and technological forms. Pecuniary externalities occur through price changes and therefore do not, strictly speaking, constitute market failures. when the external effect is transmitted through altered prices, thus it does not cause a market failure. For example: if the opening of a new factory increases demand for housing in the surrounding area, property owners benefit from higher rents while existing tenants face higher costs. The losses of renters are offset by the gains of landlords, so the overall allocation remains efficient, only the distribution of wealth changes. By contrast, technological (or non-pecuniary) externalities, such as air or water pollution, impose direct harms that markets fail to compensate. See more: Arthur Cecil Pigou, *The Economics of Welfare* (4th edn, Macmillan 1932) Part II, Chapter IX §10; Tom Tietenberg and Lynne Lewis, *Environmental & Natural Resource Economics* (12th edn, Routledge 2024) 25-27.

⁶⁹² “In conventional economic analysis, the factory’s production is socially beneficial if and only if the value of production exceeds all of its costs, including the costs of pollution. This misallocation occurs because market process fails to reflect the true social cost or resource use”. See: Eric A Posner and Alan O Sykes, *Economic Foundations of International Law* (Harvard University Press 2013) 225.

externalities, generating a substantial body of scholarship in environmental and resource economics.⁶⁹³

Although externalities can have significant negative impacts on the economy, they are often not properly addressed by market mechanisms. To manage these effects, according to neoclassical economics, it is essential to evaluate their impact within the market framework. This process, known as the *internalization* of externalities in market language, refers to assigning monetary value to costs – such as environmental or social harms – that lie outside traditional market transactions and incorporating them into economic and legal decision-making.⁶⁹⁴ Proper internalization requires accurately assessing the external impacts that have not previously been priced and adjusting production and consumption accordingly to reflect their true *social costs*.⁶⁹⁵ When producers account for externalities, the assumption of welfare economics is that the perceived cost of production increases, which typically results in a reduction in the level of output. This adjustment leads to a new, socially optimal production level that better reflects the true cost to society.

From an economic perspective, the use of LEO clearly illustrates a (debris pollution) *negative externality*, structurally similar to terrestrial problems like greenhouse gas emissions or overfishing, but with a more persistent and potentially irreversible costs.⁶⁹⁶ Political-economic issues that shape terrestrial environmental management also surface in orbital space. When an operator launches a satellite, the activity generates private benefits in the form of revenue, services, and technological advancement. Yet, it also creates risk – most notably collision hazards and the generation of long-lived debris – that are borne not only by the

⁶⁹³ The significance of the link between environmental harm and economic analysis was underscored in 2018, when William Nordhaus was awarded the Nobel Prize in Economics for his pioneering work on integrating the impacts of pollution – particularly greenhouse gas emissions – into models of economic growth and output valuation. Nordhaus shared the Nobel Prize with Paul Romer, both of whom highlighted the limitations of markets and demonstrated how government intervention can improve outcomes. See: Binyamin Appelbaum, ‘2018 Nobel Prize is Awarded to William Nordhaus and Paul Romer’ *The New York Times* (8 October 2018) <https://www.nytimes.com/2018/10/08/business/economic-science-nobel-prize.html> accessed 20 October 2025.

⁶⁹⁴ Eric A Posner and Alan O Sykes, *Economic Foundations of International Law* (Harvard University Press, 2013) 225.

⁶⁹⁵ *Social cost* is the sum of *private costs* (borne directly by the producer) and *external costs* (the harms imposed on others, such as pollution). When external impacts are ignored, markets underestimate the true costs of production. See: Kentaka Aruga, *Environmental and Natural Resource Economics* (Springer 2022) 22.

⁶⁹⁶ „What has been happening with the terrestrial environment is more-or-less being replicated in orbital space”. See: Nodir Adilov, Peter Alexander and Brendan Cunningham, ‘Understanding the Economics of Orbital Pollution Through the Lens of Terrestrial Climate Change’ (2022) 59(2) *Space Policy* 1, 20.

launching operator but by all other present and future users of the orbital environment, including the highly affected astronomical sector. These costs are externalised because they are not reflected in market prices: the operator does not bear the full expense of the increased collision risk, which instead fall on other satellite operators and even on non-spacefaring states that rely on orbital services.⁶⁹⁷ In addressing the economic dynamics of orbital debris, Adilov et al. explicitly model debris as a negative externality and demonstrate that a competitive market structure leads to excessive debris generation, far beyond what is socially optimal.⁶⁹⁸ Adilov and his colleagues identify two primary externalities linked to debris creation. First, satellite operators do not account for the broader damaging effects their launches have on the orbital environment, particularly through the increased probability of collisions due to additional debris. As a result, companies have incentives to launch more satellites than socially optimal, leading to an over-saturation of the orbital environment. Second, firms under-invest in debris-mitigating technologies. Their investment decisions are based on a comparison of private costs and benefits, ignoring the broader social consequences. Technologies that could reduce debris risks, such as deorbiting mechanisms or satellite designs with longer lifespans, are often seen as unnecessarily burdensome or expensive from an individual firm's perspective, despite their aggregate benefit to all orbital users. Thus, it is argued that as the dynamics of the tragedy of commons and free-riding – two tendencies examined later in this section – intensify in the absence of effective cooperation, the costs of remediation rise sharply. These costs do not increase in a linear fashion but rather escalate exponentially over time, since each episode of debris generation amplifies collision risk and produces additional fragments that can persist in orbit for decades or even centuries.⁶⁹⁹

⁶⁹⁷ When a satellite is launched, the operator internalises only its private costs – manufacturing, launch and operational expenses – thus much of the harm generated is externalised. These social costs are not reflected in market prices: the operator does not bear the full expense of the increased collision risk, which instead falls on others. Competing satellite operators must perform costly avoidance manoeuvres that consume fuel and shorten mission lifetimes; insurance premiums rise for all participants as the risk increases. Non-spacefaring states, which rely heavily on orbital services without contributing to debris creation, are disproportionately affected by these spillovers, including through the danger of uncontrolled re-entries. See for example: Alexander William Salter, 'Space Debris: A Law and Economics Analysis of The Orbital Commons' (2016) 19 *Stanford Technology Law Review* 221, 221-238.

⁶⁹⁸ Nodir Adilov, Peter Alexander and Brendan Cunningham, 'Understanding the Economics of Orbital Pollution Through the Lens of Terrestrial Climate Change' (2022) 59(2) *Space Policy* 1, 6.

⁶⁹⁹ *Ibid.*, 13.

There are three groups of policy instruments according to environmental and resource economics that support the internalization of externalities: (a.1) direct regulation (including total emission regulation, emission standard regulation); (a.2) economic instruments (such as tax and emission trading system); and (a.3) voluntary means (e.g., standards and guidelines).⁷⁰⁰ While this taxonomy is mainly developed in the context of domestic regulation, it is equally relevant to the governance of global commons, such as the orbits, because both domains confront similar challenges of scarcity, externalities, and collective action, even if they operate without the backing of a centralized authority. Importantly, none of the three instruments is flawless; in practice, the complexity of environmental problems often necessitates a tailored mix of regulatory tools rather than reliance on any single mechanism. The following section examines these instruments in greater detail.

a.1 Internalization with direct regulation

Direct regulation, often referred to as *command-and-control*, central to this dissertation, is a policy measure whereby binding rules or standards set explicit limits on permissible levels of pollution in order to address negative externalities.⁷⁰¹ Unlike other costs, pollution is not automatically reflected in market prices because it is borne partly by victims rather than producers. In fact, following the Friedman's doctrine, firms – and, particularly in the global commons context, states – that invest in reducing pollution face higher costs and thus a competitive disadvantage, while less conscientious competitors benefit.⁷⁰² As a result, markets both fail to deliver efficient pollution control and punish voluntary efforts, making government

⁷⁰⁰ See: Kentaka Aruga, *Environmental and Natural Resource Economics* (Springer 2022) 39. Driesen refers to such instruments as “instrument choice”, to refer to policy tools, rather than merely legal forms. See: David Driesen, 'Instrument Choice' in Lavanya Rajamani and Jacqueline Peel (eds.) *The Oxford Handbook of International Environmental Law* (2nd edn, Oxford Handbooks 2021) 102, 103.

⁷⁰¹ Command-and-control regulations, most commonly in the form of technology and performance standards, prescribe specific limits or methods of compliance and therefore leave actors relatively little flexibility in how to achieve the regulatory objective. Robert N. Stavins, 'Experience with Market-Based Environmental Policy Instruments' (Resources for the Future, 2001) 1-2; see also: David Driesen, 'Instrument Choice' in Lavanya Rajamani and Jacqueline Peel (eds.) *The Oxford Handbook of International Environmental Law* (2nd edn, Oxford Handbooks 2021) 102, 104-105.

⁷⁰² Milton Friedman, 'A Friedman doctrine – The Social Responsibility of Business is to Increase Its Profits' *The New York Times* (New York, 13 September 1970). This dynamic also underpins both the tragedy of the commons and the free-rider problem, explained below.

intervention particularly necessary.⁷⁰³ The role of environmental law, in economic terms, is to translate (internalise) externalised costs (such as pollution, waste, and ecological degradations) by placing these obligations on the actors responsible, most often states and their authorised operators. In doing so, law seeks to align individual or national decision-making with collective welfare, thereby steering the use of shared environments toward more efficient and sustainable outcomes. Regulation techniques to address externalities generally take two main forms: *quantitative limits* on the total volume of emissions attributable to an industry or individual operators (total emission caps),⁷⁰⁴ and *qualitative restrictions*, which prescribes binding technical and operational standards or set maximum allowable emissions per unit of production or concentration levels of pollutants, rather than relying on market-based pricing mechanisms (emission standards).⁷⁰⁵

⁷⁰³ Tom Tietenberg and Lynne Lewis, *Environmental & Natural Resource Economics* (12th edn, Routledge 2023) 160-162.

⁷⁰⁴ The Montreal Protocol provides a clear example of successful cap-and-reduce regulation in international environmental law, establishing binding, quantity-based national targets to cut total emissions of ozone-depleting substances (notably CFCs and halons), relative to 1980 baseline levels. This sets binding, enforceable limits on total volume emitted or consumed, where the effectiveness was tied to global compliance. See: Montreal Protocol on Substances that Deplete the Ozone Layer of 16 September 1987, entered into force 1 January 1989, 26 ILM 1550 (Montreal Protocol).

⁷⁰⁵ A leading example of the emission-standard model is the International Convention for the Prevention of Pollution from Ships (London, 2 November 1973, not in force) 1340 UNTS 184, as amended by the Protocol of 1978 relating thereto (London, 17 February 1978, in force 2 October 1983) 1340 UNTS 61 [MARPOL 73/78 or MARPOL] as further amended by the Protocol of 1997 (London, 26 September 1997, in force 19 May 2005). The MARPOL regime contains the main international agreements covering prevention and mitigation of pollution of the marine environment by ships from operational or accidental causes. They primarily rely on quality-based, per-unit standards, meaning that regulation targets the characteristics of each unit of activity rather than the overall scale of activity. For example, Annex 1 of MARPOL sets out the pollution prevention requirement, stating that discharges are only permitted if very restrictive limits and technical standards are met. Furthermore, MARPOL ensures compliance with its technical standards through a system of mandatory inspections and certification. In general, these measures do not place an absolute cap on the total volume of global maritime traffic or overall emissions. Instead, they seek to reduce the environmental impact of each individual activity by imposing technical or performance-based standards. In other words, rather than limiting the number of ships at sea, MARPOL seeks to make each vessel operate more “cleanly” – through requirements such as lower sulphur fuel, exhaust filters, or restrictions on discharges – an approach that is particularly effective when environmental impacts can be mitigated through technological improvements. See: Peter Ehlers, ‘A success Story? Fifty Years of MARPOL’ (2025) 40(1) *The International Journal of Marine and Coastal Law* 57, 60-61; Regulations for the Prevention of Pollution by Oil (entered into force 2 October 1983) of the International Convention for the Prevention of Pollution from Ships, Annex I.; Oil tankers above 150 gross tonnage and other ships over 400 gross tonnage, for example, must undergo regular surveys by their flag state or by recognised classification societies, which themselves must meet criteria set by the IMO Code for Recognized Organization. Successful compliance results in the issuance of an International Oil Pollution Prevention Certificate (IOPP), updated as technical standards evolve. See: MARPOL

In assessing command-and-control regulation, both its strengths and limitations must be considered. In theory, it is possible to define the “efficient” level of pollution by identifying the exact point at which the marginal costs of pollution control equal the marginal damages caused by pollution. In practice, however, this is rarely feasible: regulators typically lack precise information about firms’ control costs or the social harms caused by each additional unit of pollution. To cope with this information burden, many states have opted to set fixed legal thresholds – such as maximum allowable concentrations of pollutants. Yet establishing such threshold only addresses part of the problem. Once collective limits are agreed, the challenge shifts from rule-setting to implementation – namely, how to allocate or distribute responsibilities among multiple emitters in a way that is both effective and perceived as equitable.⁷⁰⁶ A central difficulty lies in attributing responsibility for relevant emissions, since different allocation principles imply different burden-sharing outcomes. Competing models drawn from climate governance debates illustrate the range of possible approaches that are also present in the debate relevant to space debris: historical responsibility (placing greater obligations on major past polluters); current emissions (linking responsibility to present contributions); per-capita allocations (emphasizing equal entitlements to a clean environment, by large-population countries gaining larger allowable shares); efficiency-based metrics (rewarding actors that use resources more productively and penalising those that are inefficient); and consumption-based approaches (assigning responsibility to end-users, consumers of carbon intensive goods and states that import carbon intensive goods); or hybrid “shared responsibility” models that combine both perspectives.⁷⁰⁷ These choices are not merely technical; they reflect deeper normative judgements about equity, accountability, and sustainability. In the governance of global commons, states may agree on the need for cooperation, yet consensus often breaks down over the distribution of responsibilities.⁷⁰⁸ The

Annex 1 Reg 4 and Reg 6. It is important to note that MARPOL is widely regarded as a successful international environmental treaty in reducing pollution from individual ships through enforceable technical standards. However, its success remains sector-limited and does not extend to the most significant sources of marine pollution, such as land-based discharges or offshore activities. See: Ehlers, Peter, ‘A success Story? Fifty Years of MARPOL’ (2025) 40(1) *The International Journal of Marine and Coastal Law* 57, 111-112.

⁷⁰⁶ Tom Tietenberg and Lynne Lewis, *Environmental & Natural Resource Economics* (12th edn, Routledge 2023) 162-163.

⁷⁰⁷ See for example: Steven J Davis and Ken Caldeira, *Consumption-based accounting of CO2 emissions* (2010) 107(12) *Proceedings of the National Academy of Sciences of the United States of America* 5687, 5687-5692.

⁷⁰⁸ This dynamic mirrors the *Battle of the Sexes* model: all actors agree that cooperation is better than defection, but disagreement over how to share burdens makes coordination difficult.

central question then shifts from *whether* to cooperate, to *how* cooperation can be sustained – namely by designing instruments such as taxes, liability rules or voluntary instruments that ensure actors internalize the costs they impose on others and align their incentives with the collective interest, rather than systematically underinvesting in sustainability.

When moving from the domestic framework to the international domain of Law and Economics, the categorization of instruments takes on a different character. In domestic policy analysis, economic theory commonly distinguishes between regulatory instruments, economic instruments (e.g., taxes), and voluntary or informational tools. By contrast, international law structures regulation through international, customary international law, and soft-law instruments, categories that do not map neatly onto this economic taxonomy. International sources and legal instruments mostly function at a higher level of abstraction, formulating general obligations, principles, or standards of conduct rather than prescribing detailed, quantifiable limits on behaviour. As a result, from a Law and Economics lens, many international norms require domestic implementation to translate them into concrete regulatory measures such as numerical caps, technical standards, or enforceable performance thresholds. The result is a regulatory gap between general international obligations and the concrete policy instruments required to align individual incentives with collective sustainability.

A parallel can be observed in space law: while the *corpus juris spatialis* lays down framework principles and obligations, and a number of soft-law instruments provide qualitative recommendations or technical best practices for space debris mitigation, there are currently no internationally agreed binding caps, or operational standards specifically governing the intensity of orbital use.⁷⁰⁹ Especially LEO governance currently relies only on *soft-law* emission standards. The most prominent examples include the UNCOPUOS LTS Guidelines, the IADC Guidelines, and technical standards, such as ISO 24113:2023.⁷¹⁰ These instruments do not cap the total number of launches or satellites based on the *socially optimal launch rate*,⁷¹¹ but they impose technical standards, such as post-mission disposal within 25-year rule,

⁷⁰⁹ This is exceptional to the *a priori* allocation of the geostationary orbit, however it is only a small portion of that trajectory.

⁷¹⁰ See: LTS Guidelines; UNCOPUOS, Space Debris Mitigation Guidelines; IADC Guidelines; and ISO 24113:2023 Space systems – Space debris mitigation requirements.

⁷¹¹ In economic models of orbital congestion, the *socially optimal launch rate* can be defined as “the launch rate that maximizes the long run [sustainable] number of satellites.” Sébastien Rouillon, ‘A Physico-Economic Model of Low Earth Orbit Management’ (2020) 77(4) *Environmental and Resource Economics* 695, 695-723.

passivation of spacecrafts, collision-avoidance protocols, etc. However, even though these instruments resemble command-and-control mechanisms, they remain voluntary in nature, lacking binding force, enforcement mechanisms or sanctions for non-compliance. Their principal contribution is therefore one of coordination – reducing uncertainty and harmonizing expectations across operators – rather than coercive internationalization of externalities. While much of the space law literature adopts an optimistic stance, focusing on the national implementation of soft-law instruments through domestic legislation,⁷¹² Adilov et al. argue that such voluntary debris-mitigation guidelines, though symbolically significant, remain largely ineffective in addressing the underlying market failures.⁷¹³ The absence of binding rules and enforcement mechanisms allows firms to disregard best practices without consequence. Thus, Adilov argues that without effective international coordination or regulation, the commercial use of orbital space will continue to generate unsustainable levels of debris. The expert's analysis supports the case for stronger governance instruments that internalize the environmental costs of orbital activity.

In narrow Law and Economics terms, restrictions on the freedom principle in LEO would be most easily justified if all states perceived themselves as better off under sustainability rules than in the absence – a condition approximating a *Pareto improvement*. Yet such conditions rarely achievable in practice. First, the distribution of benefits from orbital activities is highly uneven: technologically advanced states and their corporations capture immediate commercial and strategic gains from satellite services, while many others enjoy little or no access but nevertheless share in the collective risks of orbital overexploitation.⁷¹⁴ Second, there are no effective mechanisms to transfer resources or redistribute benefits to compensate “losers” (developing states facing reduced access or exclusion) from the gains of “winners”. Unlike domestic systems, international law lacks a supranational authority with

⁷¹² Responsibility for regulating space operators continues to rest primarily with individual states through their domestic legislation – a framework that remains rooted in qualitative obligations, rather than internationally agreed quantitative measures aimed at ensuring equity and long-term sustainability.

⁷¹³ Nodir Adilov & Peter Alexander and Brendan Cunningham, ‘Understanding the Economics of Orbital Pollution Through the Lens of Terrestrial Climate Change’ (2022) 59(2) *Space Policy* 1, 2.

⁷¹⁴ This mirrors the dynamics of the climate change debate between developed and developing states, where those who have contributed least to the problem are often the most severely affected by its consequences today, such as global warming and sea-level rise. This is relevant to a further dimension that complicates the governance of global commons is the question of legacy harms – the damage already caused by past activities, which continues to constrain the resource base for present and future users.

power to impose taxes or enforce redistributive transfers. From a Kaldor-Hicks lens, cooperation in managing orbital resources could, in theory, be achieved through side-payments or bargaining, whereby actors that incur lower compliance costs or derive greater immediate gains could compensate those that bear disproportionate short-term costs, while collective long-term benefits are preserved. In practice, however, institutionalizing such redistribution at the international level has proven politically difficult. The clearest example is the CHM principle embodied in the 1979 Moon Agreement, which envisaged an international regime for sharing benefits from lunar resource exploitation. The Moon Agreement's failure to attract ratification from major spacefaring powers highlights the difficulty of embedding redistribution in global commons governance.⁷¹⁵ Even under a Kaldor-Hicks efficiency framework, however, certain regulatory choices, such as the setting of a strict cap on orbital use, are not negotiable through bargaining or compensation, but must be determined by the physical limits of the orbital environment itself.

a.2 Internalization with economic instruments

Another type of policy instrument that supports internalisation of environmental externalities are economic instruments. Under economic approaches, especially in domestic settings, four principal instruments are typically identified: environmental taxes (so-called

⁷¹⁵ “States Parties to this Agreement hereby undertake to establish an international regime, including appropriate procedures, to govern the exploitation of the natural resources of the moon as such exploitation is about to become feasible”. See: Moon Agreement article 11 para. 5. On this regard, Mickelson also asks “whether the common heritage principle lives up to the promise of providing an appropriate foundation for governance of the global commons and in particular, whether it may impose meaningful limitations on resource extraction to prevent ecological harm”. See: Karin Mickelson, ‘Common Heritage of Mankind as a Limit to Exploitation of the Global Commons’ (2019) 30(2) *The European Journal of International Law* 635, 636.

Pigouvian taxes);⁷¹⁶ subsidies;⁷¹⁷ deposit-refund systems;⁷¹⁸ and emission trading schemes. These mechanisms can be broadly distinguished by their logic of intervention – taxes function primarily as penalties, subsidies as rewards (or incentives), deposit-refund systems as hybrids, and trading schemes as market-based incentives that combine both punitive and incentive elements.

Among the above mechanisms, *emission trading systems* have become one of the most widely used economic instruments for internalising externalities in the global commons scene, particularly by addressing climate-related pollution through market-based mechanisms. In these systems, authorities issue permits for a limited quantity of emissions, which polluters can buy and sell. Two main models exist: the cap-and-trade and baseline-and-credit systems. Under a *cap-and-trade* scheme, a fixed overall ceiling (cap) is imposed on total emissions, and emission allowances are allocated to covered states, either free of charge (for instance through grandfathering or benchmarking) or via auctioning.⁷¹⁹ Firms (or states in international settings)

⁷¹⁶ In terms of tax, a *Pigouvian tax* – named after Arthur Pigou – refers to a corrective tax imposed on activities that generate negative externalities, designed to align private costs with social costs by making actors pay for the harm they impose, thus, reducing output to a more socially efficient level while creating incentives to firms to adopt cleaner technologies. In terrestrial context, this logic underpins carbon taxes that internalise the social costs of emission. The challenge with Pigouvian tax lies in setting the optimal tax rate, since regulators lack full information about actual external costs and behavioural responses. Compared with direct regulation, environmental taxes promote technology development and efficient cost allocation, but they may be slower in achieving specific targets and can impact competitiveness in the short run. See: Arthur Cecil Pigou, *The Economics of Welfare* (4th edn, Macmillan 1932) Part II, Chapter IX, §13.

⁷¹⁷ Instead of penalising polluters, *subsidies* reward firms that adopt cleaner technologies or reduce emissions below a specified threshold. By lowering the private cost of environmentally friendly behaviour, subsidies can encourage firms to shift toward practices that align more closely with social welfare.

⁷¹⁸ *Deposit-refund system*, a hybrid mechanism that combines elements of both Pigouvian taxes and subsidies. Like a tax, a deposit increases the upfront cost of producing or consuming a good, thereby discouraging excessive use. But unlike a pure tax, it also offers a refund when the good is returned or properly disposed of, creating a direct incentive for consumers to reduce environmental harm. This way, the system internalises externalities from both the producer side (through the deposit charge) and the consumer side (through the refund). See: Kentaka Aruga, *Environmental and Natural Resource Economics* (Springer 2022) 42-54; This may be an interesting instrument for orbital space governance. Operators could be required to pay a deposit linked to the potential debris their satellite might create. This deposit would be refunded if satellites are safely deorbited or otherwise responsibly managed at the end of their life. Unlike taxes, deposit-refund systems directly tie economic incentives to responsible behaviour, aligning both producer actions with sustainability goals in managing the orbital commons. See: OECD, ‘*The Economics of Space Sustainability: Delivering Economic Evidence to Guide Government Action*’ (OECD Publishing, 2024) 37.

⁷¹⁹ Under *grandfathering*, emission allowances are given out for free to actors based on their past behaviour. So, if an actor polluted more in the past, it tends to get more allowances in the future. Through *benchmarking*,

that reduce emissions cheaply can sell permits to others, ensuring the cap is not exceeded while minimizing overall abatement costs. The Paris Agreement, for instance, represents a shift from the strict caps and reduction targets on industrialised countries of the Kyoto Protocol,⁷²⁰ to a bottom-up system of Nationally Determined Contributions (NDCs).⁷²¹ In Article 6 it enables the cap-and-trade system: an overall emissions ceiling is set, and permits are distributed or auctioned.⁷²² By contrast, under a *baseline-and-credit* scheme, each polluter is given a baseline standard, and those who emit below it earn credits that can be sold to those who exceed it. Unlike cap-and-trade, no total emissions ceiling exists, so aggregate emissions may still rise if many new entrants join, or if baselines are weak.⁷²³

Additionally, there is a broad agreement among economists reflecting on climate change mitigation, that a mix of *penalties* for non-cooperation and *rewards* for cooperation is essential to make collective regimes work and to curb free-riding.⁷²⁴ In Nordhaus' well-known *climate club* proposal, for instance, which will be also addressed under public goods, penalties

regulators allocate allowances based on performance standards tied to efficiency, thereby rewarding efficient actors and creating incentives to adopt cleaner technologies that reduce pollution. In *auctioning*, the regulator does not give away allowances but instead sells them to the highest bidders through auctions. See: Ian MacKenzie & Nick Hanley and Tatiana Kornienko, 'Using contests to allocate pollution rights' (2009) 37(7) *Energy Policy* 2798, 2798.

⁷²⁰ While the Kyoto Protocol created legally binding quantitative emissions caps for a limited group of industrialised countries listed in Annex I of the Kyoto Protocol (reflecting the common but differentiated responsibilities (CBDR) principle of environmental law), emerging economies, including China, India, and Brazil were not enlisted in Annex I at the time the agreement was adopted (in 1997). Although the USA signed the Protocol, it ultimately declined to ratify it, arguing that the Treaty imposed binding obligations on industrialized states while exempting major developing emitters, thereby raising concerns about fairness and potential adverse effects on national competitiveness. Additionally, withdrawals (e.g., Canada, Japan) further weakened the Protocol. This largely limited coverage, of emission caps, only about 18% of global emission. See for example: European Commission, 'The Kyoto Protocol' <https://climate.ec.europa.eu/eu-action/international-action-climate-change/kyoto-protocol_en> accessed 20 October 2025; on the US position: Susan R Fletcher, 'CRS Report for Congress, Climate Change: The Kyoto Protocol and International Actions' (8 June 2007) CRS-11 <https://nationalaglawcenter.org/wp-content/uploads/assets/crs/RL33826.pdf?utm_source=chatgpt.com> accessed 20 October 2025.

⁷²¹ Paris Agreement art 13.

⁷²² From a Law and Economics perspective, the Paris Agreement does not establish a Pareto-efficient regime but rather approximates a Kaldor-Hicks logic, prioritizing aggregate climate outcomes while tolerating distributional asymmetries. Flexibility mechanisms (most notably in Article 6 of the Paris Agreement) allow states to adjust mitigation efforts through cooperation and trading, even though compensation of losers is neither automatic nor guaranteed.

⁷²³ A real-life example of the baseline-and-credit model is the Clean Development Mechanism (CDM) under the Kyoto Protocol, which served as its flagship flexibility mechanism for non-Annex I states, allowing capped states to offset part of their obligations through projects in developing countries. See: Kyoto Protocol article 2.

⁷²⁴ Nodir Adilov, Peter Alexander and Brendan Cunningham, 'Understanding the Economics of Orbital Pollution Through the Lens of Terrestrial Climate Change' (2022) 59(2) *Space Policy* 1, 19.; and Joseph E Stiglitz, 'A New Agenda for Global Warming' (2006) 3(7) *The Economists' Voice* 1, 1-4.

would take the form of import tariffs on goods from non-participating states.⁷²⁵ Crucially, Nordhaus argues that such tariffs must apply at the country level (rather than industry by industry), since measuring the carbon content of each imported product is administratively unfeasible.⁷²⁶ Tariff levels, he suggests, should be calibrated to reflect the social costs of non-compliance, thereby directly internalising externalities and aligning national incentives with the collective interest.⁷²⁷ Designing rewards for cooperation, however, proves more complex. While direct transfers between states might, in principle, achieve efficient burden-sharing, they are often politically unpopular in donor countries and vulnerable to perceptions of unfairness. Jean Tirole therefore emphasizes the value of indirect incentives, such as technology sharing, preferential trade arrangements, or targeted development aid, which can promote cooperation while avoiding the political backlash associated with over financial redistribution.⁷²⁸ These proposals highlight how the law-and-economics “toolkit” envisions cooperation as sustainable only if both sanctions (sticks) and incentives (carrots) are credibly embedded in institutional design.⁷²⁹

Analogous ideas have been developed in the context of orbital debris. Bradley and Wein highlighted for instance purpose the use of *legacy debris fees*, which would charge operators for the continued risks posed by debris from past activities, as well as and *non-compliance fees* imposed on operators that fail to deorbit satellites at the end their mission (as penalties). The revenues generated from these penalties could then be used both to compensate operators whose satellites are damaged by debris and to fund research and development in debris-mitigation technologies (as incentives).⁷³⁰ Singer and Musacchio build on this modelling international debris-abatement clubs, showing how coalitions of states could coordinate such

⁷²⁵ William Nordhaus, ‘Climate Clubs: Overcoming Free-Riding in International Climate Policy’ (2015) 105(4) *American Economic Review* 1339, 1339–1370.

⁷²⁶ *Ibid.*, 1351.

⁷²⁷ William Nordhaus, ‘Climate Change: The Ultimate Challenge for Economics’ (2019) 109(6) *American Economic Review* 1991, 2010–2012.

⁷²⁸ Jean Tirole, ‘Some Political Economy of Global Warming’ (2012) 1(1) *Economics of Energy & Environmental Policy* 121, 123–126.

⁷²⁹ Behavioural economics – later discussed – further underlines this point: given well-documented biases and short time horizons, states (like individuals) may systematically undervalue long-term sustainability, making credible enforcement and incentive structure even more critical to overcoming collective action.

⁷³⁰ Andrew M Bradley and Lawrence M Wein, ‘Space debris: Assessing risk and responsibility’ (2009) 43(9) *Advances in Space Research* 1372, 1379.

fee-based systems and generate incentives for wider participation.⁷³¹ In principle, price-based instruments for addressing orbital externalities could take several forms, including quantitative restrictions, launch levies, or even cap-and-trade mechanisms. Yet experience from terrestrial climate regimes illustrates the limits of market-based approaches in the international sphere. While the Kyoto Protocol and the Paris Agreement have experimented with market instruments and flexibility mechanisms, these have operated without a binding global cap, universal participation, or effective enforcement. As a result, price signals have failed to align individual incentives with planetary boundaries at the international level.⁷³² It can be argued that even the Paris Agreement, despite its near-universal participation, relatively high scientific certainty regarding climate thresholds, and the availability of measurable and monitorable emissions data, has so far failed to constrain the exploitation of the atmosphere within ecological limits. If this is the case, a largely non-binding mechanism may be even less likely to succeed in governing the orbital commons, where the carrying capacity are uncertain, damage is irreversible, and incentives for early overuse are stronger. Accordingly, Adilov argues, purely voluntary weakly enforced market mechanisms are unlikely to succeed in governing the orbital commons.⁷³³

Finally, within the spectrum of economic instruments, the instrument of national *licensing* occupies a hybrid position. Unlike pure market-based tools or rigid command-and-control standards, licensing blends elements of both. On the one hand, it functions as a direct regulatory tool, requiring prior authorization to access or use a resource, as in the case of permits for satellite launches by non-governmental organizations. In this sense, licensing serves as a classic command-and-control mechanism: it determines who may participate and under

⁷³¹ Michael Singer and John Musacchio, 'An International Environmental Agreement for Space Debris Mitigation Among Asymmetric Nations' (2011) 68(1-2) *Acta Astronautica* 326, 328.

⁷³² The Paris Agreement cannot be characterised as a failure in terms of participation or procedural compliance: nearly all states have submitted NDCs contributions and largely adhere to their reporting and transparency obligations. However, it is widely regarded as substantively ineffective relative to its stated temperature objectives (ambition gap). Even under full implementation of existing NDCs, global emissions trajectories remain inconsistent with limiting warming to well below 2 Celsius degrees, let alone 1.5 Celsius degrees. The core problem lies therefore, not in non-compliance, but in the Agreement's design: by relying on voluntary, nationally determined ambition without a binding aggregate emissions cap or enforceable redistribution mechanisms, the Paris Agreement manages cooperation but does not constrain collective overuse of the atmospheric commons. See for example: Luiz Bernardo Baptista et al., 'Good practice policies to bridge the emissions gap in key countries' 73 (2022) *Global Environmental Change* 1, 1-2.

⁷³³ Nodir Adilov, Peter Alexander and Brendan Cunningham, 'Understanding the Economics of Orbital Pollution Through the Lens of Terrestrial Climate Change' (2022) 59(2) *Space Policy* 1, 11.

what conditions. On the other hand, licensing can also take on the qualities of an economic instrument when linked to fees, auctions, or tradable rights. In such cases, it not only restricts access but also creates incentives to internalize external costs by aligning private behaviour with social welfare. This dual character makes licensing particularly significant in the governance of international commons, particularly in sectors such as telecommunications and satellite operations in the domestic level. Here, in the absence of an international central authority, licensing remains primarily a function of states, exercised pursuant to their obligations under Article VI OST. States authorize and supervise national space activities by issuing licenses to operators, often embedding conditions such as debris-mitigation measures, safety standards, or liability provisions. In this way, licensing serves as the primary mechanism for controlling access to space activities and indirectly address problems of overuse and environmental risk.⁷³⁴ Although formally domestic, licensing operates within the broader international framework shaped by coordination mechanisms such as the ITU, thereby linking national regulation to the governance of the orbital commons.

Last but not least, important to note the role of *insurance* schemes, which enable satellite operators to transfer the financial risks of launch failures and on-orbit malfunctions to insurers, thereby facilitating a more efficient distribution of risk across the sector. Traditional third-party liability insurance covers damage caused by space objects to other actors. In theory, this internalises (at least partially) the cost of potential harm. However, a fundamental problem with satellite insurance lies in attribution: unlike terrestrial accidents, where investigators can usually identify fault, in orbit it is often impossible to determine whether a loss results from an internal malfunction or a collision with debris, let alone to trace the origin of the debris.⁷³⁵ This

⁷³⁴ See, for example, Outer Space and High-altitude Activities (Licences and Permits) Regulations 2017 (New Zealand, 10 July 2017) <<https://www.legislation.govt.nz/act/public/2017/0029/latest/DLM6966275.html#DLM6966258>> accessed 20 October 2025; and Regulation of the Federal Minister for Transport, Innovation and Technology in Implementation of the Federal Law on the Authorisation of Space Activities and the Establishment of a National Space Registry (Outer Space Regulation) 2015 (Austria, 26 February 2015) <https://www.ris.bka.gv.at/Dokumente/BgblAuth/BGBLA_2015_II_36/BGBLA_2015_II_36.pdf> accessed 20 October 2025, as amended in Mai 2018, art 4 <https://www.ris.bka.gv.at/Dokumente/BgblAuth/BGBLA_2018_II_90/BGBLA_2018_II_90.pdf> accessed 20 October 2025.

⁷³⁵ Tom Brown, ‘Satellites keep breaking up in space. Insurance won't cover them’ (*Space.com*, 28 June 2025) <<https://www.space.com/space-exploration/satellites/satellites-keep-breaking-up-in-space-insurance-wont-cover-them>> accessed 20 October 2025.

evidentiary gap makes liability insurance particularly problematic, since compensation depends on establishing causation. The result is a systemic weakness in insurance as an economic internalisation instrument: while it can spread financial risk, it does little to deter harmful behaviour. In fact, current practices show the opposite direction, as the density of space debris rises, an increasing number of operators choose to launch without any insurance at all. As rising collision risks drive up insurance premiums, many operators respond by building cheaper, short-lived satellites and launching them in larger number – thereby creating a feedback loop in which fragile hardware is more likely to fragment, accelerating debris growth and compounding the very risks that make insurance costly in the first place.⁷³⁶

a.3 Internalization via voluntary instruments

Instead of being compelled by binding regulation, polluters may choose to limit harmful impacts through voluntary instruments. The OECD distinguishes four main types of voluntary mechanisms: (i) unilateral commitments; (ii) private agreements; (iii) negotiated agreements; and (iv) public voluntary programmes.⁷³⁷ Translated into the context of international law, a similar taxonomy can be discerned: (i) unilateral acts of states;⁷³⁸ (ii) bilateral or “plurilateral” agreements between states;⁷³⁹ (iii) non-binding memoranda of understanding (MOUs) that

⁷³⁶ Ibid.

⁷³⁷ OECD, ‘Voluntary Approaches for Environmental Policy: Effectiveness, Efficiency and Usage in Policy Mixes’ 18-19 (*OECD Publishing*, 2003)

https://www.oecd.org/content/dam/oecd/en/publications/reports/2003/06/voluntary-approaches-for-environmental-policy_g1gh34f5/9789264101784-en.pdf accessed 20 October 2025.

⁷³⁸ The role of unilateral acts in shaping international obligations has already been discussed in Chapter I of this dissertation, with particular reference to the pledges by the United States and several other states to refrain from conducting destructive ASAT tests.

⁷³⁹ In public international law, a plurilateral agreement is understood as a treaty involving more than two parties, but without the broad, near-universal participation characteristic of multilateral conventions. “Plurilateralism focuses on targeted cooperation among a smaller set of members and has the capacity to foster focused (plurilateral) agreements among a smaller cohort of countries.” See: Georgios Dimitropoulos, Richard Chen and Julien Chaisse, ‘Plurilateralism, A New Form of International Economic Ordering?’ (2025) 26(1-2) *Journal of World Investment & Trade* 1, 1-3. A prominent space sector example is the Artemis Accords, a plurilateral arrangement that remains formally voluntary yet highly selective, with participation closely linked to access to the tangible benefits of cooperation in the United States-led Artemis programme.

facilitate coordination without creating legal obligations;⁷⁴⁰ and (iv) voluntary codes of conduct and international guidelines.⁷⁴¹

Another related concept is the use of *soft caps*. Unlike the Kyoto Protocol, which imposed a top-down hard cap on emissions for a limited group of developed states, the Paris Agreement (PA) adopted a bottom-up approach that secures broad participation,⁷⁴² requiring all States Parties to submit nationally determined contributions (NDCs) that reflect their chosen level of ambition.⁷⁴³ These pledges effectively function as soft caps: self-defined, non-binding limits that signal collective ambition but lack enforceable ceilings, relying instead on binding transparency measures and peer review to encourage compliance. This resembles a mixed governance strategy: it relies on a soft mechanism for participation through NDCs, rather than externally imposed quotas, while simultaneously introducing comparatively harder mechanisms for monitoring, reporting, and transparency, such as an enhanced transparency framework (Art 13 PA), global stocktakes (Article Art 14 PA), and ‘ratchet’ provisions Article 4 PA)) to build trust and facilitate accountability.⁷⁴⁴ Yet, crucially, the system lacks binding enforcement and permits withdrawal, which leaves it vulnerable to free-riding and strategic defection.⁷⁴⁵

⁷⁴⁰ An example of MOU was signed between USA and ESA in October 2020 concerning the Artemis programme’s Cooperation on the Civil Lunar Gateway. See: European Space Agency (ESA), ‘Gateway MoU and Artemis Accords – FAQs’ (ESA, 2020) https://www.esa.int/Science_Exploration/Human_and_Robotic_Exploration/Gateway_MoU_and_Artemis_Accords_FAQs accessed 20 October 2025.

⁷⁴¹ International guidelines on the topic of orbital space environment are the UNCOPUOS LTS Guidelines; and the UNCOPUOS Space Debris Mitigation Guidelines.

⁷⁴² As of September 2025, the Paris Agreement had 195 States Parties. See: United Nations Treaty Collection, status of the Paris Agreement https://treaties.un.org/pages/viewdetails.aspx?src=treaty&mtdsg_no=xxvii-7-d&chapter=27&clang=en accessed 20 October 2025.

⁷⁴³ The Paris Agreement’s framework allows states to determine their own level of ambition, creating wide scope for differentiation. This flexibility was the price of securing the participation of major emerging emitters as well as the United States. At the same time, the Paris Agreement incorporates a *ratchet mechanism*, requiring states to submit progressively more ambitious NDCs in successive five-year cycles, thereby ensuring a gradual strengthening of commitments over time. See: Paris Agreement art 4 para 3; and Pierre-Marie Dupuy and Jorge E Viñuales, *International Environmental Law* (2nd edn, Cambridge University Press 2018) 191.

⁷⁴⁴ “The main innovation of the Paris Agreement lies in its implementation techniques and, particularly, the ‘enhanced transparency framework for action and support established by Article 13”. See: Pierre-Marie Dupuy and Jorge E Viñuales, *International Environmental Law* (2nd edn, Cambridge University Press 2018) 193.

⁷⁴⁵ Paris Agreement art 28. It is worth considering the idea of a no-exit mechanism, similar to the United Nations Charter, in the context of truly foundational global governance regimes, such as those aimed at preventing the collapse of the climate system, where the long-term stability of the commons cannot be secured if states are free to withdraw.

Indeed, unlike soft quality-based standards – such as the mitigation measures in the LTS Guidelines – which can be incorporated into domestic licensing regimes with relative ease, the definition of an internationally agreed carrying capacity for LEO would necessarily introduce a quantitative ceiling on total orbital use. This would mark a significant shift from qualitative guidance to binding quantitative regulation, akin to hard caps in other regimes governing areas beyond national jurisdiction. Furthermore, even though, the experience of climate governance suggest that a soft cap ratchet-based system may offer a politically feasible pathway in environments marked by scientifically and politically complexity, such as LEO, this model proves far less plausible in practice. Unlike GHG emissions, where states can voluntarily pledge reductions without directly pre-empting other's options, LEO is characterised by finite, congestible shells in which capacity is effectively rivalrous. Once a global ceiling is scientifically defined, the very act of operating within that limit generates scarcity and fuels competition for the remaining “free” positions. In this context, soft distributions are unlikely to be sustainable, since voluntary pledges cannot prevent early movers from appropriating capacity and locking out latecomers.

b) Information asymmetry

Informational asymmetry arises when one party in a transaction possesses more or better information than the other, undermining trust and leading to market failure. In such cases, trade may occur at inefficient levels, or collapse entirely, because buyers or sellers cannot accurately assess quality.⁷⁴⁶ Information asymmetry, and its link to bounded rationality, will be examined in a greater detail in the subsequent section on behavioural law and economics.

⁷⁴⁶ Kentaka Aruga, *Environmental and Natural Resource Economics* (Springer 2022) 37.

c) Market power

Market power arises when a producer or consumer can influence prices in a market instead of merely accepting them. In such cases, a dominant supplier establishes a monopoly,⁷⁴⁷ and becomes a “price-maker”, in contrast to actors in perfectly competitive markets, who are “price-takers”. Monopolies typically emerge where one actor controls essential resources or technologies, where government grants exclusive rights, or where economies of scale make it prohibitively costly for smaller competitors to enter, creating so-called natural monopolies.⁷⁴⁸ While monopolies can generate profits for dominant firms, they usually reduce social welfare by raising prices, limiting supply, and lowering product quality. They also undermine consumer influence: when monopolists produce in environmentally harmful ways, consumers cannot easily switch to cleaner alternatives if no competitors exist. The result is “deadweight loss” – an efficiency loss compared to the outcomes of a competitive market.

In law and economics scholarship, antitrust and competition law have evolved precisely to prevent or regulate monopolistic practices, ensuring that markets remain competitive and efficient. The state intervenes, when market power leads to inefficiencies or harms consumers. Relevant to states, a technologically advanced state may hold a monopoly over certain resources or capabilities (e.g., launch services, satellite constellations).⁷⁴⁹ This allows that state to shape outcomes in ways that maximize its own welfare, even if doing so produces inefficiency or harms weaker states. This dynamic mirrors broader challenges in the governance of global commons, where the benefits are concentrated among a few powerful actors while the costs are dispersed across all entire international community – an issue to which the following section now turn.

⁷⁴⁷ A dominant buyer creates a monopsony, two dominant firms form a duopoly, and a small group of powerful actors results in an oligopoly. See: Ibid., 26-27.

⁷⁴⁸ See for example: Paul J Joskow, ‘Regulation of Natural Monopoly’ in A.M. Polinsky and S. Shavell (eds.) *Handbook of Law and Economics* (Elsevier 2007) Vol 2, 1227, 1227.

⁷⁴⁹ The relationship between the United States and SpaceX highlights how monopoly power in the global commons can be exercised not only by states but also through state-corporate partnerships, as SpaceX has rapidly become the dominant provider of launch services and is deploying large-constellations in LEO at a scale that no other private actor – and only a handful of states – can match. This tendency has been addressed in the first chapter of this dissertation, where its implications were discussed in greater depth.

d) Public goods and common pool resources

The theory of public goods was developed by Paul A. Samuelson in 1954, the first American Nobel laureate in economics, and it is fundamental to environmental economics today.⁷⁵⁰ The two key attributes of a *public good* are, one person's use does not reduce availability for others (nonrivalry) and, second, that it is impossible to exclude individuals from enjoying it (non-excludability).⁷⁵¹ Because of these defining characteristics, public goods give rise to market failures, as markets cannot supply them efficiently. Non-excludability prevents producers from charging users, while non-rivalry means individuals can benefit without reducing others' enjoyment – creating the classic free-rider problem. As a result, people have little incentive to contribute to their provision or protection. Examples include public television broadcasting or national defence that everyone can access simultaneously without diminishing others' use. Public goods theory therefore underscores the necessity of law and governance to secure collective benefits that markets alone will underprovide. Resource economics refines this framework by distinguishing between different categories of goods: *private goods* (e.g., groceries) are both excludable and rivalrous; *common pool resources* such as fisheries are non-excludable but rivalrous, making them prone to overuse, and *club goods* (e.g., private golf courses or streaming services, such as Netflix or Spotify) are excludable but non-rivalrous, where access is limited but shared use does not reduce availability.⁷⁵²

⁷⁵⁰ Paul A. Samuelson, 'The Pure Theory of Public Expenditure, The Review of Economics and Statistics' (1954) 36(4) *MIT Press* 387, 387-389.

⁷⁵¹ William Nordhaus, 'Climate Change: The Ultimate Challenge for Economics' (2019) 109(6) *American Economic Review* 1991, 1992; and Fabrizio Cafaggi and David D. Caron, Global Public Goods Amidst a Plurality of Legal Orders: A Symposium (2012) 23(3) *European Journal of International Law* 643, 644.

⁷⁵² While it is important to keep the two economic concepts, public goods and common pool resources separate, it is not a concrete distinction. As Ostrom points out, characterising resources as open access or subtractable (public goods) is not a hard and fast classification. Rather it is useful to think these traits as dynamics. See: Kentaka Aruga, *Environmental and Natural Resource Economics* (Springer 2022) 31-32; and Brian Weeden, and Tiffany Chow, 'Taking a common-pool resources approach to space sustainability: A framework and potential policies' (2012) 28(3) *Space Policy* 166, 166-167. *Club goods* are excludable, (one can restrict access to members only), but still largely non-rivalrous (one member's use does not prevent another from using it, at least up to a point). Because non-members can be kept out, the main challenge is not how to force everyone to contribute, but how to design fair and efficient rules for members (e.g., how to divide the costs of maintaining the good and how to allocate its benefits). See Samuel Barkin and Yuliya Rashchupkina, Public Goods, Common Pool Resources, and International Law (2017) 111(2) *The American Society of International Law* 376, 379-380.

Since common resources are accessible to all yet depletable, they are particularly vulnerable to overuse, a dynamic known as the *tragedy of the commons*.⁷⁵³ When many actors extract from a shared resource, each pursuing private gain, the cumulative effect is depletion that harms everyone. As resources become scarcer, their capacity to regenerate diminishes and the risk of irreversible collapse rises. In fact, as the stock declines, the cost of extraction rises, thus the timing becomes even more relevant.⁷⁵⁴ The result is an “erosion loop”, where declining capacity accelerates further degradation until the resource is destroyed, leaving all users worse off. Climate change illustrates this logic on a planetary scale: while short-term incentives encourage continued fossil fuel use, the cumulative emissions of greenhouse gases and pollutants drive long-term environmental decline.⁷⁵⁵

In addressing how to avoid the tragedy of the commons in common pool resources, resource and environmental economics typically identifies three main approaches. The first is the *allocation of property rights*, which makes resources excludable and thereby restrict their

⁷⁵³ The term, *tragedy of the commons*, was first coined by Garrett Hardin. In his book, *The Tragedy of the Commons*, Hardin gives the example of a herd, where each herdsman has the ability to keep and increase as many cattle as possible on the pasture, which is a commons. The herdsman then is expected to add more animal to its herd, as they receive all the proceeds from the sale of the additional animal. At the same time, the effects of overgrazing are shared by all on the commons. According to “traditional economic reasoning”, the rational herdsman would conclude that the most logical course is to add another animal to their herd, and this number would increase by time. This is the conclusion reached by each and every rational herdsman sharing a commons, which is itself the tragedy. Each is locked into a system, pursuing their best personal interest, that compels them to increase their herd without limit; in a world that is limited. See: Garrett Hardin, ‘The Tragedy of the Commons’ (1968) 162(3859) *Science* 1243, 1243–1248. Another example is the deterioration of lake water quality as more fishermen exploit the lake. As the intensification of its use make it more difficult for producers to continue extracting resources from the commons (the lake). Ideally, there is an optimal level of production, when taking future resource depletion into account, however, in a tragedy of the commons scenario, producers ignore these external costs and continue producing at their optimal level. This leads to overproduction and ultimately harms the natural resource base. See: Donella H Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 117.

⁷⁵⁴ This leads to a dynamic inefficiency: a race to use the resource sooner, even when society would be better off pacing extraction in a way that maximizes long-term benefits.; Hao Zhao and David Porter, ‘Vote and trade: An efficient mechanism for common-pool resource management with stock externalities’ (2025) 249 *Journal of Public Economics* 1, 1-2.

⁷⁵⁵ Shaye Wolf, Robert Bullard, Jonathan J Buonocore, Nathan Donley, Trisia Farrelly, John Fleming, David J X González, Naomi Oreskes, William Ripple, Robin Saha, Mary D Willis, ‘Scientists’ warning on fossil fuels’ (2025) 5(1) *Oxford Open Climate Change* 1, 1 <<https://doi.org/10.1093/oxfclm/kgaf011>> accessed 20 October 2025; United Nations Environment Programme (UNEP), ‘Emissions Gap Report 2024: No more hot air ... please! With a massive gap between rhetoric and reality, countries draft new climate commitments’ (2024) 11 <<https://doi.org/10.59117/20.500.11822/46404>> accessed 20 October 2025.

use, with the expectation of preventing depletion.⁷⁵⁶ However, resources such as the climate and orbital space are systemically interconnected: debris from a single satellite breakup increases risks for all operators, just as carbon emissions anywhere contribute to global warming everywhere. Thus, even if property rights were allocated, negative spillovers would persist across borders and generations. In such contexts, the alternative for such global commons is what Hardin described as “mutual coercion, mutually agreed upon”: the establishment of collectively accepted, self-imposed rules and restrictions on access.⁷⁵⁷ Consequently, the second approach in avoiding the tragedy of the commons is *regulation* of access, through rules imposed by local, national or global governments. Both represent top-down regulatory approaches, sometimes referred to as the Leviathan model.⁷⁵⁸ By contrast, many scholars have criticised Hardin’s binary framing and argued for a third method: community-based or voluntary management, which relies on local cooperation and shared norms rather than solely on externally imposed restrictions.⁷⁵⁹

Similar logic explains the *free-rider problem*, directly related to global commons. Since public goods are non-excludable, actors may benefit without contributing, expecting others to bear the costs. When many adopt this strategy, provision of the good collapses, leading to collective loss.⁷⁶⁰ The problem escalates when others observe free riders and begin to imitate them, realizing they too can benefit without paying. Because public goods and services rely on collective financing, widespread free riding reduces the available resources. Over time, this

⁷⁵⁶ Allocation of property proposes dividing the commons so that each individual or entity bears the direct consequences of their own actions, thereby remaining within the sustainable limits of their allocated share. In such a system, users harm only their own resources, not those of others. However, not all resources are amenable to privatization. Global commons such as the atmosphere, the high seas, or outer space defy clear individual ownership and cannot easily be divided into exclusive parcels.

⁷⁵⁷ Hardin asserted that the coercion is not imposed from outside but is self-imposed by the community of users (actors), because they recognize that without such rules, everyone will be worse off. See: Garrett Hardin, ‘The Tragedy of the Commons’ (1968) 162(3859) *Science* 1243, 1247-1248.

⁷⁵⁸ See for example: “Hardin argued that the only way to avoid this tragedy was either to install a Leviathan authority, which would manage and oversee the resource management, or to privatize the commons” See: Brian Weeden and Tiffany Chow, ‘Taking a common-pool resources approach to space sustainability: A framework and potential policies’ (2012) 28(3) *Space Policy* 166, 167.

⁷⁵⁹ Among others, Elinor Ostrom challenged Hardin’s call for a Leviathan-style central authority. Her critique of top-down centralisation, and the alternative design principles she proposed, will be examined in greater detail under the behavioural approach section.

⁷⁶⁰ For example, services like national defence, policing, and firefighting are typically funded through taxes, yet even those who do not pay taxes still benefit from them. This creates a situation in which some individuals attempt to enjoy the benefits of public goods without contributing – this behaviour is referred to as free riding.

may lead to underfunding, degradation, or even the complete loss of these goods and services, ultimately harming everyone – including those who initially paid their fair share.⁷⁶¹

The problem of free riding becomes far more complex in the context of the global commons and areas beyond national jurisdiction. In domains such as climate change and orbital space management, the challenge is compounded by intergenerational dynamics. Present generations often engage in what scholars term “generational free riding” – reaping the immediate benefits of resource exploitation while postponing the cost of mitigation or debris prevention.⁷⁶² Despite the persistent risk of free-riding, states have repeatedly managed to overcome transboundary externalities through international agreements. Cooperation, thus becomes possible because joint action enables participants to internalize spillover effects – ensuring that each state perceives itself as better off cooperating than acting alone.⁷⁶³ As Nordhaus, proponent of the rationalist approach, notes, “even the most democratic of nations acting noncooperatively in its own interest would take minimal action because most of the benefits of cooperation spill out to other nations”.⁷⁶⁴ He therefore, argues that only carefully designed, self-enforcing multinational regimes – such as “climate clubs” with both incentives for participation and penalties for defection – can make collective governance effective, though such arrangements still require states to accept limits on their freedom of use.⁷⁶⁵ This climate club idea can be regarded as a hybrid mechanism in dealing with common pool resources, as it is voluntary to join, but once inside, actors have binding commitments backed by sanctions.

⁷⁶¹ Penalizing free riding can disincentivize free riders. Another strategy is to assign responsibility to private actors, so that the costs of use are directly borne by those who access the service (for instance, maintenance fees).

⁷⁶² Since the most benefits of costly reductions in emissions or orbital debris will only accrue decades later, current actors face weak incentives to act. This creates a double free-riding dilemma: state and private operators free ride in each other in the present, while entire generations externalize long-term environmental costs onto their successors. At the same time, effective penalization and monitoring are far more difficult to implement in the global commons, where existing international institutions often lack the capacity or mandate to ensure that all actors contribute fairly to preventing overuse and environmental harm. See: William Nordhaus, ‘Climate Change: The Ultimate Challenge for Economics’ (2019) 109(6) *American Economic Review* 1991, 2007.

⁷⁶³ Nordhaus highlights that global environmental concerns pose governance problems of a fundamentally different order than domestic ones. Within national systems, governments can address externalities by legislating, however, individual states capture only a fraction of the benefits of their mitigation efforts while most gains spill over to others, and no central authority exists to enforce cooperation. William Nordhaus, ‘Climate Change: The Ultimate Challenge for Economics’ (2019) 109(6) *American Economic Review* 1991, 2010.

⁷⁶⁴ William Nordhaus, ‘Climate Change: The Ultimate Challenge for Economics’ (2019) 109(6) *American Economic Review* 1991, 1992-1993.

⁷⁶⁵ William Nordhaus, ‘Climate Clubs: Overcoming Free-Riding in International Climate Policy’ (2015) 105(4) *American Economic Review* 1339, 1339-1370.

Moreover, the question of how to *allocate use rights* is central to the governance of common pool resources, and it has already surfaced in this dissertation, with respect to externality internalization and cap-and-trade system. Because common pool resources are rivalrous but non-excludable, the core challenge lies in determining who may access the resource, under what conditions, and in what quantities, so that use remains within sustainable limits and allocation happens equitably. From a Law and Economics perspective, several allocation mechanisms have been developed to manage scarcity and align incentives: such as first-come first-served, auctions, lotteries, tradable permits, grandfathering, and benchmarking. A prominent example of the first-come, first-served approach is the allocation of GEO slots and associated frequency bands through the ITU, which grants priority to those who file first. While this system provides a measure of order and formally enshrines the principle of the “rational, efficient, and equitable use” of the radio-frequency spectrum and associated orbits, in practice it is often criticised for entrenching first-mover advantage and disproportionately favouring technologically advanced states. By contrast, in LEO, the first-come, first-served logic continues to operate without any comparable binding allocation regime, leaving access to orbital capacity largely unregulated and thereby intensifying the dynamics of overuse and the tragedy of the global commons.

Although various incentive-based instruments have been widely discussed in the literature, mechanisms such as auctions⁷⁶⁶ or lotteries⁷⁶⁷ have not, to date, been applied in practice to the allocation of rights within the global commons. Other mechanisms, such as tradable permits, grandfathering and benchmarking, are primarily designed to limit externalities and are therefore addressed in the section on internalization of externalities of this dissertation. Unlike allocation mechanisms that determine who can access a common resource, these instruments focus on how the burdens of pollution control and mitigation are distributed among actors.

⁷⁶⁶ Auctions as distributive mechanisms, are designed not only to allocate scarce resources but also to reveal how much actors are willing to pay, thereby signalling the value they attach to the good, and the commons.

⁷⁶⁷ The lottery system is an allocation mechanism in which scarce resources, rights, or opportunities are assigned randomly among eligible participants. A well-known example is the United States Diversity Visa Lottery, which allocates a limited number of immigrant visas by random selection among qualified applicants from underrepresented countries.

A classic case of the logic of common pool resources in public international law is the high seas fisheries regime.⁷⁶⁸ Today, the governance of international fisheries is structured through a number of overarching instruments, particularly the UN Convention on the Law of the Sea (UNCLOS) of 1982,⁷⁶⁹ the 1995 UN Straddling Fish Stock Agreement,⁷⁷⁰ and further instruments adopted under the aegis of the Food and Agriculture Organization (FAO), complemented by numerous international, regional, and bilateral fisheries agreements. Most recently this framework was extended through the 2023 Agreement under UNCLOS on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction (BBNJ Agreement), which seeks to address regulatory gaps in the management of biodiversity in the high seas and the deep seabed.⁷⁷¹

Article 87 of UNCLOS explicitly establishes freedom to fish on the high seas, or the right of states to authorise their nationals to fish on the high seas conditioned to specific limitations.⁷⁷² Additionally, the Straddling Fish Stocks Agreement (UNFSA), an important international treaty on fishing on the high seas, importantly adopts a precautionary and

⁷⁶⁸ It is notable, however, that approximately 90% of all commercially exploited fish stocks are located within areas subject to national jurisdiction – the territorial seas and the Exclusive Economic Zone (EEZ) – hence do not fall within the governance framework of the high seas. See: Michael Bowman, Peter Davies and Catherine Redgwell, Lyster's *International Wildlife Law* (2nd edn, Cambridge University Press 2010) 125.

⁷⁶⁹ Convention on the law of the sea of 10 December 1982, entered into force 16 November 1994, 1833 UNTS 397 (UNCLOS).

⁷⁷⁰ Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks of 4 August 1995, entered into force 11 December 2001, 2167 UNTS 3 (Straddling Fish Stocks Agreement).

⁷⁷¹ Agreement Under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction of 19 June 2023, it has not entered into force, UN Doc. A/CONF/232/2023/4 (BBNJ Agreement). The objective of the BBNJ Agreement is specifically to ensure conservation and sustainable use of marine biodiversity in areas beyond national jurisdiction (ABNJ), meaning in this context, the high seas including the international seabed (the Area). See: Shani Friedman, 'The interaction of the BBNJ agreement and the legal regime of the Area, and its influence on the implementation of the BBNJ agreement' (2024) 167 *Marine Policy* 1, 1.

⁷⁷² Limitations under UNCLOS include: the duty to protect and preserve the marine environment, which applies to all states (UNCLOS art 192); complemented by specific conservation obligations regarding living resources of the high seas for states engaged in their exploitation (UNCLOS art 119); obligation to cooperate, including through regional or sub-regional fisheries organisations (UNCLOS art 118). Additionally, Art 63 (2) UNCLOS establishes the general rule of cooperation, stating that where a stock occurs even in ABNJ, all states fishing for the stock (including coastal states) in the high seas shall seek to agree on conservation and management measures. Fundamentally, obligations are to be understood as requiring 'due diligence' rather than a specific result. See: Pierre-Marie Dupuy and Jorge E Viñuales, *International Environmental Law* (2nd edn, Cambridge University Press 2018) 209; and Stefán Asmundsson, 'Freedom of Fishing on the High Seas, and the Relevance of Regional Fisheries Management Organisations (RFMOs)' in Myron H. Nordquist, John Norton Moore and Ronán Long (eds.) *Challenges of the Changing Arctic, Continental Shelf, Navigation, and Fisheries* (Brill 2016) 509, 513.

ecosystems approach to fisheries regulation.⁷⁷³ Notably, UNFSA was developed in a context of persistent scientific uncertainty regarding fish stock status, recognising that effective governance requires action under uncertainty rather than waiting for full scientific consensus.⁷⁷⁴ Accordingly, when faced with incomplete or contested scientific information, the *precautionary approach* embedded in the UNFSA requires states to adopt conservative and risk-averse management measures. Furthermore, the core of the UNFSA lies in its promotion of coordination between coastal and flag states through Regional Fisheries Management Organisations (RFMOs) as the preferred mechanism for high seas fisheries governance.⁷⁷⁵ Crucially, Article 8 of the UNFSA provides that where a RFMO has competence over a particular stock, only states that are member of that RFMO, or that agree to apply its conservation and management measures, may authorize vessels to engage in fishing for that stock. This mechanism directly addresses the free-rider problem that has historically undermined high seas fisheries management, by conditioning access to the resource on participation in, or compliance with, collectively agreed rules. In practice, this means that if a state wishes to authorise vessels to fish in a given area of the high seas, it must either join the relevant RFMO or formally agree to apply its rules. While UNCLOS obliges coastal states to determine a Total Allowable Catch (TAC)⁷⁷⁶ within their Exclusive Economic Zones,⁷⁷⁷ it does not impose equivalent quantitative limits for the high seas. The UNFSA builds upon this framework by requiring states, through the establishment of RFMOs, to cooperate in establishing conservation measures, including catch limits, thus enabling the collective setting of TACs or TAC-equivalent limits for straddling and highly migratory fish stocks.⁷⁷⁸ The TAC

⁷⁷³ Straddling Fish Stocks Agreement art. 5(c)–(e) and art. 6.

⁷⁷⁴ Ted L. McDorman, ‘Implementing Existing Tools: Turning Words Into Actions – Decision-Making Processes of Regional Fisheries Management Organisations (RFMOs)’ (2005) 20(3–4) *The International Journal of Marine and Coastal Law* 423, 435

⁷⁷⁵ Where such cooperation fails, states may provide a subsidiary cooperation and implementation mechanism, although states parties of the UNFSA have an obligation to cooperate in order to create an organisation or similar arrangements with a certain minimum content. Straddling Fish Stocks Agreement article 8 and 9.

⁷⁷⁶ TAC is an upper limit on the amount of fish that can be caught, set for different types of fish species, typically by weight in the fishing ground within a given period. See for example: European Commission, ‘Fishing quotas’ <https://oceans-and-fisheries.ec.europa.eu/fisheries/rules/fishing-quotas_en#total-allowable-catches> accessed 20 October 2025.

⁷⁷⁷ UNCLOS article 61(1) - (3).

⁷⁷⁸ TACs are typically established through a multi-stage process, grounded in scientific assessments of stock status that are periodically provided by specialised fishery-biological advisory bodies, such as the International Council for the Exploration of the Sea. See: ESPI, ‘Report 82 - Space Environment Capacity - Full Report’ (April 2022) 35 [ISSN:2076-6688] accessed 20 October 2025.

systems is considered effective as it ensures that the total catch is kept below the regulator's threshold level, however, the system intensifies the competition to fish first within RFMOs before the overall limit is reached. To prevent this “derby system”, several quota-based allocation mechanisms have been introduced that are allocated: *individual quota (IQ) systems* that allocate fixed, non-transferable shares of the total allowable catch to individual fishers or entities within an RFMO that must be used by the holder and are not transferable; *individual transferable quota systems (ITQ)* that allocate likewise fixed shares but allow them to be traded or leased; and *individual vessel quotas (IVQs)*, which assign catch limits to specific vessels, with or without the right of transferability.⁷⁷⁹

From a Law and Economics perspective, the TAC system functions as quantity-based regulatory instrument akin to a *hard cap*: establishing a quantifiable upper limit on total extraction (sum of all TACs), in order to reflect the ecological limits of the regenerative capacity of fish stocks. Once allocated and enforced, such caps are intended to constrain individual harvesting decisions within collectively defined sustainability thresholds. Furthermore, in the international context, TACs are typically negotiated, implemented, and monitored at the regional level through RFMOs, rather than by a single global authority, reflecting Ostrom's polycentric view.

While GSO slots – much like fish stocks within geographically bounded ecosystems – can be conceptually stabilised and physically divided, enabling the ITU to operate a quasi-property allocation system that assigns fixed positions and frequencies to states, the governance of LEO is far more complex. In LEO, “orbital shells” are not fixed positions, but functional constructs defined by specific combinations of altitude and inclination that determine the region on which satellites circulate and interact. Within a given LEO shell, satellites move with broadly similar orbital periods and velocities. This creates a shared dynamical environment in which the risk of collision or debris generation is strongly interdependent: the failure or fragmentation of one satellite can directly affect all others within the same shell. This interdependence makes orbital shells a meaningful functional unit for assessing congestion and

⁷⁷⁹ Kentaka Aruga, *Environmental and Natural Resource Economics* (Springer 2022) 147; and ESPI, ‘Report 82 - Space Environment Capacity - Full Report’ (April 2022) 35 <ISSN:2076-6688> accessed 20 October 2025.

defining separate capacity threshold,⁷⁸⁰ much like the role of total allowable catches in fisheries governance, where scientifically determined limits seek to prevent overexploitation of a finite common-pool resource.

Indeed, both LEO and GSO are best understood as common pool resources, which dynamic generates the classic tragedy of the commons, mostly characterised through the Kessler syndrome, which models how unregulated accumulation of externalities can drive a common-pool resource toward collapse. Since each actor accounts only for its own immediate benefits and private cost while disregarding the broader social and intergenerational harms, the result, as environmental and resource economics predicts, is a systemic tendency toward overuse and congestion of the orbital commons.⁷⁸¹ For both commercial and scientific operators, access to geostationary orbital slots and associated spectrum is mediated through the ITU. The process begins with a filing by the operator's national administrator, which the ITU generally approves, subject to the availability of orbital slots and frequencies. Crucially, the ITU does not impose a market-based price for slots or spectrum; the process is administrative and regulatory rather than market-driven. Yet despite this "minimal price",⁷⁸² orbital slots and spectrum remain extremely valuable commercial resources. Once an operator – more precisely, its authorizing state – successfully brings a satellite into use, and provided it remains operational and properly registered with the ITU, the state retains continuing rights of use. In practice, these rights amount to a form of de facto appropriation, carrying significant and enduring economic value despite not constituting formal ownership under international law,

⁷⁸⁰ See discussions on LEO's orbital capacity for example: Amilla Colombo, Peter Martinez, Francesca Letizia, Benedetta Cattani, Emmanuelle David, Diego Escobar, Satomi Kawamoto, Robert Rovetto, Ivan Sumelzo, 'Space capacity management and its interaction with space traffic management' (2025) 233 *Acta Astronautica* 223, 227.

⁷⁸¹ Alexander William Salter, 'Space Debris: A Law and Economics Analysis of The Orbital Commons' (2016) 19 *Stanford Technology Law Review* 221, 227.

⁷⁸² See: Nodir Adilov, Peter Alexander and Brendan Cunningham, 'Understanding the Economics of Orbital Pollution Through the Lens of Terrestrial Climate Change' (2022) 59(2) *Space Policy* 1, 4-5. While the ITU itself does not sell or auction orbital slot and spectrum, filing is far from free: for a basic satellite, the combined cost for advance publication information (API), coordination, and notification filings can easily exceed 10,000-20,000 USD, depending on complexity. Additionally, national administrators may include additional fees relevant to the filing. To access the information for cost recovery for satellite network filings of the ITU, see: Falou Dine Akim, 'Cost Recovery For Satellite Networks Filings' (Presentation at the 29th World Radiocommunication Seminar, 30 November – 11 December 2020) https://www.itu.int/en/ITU-R/seminars/wrs/2020/Plenary%20Sessions%20%20Presentations/02.%20Space%20Services%20-%201%20to%203%20Dec%202020/COST%20RECOVERY%20FOR%20SATELLITE%20NETWORKS%20FILINGS_AF.pdf, accessed 20 October 2025.

thereby allowing states to monetize their filings while maintaining international recognition and effectively creating a de facto market for access.⁷⁸³

While the ITU regime constitutes the principal international regulatory framework for managing orbital space as a global commons, it is essential to distinguish between the governance of LEO and GEO, since the ITU applies different allocation mechanisms to each in recognition of their distinct physical characteristics and sustainability challenges.⁷⁸⁴ There are two types of allocation mechanisms in the geostationary orbit ensured by the ITU: *a posteriori* allocation corresponds to a first-come, first-served approach, under which rights are granted after use has been demonstrated, with coordination and authorization occurring only once actors request access. By contrast, *a priori allocation* (planning) involves the advance allocation of use rights before actual use occurs, functioning as pre-established options that secure potential claims for all actors, including those that are not yet active. Appendices 30, 30A, and 30B of the ITU Radio Regulations establish *a priori* allocations of GSO slots and associated frequencies for fixed satellite services (FSS) and broadcasting-satellite services (BSS), moving towards a more equitable access to these scarce resources.⁷⁸⁵ However, critiques state that these dual (hybrid) allocation system itself represents challenges both relevant to equity and efficiency in governing orbital commons.⁷⁸⁶ By contrast, LEO is governed

⁷⁸³ A parallel dynamic appears in other areas of international resource governance. In deep-sea mining, for example, the International Seabed Authority allocates exploration contracts for exploration or exploitation of seabed minerals only to states or to entities sponsored by them. In both cases, the state remains internationally responsible for ensuring that private actors comply with international rules, yet in practice, companies may engage in forum shopping by choosing sponsoring states with weaker oversight.

⁷⁸⁴ For detailed discussion of the differing physical characteristics of LEO and GEO, see Chapter I-II of this dissertation.

⁷⁸⁵ International Telecommunication Union (ITU) *Radio Regulations* (rev WRC-19 ITU 2020) appendices 30, 30A and 30B. Furthermore, De Man emphasizes, even though the *a priori* system only regulates a small subset of orbital uses, they are worth studying because they represent a fundamentally different way of thinking about allocation – one based on equity and guaranteed options for all states, rather than rewarding early movers. See: Philip De Man, *Exclusive Use in an Inclusive Environment* (Springer 2016) 279-280.

⁷⁸⁶ The *a priori* system does not confer full property rights but rather provisional use entitlements. While designed to impose order on an open-access environment, it has been criticised for entrenching first-mover advantage: technologically advanced states benefit disproportionately, while developing countries – often lacking the capital or technology to activate their filings – remain unable to realise near term gains and sometimes resort to leasing or warehousing their slot. Even when latecomers acquire the necessary capacity, they face a “latecomer handicap” as only higher cost, less desirable frequencies remain available, undermining both equity and the OST principle of equal access. See: Sara-Louise Khabazian, ‘International Regulation of Access to the Geostationary Orbit:

exclusively by an *a posteriori* allocation system based on the first-come, first-served principle, with no *a priori* planning mechanism.

Additionally, *the practice of slot warehousing* and the *paper satellites problem* has emerged from the ITU's first-come, first-served regime, which is constrained only by relatively weak "bringing-into-use" requirements. From a narrow Law and Economics perspective, this phenomena can be understood as a form of strategic hoarding: the accumulation of rights in anticipation of future value rather than for immediate productive use. Such behaviour exemplifies what Michael Heller has described as an *anticommons dynamic*, in which multiple actors possess exclusionary claims over a scarce resource, yet none has clear or enforceable incentives to put it to productive use.⁷⁸⁷ The result is underutilization (from efficiency perspective), as valuable orbital capacity remains blocked on paper while idle in practice. Far from serving as a balancing mechanism against overuse, however, the anticommons effect compounds regulatory disorder by layering inefficiencies of underuse and deepening inequalities, while simultaneously amplifying the risks of congestion and overexploitation inherent in common pool resources. Moreover, these practices are exacerbated by information asymmetries inherent in the ITU coordination system. The ITU largely relies on self-reported technical filings and lacks the capacity to verify the credibility or readiness of proposed satellite networks, allowing speculative filings, such as paper satellites, to persist, particularly in LEO.

Through the lens of Law and Economics, experiences from other global commons regimes demonstrate that no single governance model is sufficient on its own. The successful Montreal Protocol illustrates how centrally agreed quantitative limits, combined with differentiated obligations, trade restrictions, and technology transfer mechanisms can successfully align individual incentives with collective environmental goals. In the context of high seas fisheries, RFMOs show how hard quantitative caps, such as TACs can internalise common-pool externalities, but also reveal the limits of cap-setting when not accompanied by effective allocation mechanisms (quota systems), enforcement, and compliance, as evidenced

Mission Impossible?' (2007) 26(2) *Communications Law Bulletin* 17, 18 <https://classic.austlii.edu.au/au/journals/CommsLawB/2007/23.pdf> accessed 20 October 2025; and Rob Frieden, 'Balancing Equity and Efficiency Issues in Global Spectrum Management' in William Drake and Ernest Wilson (eds.) *Governing Global Electronic Networks: International Perspectives on Policy and Power* (The MIT Press 2008) 127, 127-148.

⁷⁸⁷ Michael Heller, 'The Tragedy of the Anticommons: Property in the Transition from Marx to Markets' (2013) 76(1) *The Modern Law Review* 6, 18.

by the “derby system” dynamics and persistent free-riding. By contrast, the ITU regime demonstrates how regular coordination and adaptive rule-revision can provide stability in technically complex domains like the geostationary orbit. Taken together, these examples suggest that hybrid governance structures – blending elements of central authority, market-based allocation, and voluntary cooperation – might offer the most viable pathway for addressing the even greater complexity of LEO as a global common of its own.

Next, further approaches will be examined – behavioural economics and critical theories – to uncover systemic behavioural tendencies and structural dynamics that contribute to environmental overexploitation across diverse domains.

C. Behavioural economics and systems thinking

1. Behavioural international law

This section employs insights from behavioural analysis to complement the rationalist framework of law and economics. The rationale for this choice lies in the recognition that, despite certain caveats, many systemic features of individual human decision-making can also be observed in the behaviour of states within the international system.⁷⁸⁸ By incorporating these dynamics, the analysis moves beyond the oversimplified assumption of perfectly rational actors that underpins much of classical thinking, allowing for more realistic account of how states and other actors approach the governance of the orbital commons. Moreover, while law directs human behaviour, it often lacks a coherent understanding of how it actually influences that behaviour. Traditional legal theory often assumes that people (and states) act rationally and

⁷⁸⁸ Translating insights from individual psychology into the realm of behaviour is not straightforward. While behavioural economics highlights systemic biases and cognitive limits in individual decision-making, it is less clear how these dynamics map onto the collective and often fragmented processes through which states act. This raises a persistent challenge for rational-choice analysis in international law and international relations: should the sovereign state be treated as a “black box” with unified, stable preferences, or should the internal complexity also be taken into account? See: Eyal Zamir and Doron Teichman, *Behavioral Law and Economics* (Oxford University Press 2018) 423-425; and Tomer Broude, ‘Behavioural International Law’ (2015) 163(4) *University of Pennsylvania Law Review* 1099, 1121– 1130.

will comply with laws based on incentives or sanctions.⁷⁸⁹ However, the assumption of perfect rationality remains largely theoretical and empirically untenable.⁷⁹⁰ Accordingly, the task of behavioural law and economics is to examine how real-world patterns of human behaviour affect the design, effectiveness, and legitimacy of legal rules.⁷⁹¹ “This is not to say that behavioural analysis is contrary to standard rational choice but rather a complement and supplement” of it.⁷⁹²

Behavioural economics challenges the foundation of neoclassical welfare economics by questioning its core assumption that individuals possess stable, rational preferences.⁷⁹³ Empirical findings demonstrate instead that preferences are often biased, uninformed, inconsistent, or even self-destructive, which undermines the neat welfare-maximization model that underpins much of traditional economic and legal analysis.⁷⁹⁴ Because of this, behavioural economics often emphasizes *values* beyond narrow utility, such as fairness, legitimacy, identity, reputation, solidarity, or environmental stewardship. As a result, law and policymaking cannot rely solely on the welfare economics logic of maximizing aggregate

⁷⁸⁹ Claire Finkelstein, 'Legal Theory and the Rational Actor' in Alfred R. Mele, and Piers Rawling (eds) *The Oxford Handbook of Rationality* (Oxford Academic 2009) 399, 401-404

⁷⁹⁰ For example, behaviouralists argue that the human brain makes shortcuts in judgement and decisions making that diverge from expected utility theory.

⁷⁹¹ The most important insight of behavioural psychology to emerge within the economic analysis is *prospect theory*. Rather than assessing outcomes in absolute terms, individuals evaluate them relative to a reference point – often their current status quo, shaped by what is known as the *status quo bias*. This shift in perspective explains a range of behavioural patterns that systematically depart from the assumptions of rational choice theory, most notably *loss aversion* (the tendency to weigh losses more heavily than equivalent gains), the *endowment effect* (overvaluing what one already possesses), and *framing effects* (different responses to identical outcomes depending on how they are presented). See: Daniel Kahneman, Jack Knetsch and Richard Thaler, 'Experimental Tests of the Endowment Effect and the Coase Theorem' (1990) 98(6) *Journal of Political Economy* 1325, 1325-1328; and Tomer Broude, 'Behavioural International Law' (2015) 163(4) *University of Pennsylvania Law Review* 1099, 1115.

⁷⁹² Tomer Broude, 'Behavioural International Law' (2015) 163(4) *University of Pennsylvania Law Review* 1099, 1103.

⁷⁹³ Incorporating insights from cognitive psychology, behavioural law and economics emphasizes that human rationality is bounded – shaped by systematic biases, and seemingly “irrational” concerns such as fairness – while at the same time highlighting the descriptive and empirical strengths of this perspective for understanding legal and economic behaviour. See: Tomer Broude, 'Behavioural International Law' (2015) 163(4) *University of Pennsylvania Law Review* 1099, 1103.

⁷⁹⁴ Behavioural science further demonstrates that human decision-making is shaped not by perfect rationality but by systematic biases. We routinely misperceive risks, exaggerating some while underestimating others; we give undue weight to recent experiences while neglecting historical patterns; and we focus on immediate events rather than long-term trends. Moreover, we filter out information that contradicts our mental models or preferences, reinforcing cognitive blind spots. In practice, this means that we often fail even to optimise our own individual welfare – let alone the welfare of the system as a whole. See, for example: Cass Sunstein, Christine Jolls and Richard Thaler, 'A Behavioral Approach to Law and Economics' (1998) 50 *Stanford Law Review* 1471, 1476-1480.

utility, but must also take into account real patterns of human behaviour, bounded rationality, and broader notions of fairness.⁷⁹⁵ This insight is particularly important in domain such as environmental and resource economics, where the welfare framework has historically risked externalizing harms: by defining the “good” narrowly in terms of economic or utility gains, it has often disregarded ecological sustainability and intergenerational justice. For example, research shows that people sometimes punish free riders even at a personal cost – a form of *altruistic punishment*.⁷⁹⁶ This has direct implications for international law, where enforcement is decentralised and depends less on a central Leviathan and more on states (or sometimes non-state actors) being willing to sanction defectors to protect collective goods.⁷⁹⁷ Importantly, recognising that actors may deviate from strict profit- or utility-maximisation does not mean abandoning the idea that they act strategically. Rather, behavioural insights suggest that the very structure of preferences – including fairness concerns, reciprocity, and willingness to punish – must be considered when designing governance mechanisms for global commons like the orbital environment.

As a complementary social science, behavioural economics offers valuable insights for designing more effective legal systems, especially in relation to the sustainable and equitable governance of global commons. Unlike welfare economics, which assumes stable and rational preference-maximisation, behavioural economics examines how actors actually behave, that is often in biased, short-sighted, or inconsistent ways. By revealing how such departures from rationality shape decision-making and its consequences, behavioural analysis helps to explain why actors (including states) may make choices that undermine long-term sustainability, and how law and governance can be structured to “nudge” them toward more socially and environmentally desirable outcomes.⁷⁹⁸

⁷⁹⁵ The theory of *bounded rationality* – one of the foundational concepts of behavioural economics – proposed by Herbert Simon, suggests that individuals make reasonably sound decisions based on the limited information available to them. However, they do not possess perfect knowledge, particularly regarding the more distant or complex parts of a system. Simon refers to this limitation as the “invisible foot”, highlighting how individual decisions, though rational within local contexts, can lead to unintended and often detrimental collective outcomes. See: Herbert Simon, ‘Theories of Bounded Rationality’, in R. Radner and C. B. McGuire (eds.) *Decision and Organization* (North Holland Publishing Company 1972) 161, 161-176.

⁷⁹⁶ See for example: Armin Falk, et al., ‘Driving Forces Behind Information Sanctions’ (2005) 76(6) *Econometrica* 2017, 2017-2030.

⁷⁹⁷ Anne van Aaken, ‘Behavioral international law and economics’ (2014) 55(2) *Harvard international Law Journal* 421, 433.

⁷⁹⁸ Edward Cartwright, *Behavioural Economics* (3rd edn, Routledge 2018) 3.

A central critique of applying behavioural economics to international law concerns the status of the state as a decision-making actor. Traditional Law and Economics often treats the state as a unitary rational actor (“black-box”, or “billiard ball”), simply extending the model of individual utility maximisation to the international plane.⁷⁹⁹ Behavioural international law, however, does not aim to transpose individual-level psychological findings fully onto states. Instead, its ambition is more nuanced: to identify systematic, observable deviations from rational-choice predictions in state behaviour, while recognising that the cognitive biases and heuristics documented in individuals (such as fairness bias or loss aversion) cannot be assumed to exist at the collective level without empirical evidence. From this perspective, the state remains the relevant decision-making unit, but analysis focuses on whether its output exhibit consistent patterns of bounded rationality, misperception, or non-linear responses that may shape – and sometimes undermine – the effectiveness of international governance of the commons.

2. The carrot and stick dilemma

A central topic of behavioural economics is the impact of *incentives* on behaviour. Traditional rational-choice models assume that people respond predictably to incentives and deterrents: rewards (carrots) increase good behaviour, and punishment (sticks) reduce bad behaviour. This is the logic behind fines for pollution, bonuses for performance, or deterrence-based criminal justice. Behavioural economics, however, shows that this is psychologically naïve. Human behaviour is not driven only by utility maximization. Other factors matter just as much – or sometimes more: autonomy (people resist when they feel their freedom is being undermined); fairness and ethics (people care deeply about whether a policy is perceived as just, even if the incentives are “efficient”); appropriateness norms (many decisions are guided by “what seems right” rather than pure calculation).⁸⁰⁰

⁷⁹⁹ Tomer Broude, ‘Behavioural International Law’ (2015) 163(4) *University of Pennsylvania Law Review* 1099, 1124.

⁸⁰⁰ Nick Chater and George F Loewenstein, ‘The i-Frame and the s-Frame: How Focusing on Individual-Level Solutions Has Led Behavioral Public Policy Astray’ (2023) 46(147) *Behavioural and Sciences* 1, 16.

This is also where the *crowding-out effect* becomes relevant. When external rewards or punishments dominate, intrinsic motivations to act responsibly are undermined. Compliance is reframed as a transactional exchange rather than a shared duty: fines are interpreted as a price to pollute, and penalties as a purchased license to delay compliance. What was intended as a deterrent may instead legitimise continued harmful behaviour.⁸⁰¹ In this way, over-reliance on incentive structures can generate incomplete or even perverse outcomes.⁸⁰² Environmental taxation illustrates the tension clearly. By converting environmental damage into a monetary cost, such measures embody a utilitarian logic in which harm is treated as something that can be offset rather than avoided. This facilitates economic modelling and internalisation of externalities. But it also sidesteps the moral and ecological dimensions of harm. Ecosystems, intergenerational justice, and equity are valued only insofar as they can be priced or compensated. Applied to states, the crowding-out effect means that if international law reduces compliance to a calculation of fines versus benefits, it risks eroding broader motivations for stewardship and solidarity, thereby weakening the foundations of collective governance.

In their distinction between the i-frame (fixing individual behaviour through “nudges” and individual interventions)⁸⁰³ and the s-frame (changing systemic rules, institutions, and incentives) insights, Chater and Loewenstein argue that governance failures arise when policy relies too heavily on adjusting individual incentives.⁸⁰⁴ The i-frame assumes that fines, subsidies, or nudges will correct behaviour by shifting the costs and benefits faced by individuals or firms. Yet this logic overestimates rational utility-maximization: actors often ignore, misinterpret, or even resist such measures, and deeper structural drivers of unsustainable behaviour remain unaddressed. From a behavioural perspective, this reflects

⁸⁰¹ The *crowding-out effect* is well illustrated by a study in Israeli day-care centre, where parents were fined for arriving late to pick up their children. Instead of reducing tardiness, the fines increased it: many parents began treating the penalty as a fee for purchasing extra childcare time, thereby replacing a sense of moral obligation with market transaction. See: Uri Gneezy and Aldo Rustichini, ‘A Fine is a Price’ (2000) 29(1) *Journal of Legal Studies* 1, 1–17.

⁸⁰² *Perverse incentives* (also referred to as the “cobra effects”) describe situations in which an incentive structure produces outcomes that are not only unintended but directly contrary to the goals if its designers.

⁸⁰³ In behavioural economics, *nudging* refers to the design of legal or policy measures that steer people toward certain behaviours without restricting their freedom of choice or imposing significant economic incentives or penalties. See, for instance: Richard Thaler and Cass Sunstein, *Nudge: Improving Decisions About Health, Wealth, and Happiness* (Penguin 2009) 6.

⁸⁰⁴ Nick Chater and George F Loewenstein, ‘The i-Frame and the s-Frame: How Focusing on Individual-Level Solutions Has Led Behavioral Public Policy Astray’ (2023) 46(147) *Behavioural and Sciences* 1, 1.

bounded rationality and *time-inconsistency*: just as individuals may sacrifice long-term welfare for short-term gratification, governments or corporate actors may privilege immediate political or commercial gains (such as electoral success or rapid market share), and economic growth over long-term sustainability, thereby reproducing “short-termism”.⁸⁰⁵ I-frame in global governance leaves structural drivers untouched: first-come, first-served allocations, absence of use/pollution caps, weak enforcement, and strong incentives for free-riding.

By contrast, the s-frame shifts attention to the rules of the game themselves. Here, incentives and penalties are still crucial, but they operate at the systemic level: banning single-use plastics rather than nudging recycling; restructuring energy markets through binding caps and technology mandates rather than relying on carbon taxes alone; or, in climate governance, using tariffs, technology transfers, and trade preferences to enforce cooperation rather than assuming voluntary alignment of state interests. The critique is not that incentives are irrelevant, but that incentives applied only at the individual level are incomplete and sometimes counterproductive. Used at the systemic level, however, carrots and sticks can realign the entire institutional context, reducing the scope of free riding and enabling long-term commitments that help governments and firms self-bind against short-term political or commercial temptations.

The key question, then, is whether this line of thinking can be meaningfully extended to the realm of international law – specifically, to the governance of state behaviour in managing global commons. Applied to orbital space, for example, the i-frame corresponds to voluntary guidelines and national licensing, which remain inadequate because they leave core structural drivers untouched: the first-come, first-served allocation of orbital slots, the absence of binding debris caps, weak enforcement, and strong incentives to free-ride. From an s-frame perspective, systemic reform is needed, such as binding international standards on debris mitigation, launch caps, or economic instruments like tradable permits. These measures shift the incentive structure at the global level, ensuring that individual firms and state operate within a framework where sustainable use becomes the default outcome. This line of thinking aligns with the argument of van Aaken, who claims that rather than designing nudges for individuals,

⁸⁰⁵ Anne van Aaken, ‘Behavioral international law and economics’ (2014) 55(2) *Harvard International Law Journal* 421, 432.

the focus should be on political economic mechanisms that enable state to self-bind⁸⁰⁶ – in other words, to lock themselves into long-term commitments that prevent future backsliding.⁸⁰⁷ When behavioural mechanisms, such as defaults, are embedded in institutional rules that apply to states or organizations, they do no longer target individual choice but instead operate at the systemic, s-frame level of governance. In that context a “nudge” is no longer just a gentle push on individual psychology; it becomes part of the system’s rule design, shaping the menu of choices available to states and altering the structural incentives under which they operate. Examples include treaty mechanisms with binding caps, independent monitoring bodies, or trade penalties for defectors, all of which reduce the temptation for governments to sacrifice long-term sustainability of global commons (like the climate or orbital space) for immediate political or economic benefits. For orbital governance, this would entail designing treaties, licensing rules, or ITU procedures so that the default institutional settings favour sustainability, for example, by making satellites operators automatically responsible for end-of-life disposal unless they can justify a duly authorised alternative. In this sense, what looks like an individual-level nudge becomes a system-level default rule once it is formalized in international governance.⁸⁰⁸

⁸⁰⁶ Anne van Aaken, ‘Behavioral international law and economics’ (2014) 55(2) *Harvard International Law Journal* 421, 432.

⁸⁰⁷ This dynamic reflects a well-documented behavioural tendency. Individuals often procrastinate or adhere to the status quo rather than actively making new choices. For this reason, default options play a crucial role, since people are disproportionately likely to stick with whatever option is presented as the norm. The design of these defaults – what behavioural scholars call *choice architecture* – can strongly shape outcomes. A classic example is organ donation regimes: in countries where donation requires explicit consent (*opt-in*), participation rates are significantly lower than in countries where individuals are presumed donors unless they *opt out*. Empirical studies confirm that shifting the default from “no donation” to “donation” dramatically increases consent rates, illustrating how subtle changes in institutional design can harness cognitive biases to produce very different collective results. See: Eric Johnson and Daniel Goldstein, ‘Do Defaults Save Lives?’ (2003) 302 *Science* 1338-1339 <http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1324774> accessed 20 October 2025; Interestingly, this widely cited assumption has been challenged by recent findings based on longitudinal data, which shows that in five countries the shift to opt-out defaults did not lead to higher organ donation rates. See: Mattea Dallacker et al., ‘Opt-out defaults do not increase organ donation rates’ (2024) 236 *Public Health* 436-440 <<https://doi.org/10.1016/j.puhe.2024.08.009>> accessed 20 October 2025. Furthermore, there are discussions on a third possible alternative to the opt-out system, called *mandatory choice system*, where citizens would have to explicitly register their consent or objection to organ donation, when applying for a driver’s license or ID card for example. Scientists believe, by allowing this option, it would prompt people to make an informed decision, which would eliminate the perceived ambiguity about their preference. See: Max-Planck-Gesellschaft, ‘Organ donation: Opt-out defaults do not increase donation rates’ (14 November 2024) <<https://www.mpg.de/23726833/1113-bild-organ-donation-opt-out-defaults-do-not-increase-donation-rates-149835-x>> accessed 20 October 2025.

⁸⁰⁸ Such *delegation* to the international sphere may serve to make commitments more credible, as powers transferred to independent institutions are harder to reverse unilaterally and carry stronger reputational consequences for non-compliance.

As Chater and Loewenstein suggest, the most plausible way forward is a hybrid system combining elements of both frames. In LEO, for example, soft caps on aggregate use of collisions risk would require systemic, s-frame mechanisms with robust monitoring and burden-sharing. At the same time, quality-based standards – such as the LTS Guidelines, ISO norms, IADC Guidelines – can be advanced through i-frame techniques embedded in domestic regulation. A hybrid model would thus combine global ceilings to respect the physical limits of the commons with more flexible, local standards to secure compliance in practice, balancing systemic coordination with operational adaptability.

3. Systems thinking

Behavioural economics highlights systematic deviation from rationality – biases, heuristics, and framing effects – that shape how actors actually respond to legal rules.⁸⁰⁹ However, these biases do not occur in isolation; they interact with broader institutional and environmental dynamics. Accordingly, regulation must take into account not only biased individual decision-making (as behavioural economics shows), but also how these biases interact with systemic feedback dynamics over time. Hence, integrating systems thinking with behavioural law and economics helps move beyond static, incentive-based analysis. It supports the design of adaptive legal frameworks that anticipate bounded rationality, delayed feedback, and tipping points – features that are especially salient in managing global commons.

⁸⁰⁹ *Heuristics* are mental shortcuts or rules of thumb people use to make decisions under uncertainty. They are useful because they reduce cognitive effort, but they can systemically mislead. *Biases* are predictable deviations from rational judgement that stem from these heuristics or from cognitive or emotional tendencies. *Framing effects* describe how people's choices depend on how information is presented, even if the underlying facts are the same. Together, these concepts explain why legal and regulatory systems cannot rely on the assumption of perfectly rational actors. Instead, Law and Economics must incorporate the reality of bounded rationality and design governance mechanisms that anticipate systematic errors in judgement. See for example: Daniel Kahneman, *Judgment under Uncertainty: Heuristics and Biases* (Cambridge University Press, 1998); and Amos Tversky and Daniel Kahneman, 'The Framing of Decision and the Psychology of Choice' (1981) *Science* 211(4481) 453, 453-458.

Classical thermodynamics and astrophysical literature classify the Solar System as an open system due to its ongoing energy and limited matter exchange with the broader cosmos.⁸¹⁰ However, from a governance perspective – within the limits of current human technological capabilities and foreseeable resource access – it can be regarded as functionally closed.⁸¹¹ On human timescales, material inflows and outflows in the Solar System are negligible, making the accessible stock of matter effectively finite and any depletion or degradation a lasting loss.⁸¹² It has been widely calculated for example that in case the global space economy continues to exponentially grow at 3.5% per year,⁸¹³ then in 400 years the ratio of asteroid metal reserves to annual extraction would be the same as the current ratio between terrestrial iron reserves and annual iron production.⁸¹⁴ In other words, asteroid metal reserves would be

⁸¹⁰ “For the purposes of thermodynamics, the universe is divided into two parts, the system and its surroundings. The system is the part of the world in which we have a special interest. It may be a reaction vessel, an engine, an electrochemical cell, a biological cell, and so on. The surroundings comprise the region outside the system and are where we make our measurements. The type of system depends on the characteristics of the boundary that divides it from the surroundings. If matter can be transferred through the boundary between the system and its surroundings the system is classified as open. If matter cannot pass through the boundary the system is classified as closed. Both open and closed systems can exchange energy with their surroundings. For example, (...) a closed system may (...) transfer energy to the surroundings if they are at a lower temperature. An isolated system is a closed system that has neither mechanical nor thermal contact with its surroundings.” See: Peter Atkins and Julio de Paula, *Physical Chemistry, Thermodynamics, Structure, and Change* (10th edition, W H Freeman and Company 2014) 64. From a scientific standpoint, the Solar System is generally classified as an open system: it continuously exchanges energy – most notably through incoming solar radiation and outgoing thermal emissions – and, although to a much lesser extent, it also exchanges matter, such as solar wind, cosmic rays, interstellar dust, and meteoroids. See on the matter of interstellar objects for example: Karen Meech, Robert Weryk, Marco Micheli, et al., ‘A brief visit from a red and extremely elongated interstellar asteroid’ (2017) 552(7685) *Nature* 378, 378-381.

⁸¹¹ A governance perspective shifts the focus from the physical properties of the orbital environment to the institutional and legal frameworks that determine how it is used.

⁸¹² Humanity does not have the means, yet, to exploit resources outside the Solar system, nor to offload waste (e.g., space debris or pollutants) beyond it. See for example: Martin Elvis, and Tony Milligan, ‘How much of the Solar System should we leave as wilderness?’ 162 (2019) *Acta Astronautica* 574, 575.

⁸¹³ Global GDP has been growing at an exponential rate of 2-3 % per year, effectively doubling the size of the economy approximately every twenty-three to thirty-five years. Comparably, the space economy growth rate lies between about 4% (long-term forecast) and 7.8% (annual growth in 2024), driven primarily by commercial expansion and evolving market dynamics. Thus the 3.5 % growth rate may in fact be a conservative figure compared to more recent estimates. See for example: GlobalData, ‘Space Economy: Strategic Intelligence’ (May 2025) <<https://www.globaldata.com/media/thematic-research/global-space-economy-market-surpass-511-billion-2029-forecasts-globaldata/>> accessed 20 October 2025; and Space Foundation, ‘The Space Report 2025 Q2 Highlights Record \$613 Billion Global Space Economy for 2024, Driven by Strong Commercial Sector Growth’ (July 2025) <<https://www.spacefoundation.org/2025/07/22/the-space-report-2025-q2/>> accessed 20 October 2025

⁸¹⁴ Martin Elvis, and Tony Milligan, ‘How much of the Solar System should we leave as wilderness?’ 162 (2019) *Acta Astronautica* 574, 579.

as close to running out as Earth's iron reserves are today.⁸¹⁵ At that point, according to the estimate, only about 60 years would remain before the accessible asteroid metals were exhausted.⁸¹⁶ From a systems thinking perspective, this highlights the danger of treating orbital space resources as if they were infinite or self-renewing.

Systems thinking enables us to re-engage our intuitive understanding of whole systems, to analyse their constituent parts, to identify and interpret interconnection, to explore “what-if” scenarios regarding potential future behaviours, and to approach system redesign with both creativity and courage.⁸¹⁷ Many environmental scientists have adopted a systems approach to address environmental protection and climate change, aiming to understand the root causes of emerging problems, and viewing Earth (here considered without reference to its orbital environment) as a closed system whose full complexity remains far from completely understood.⁸¹⁸ As systems thinking involves examining similarities across domains by identifying shared concepts, principles, and patterns. Consequently, this section attempts to examine the problem of over-exploitation of the orbital space environment from the systems thinking perspective, and to compare it with well-studied Earth systems – particularly the climate as a limited natural resource and closed subsystem.

In the context of systems theory, *systems* can be understood as a set of things interconnected in such a way that they produce their own pattern of behaviour over time.⁸¹⁹ A

⁸¹⁵ This tendency reflects the so-called *dynamics of depletion*, which hold that larger initial resource endowments do not guarantee long-term stability. On the contrary, abundance often fosters overconfidence and over-expansion, accelerating depletion and leading to a more abrupt and earlier collapse. See: Donella H. Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 66.

⁸¹⁶ This stage of “super-exploitation” would be even more serious, according to the researcher, than exhausting Earth's remaining iron, because there would be no larger supply of accessible metals to turn to without going beyond the Solar System. See: Martin Elvis, and Tony Milligan, ‘How much of the Solar System should we leave as wilderness?’ 162 (2019) *Acta Astronautica* 574, 580.

⁸¹⁷ Donella H Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 6-7.

⁸¹⁸ Earth can be considered a closed system in relation to the flow of matter. While meteors, comets and planetary debris occasionally enter the atmosphere, and hydrogen and helium gradually escape from the upper layers, these exchanges are negligible in scale. From the standpoint of human timescales and ecological concerns, such material fluxes are minimal, supporting the classification of Earth as a materially closed system. See: Harold Morowitz, John P Allen, Mark Nelson and Abigail Alling, ‘Closure as a scientific concept and its application to ecosystem ecology and the science of the biosphere’ (2005) 36(7) *Advances in Space Research* 1305, 1307.

⁸¹⁹ Donella H Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 2.

system consists of three kind of things: *elements*,⁸²⁰ *interconnections*,⁸²¹ and a *function* (or purpose).⁸²² Furthermore, in systems theory, two crucial concepts for understanding and analysing natural resources are stocks and flows. *Stocks* represent the observable and measurable quantities within a system – such as the amount of oil reserves, the number of operational satellites or the volume of accumulated space debris. These stocks change over time as a result of *flows*, which may increase through *reinforcing loops* or decrease through *balancing loops*, driven by processes, such as accumulation, use, or disposal.⁸²³ While both elements are essential for understanding system dynamics, psychological research has shown that the human mind and decision-makers tend to focus more readily on stocks because they are tangible and measurable at any given time.⁸²⁴ Conversely, flows – particularly outflows – are less intuitive and therefore often overlooked in decision-making. This *cognitive bias* often results in a focus on increasing inflows rather than on reducing outflows when a goal is to stabilise a stock. For example, prolonging the availability of a finite resource such as oil can be achieved not only by identifying new sources through introducing reinforcing feedback loops (e.g., discovering new oil reserves), but also by reducing consumption through the application of balancing feedback loops (e.g., burning less oil).⁸²⁵ Both approaches have an equivalent effect on the stock of available oil, yet they benefit different actors – those who extract versus those who conserve.⁸²⁶ This illustrates the importance of incorporating both inflow and outflow dynamics into regulatory and policy frameworks, particularly in fields like environmental protection and climate change mitigation.

⁸²⁰ The *elements* of a system are often the easiest parts to notice, because many of them are visible, tangible things. The elements that make up a tree are roots, trunk, branches, and leaves for example. But not all elements must be visible. Ibid., 11-12.

⁸²¹ *Interconnections* are the relationship, (many times through the flow of information) that hold the elements together. For instance, the water flow in the tree's trunk or other chemical reactions that allow one part to respond to what is happening in another part of the tree. Ibid., 13.

⁸²² *Purposes* (related to human elements) and *function* (for nonhuman elements), which are inferred from actual behaviour rather than rhetoric or stated goals. For example, the function of a plant is to bear seeds and produce more plants; the purpose of a national economy, judging by its behaviour, is to keep growing. In fact, an important function of almost every system is to ensure its own perpetuation. See: Ibid., 14-15.

⁸²³ *Reinforcing feedback loops* amplify the direction of change within a system and occur whenever an element can reproduce or grow in proportion to its current size – as in populations, economies, bank deposits earning interest, and other self-perpetuating processes. By contrast, a *balancing loop* or *self-correcting loop* resists direction of change imposed on a system, acting as a source of stability. A simple example is body temperature regulation: when the body overheats, it sweats to cool down; when it gets too cold, it shivers to generate heat.

⁸²⁴ Donella H. Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 22.

⁸²⁵ Ibid. 22-34.

⁸²⁶ Ibid. 22-34.

Physically, orbital space is considered an open subsystem, linked to both terrestrial activities and deep space (i.e., regions beyond Earth's orbital environment), as it is subject to constant energy exchange and minor matter exchange – including micrometeoroid flux, or atmospheric drag. Yet, from a resource governance standpoint, it can be regarded as a functionally closed system – characterised by finite capacity, in which natural balancing mechanisms and delays cannot keep pace with accelerating pressure of overexploitation and debris growth. Viewing orbital space as a closed system enables the application of systems thinking, as it frames the environment as a finite, bounded resource where feedback loops, accumulation, and delayed effects can be systematically analysed to guide sustainable governance. Applying systems thinking to the orbital space environment and space sustainability has so far been addressed in only a few published articles.

In their 2023 study on the space debris problem through a systems thinking lens, Verma et al. adopt a more closed framing, analysing orbital debris dynamics in terms of feedback loops: satellite launches and debris-generating collisions act as reinforcing loops that intensify congestion, while prospective measures such as space traffic management, reusability, active debris removal, and dedicated debris policies – still largely undeveloped – are envisioned as balancing loops to stabilise the system.⁸²⁷ Although, Verma et al. highlight important correlations concerning the over-exploitation of orbital space – which will be elaborated further in this chapter – their framing overlooks certain feedback effects. For example, the scholars in the article disregard controlled deorbiting, as well as natural processes of orbital decay in LEO.⁸²⁸ As a result, the article advances the questionable conclusion that “because there is no system in place to remove space junk, all satellites launched to date will become junk in the coming years”,⁸²⁹ a claim that does not fully reflect current technical and operational realities.

Responding to the earlier piece, Perks et al. in 2024 examined the orbital space dynamics from a broader perspective under the framework of a “holistically sustainable space

⁸²⁷ Virendra Verma, Rajan Gangadhari and Pramod Pandey, ‘A re-examination of the space debris problem using systems thinking’ (2023) 2 *Space Mission Planning and Operations* 28, 35-39.

⁸²⁸ These mechanisms do exist, but as noted earlier, they are far too limited to counterbalance the pressures of orbital overuse.

⁸²⁹ Virendra Verma, Rajan Gangadhari and Pramod Pandey, ‘A re-examination of the space debris problem using systems thinking’ (2023) 2 *Space Mission Planning and Operations* 28, 38.

system”.⁸³⁰ The researchers argue that a *space sustainability approach* should be framed in connection with Earth systems – particularly the atmosphere – and should also encompass “sensor systems”, including concerns such as dark and quiet skies, as well as broader policy and economic dimensions, while – understandably – excluding security-related matters such as anti-satellite tests.⁸³¹ These factors create feedback loops that,⁸³² they contend, need to be integrated into orbital space models.⁸³³

Moreover, a key contribution of the approach of Perks et al. is the emphasis on *delays*, which in systems thinking can be decisive – delays in balancing feedback loops strongly shape system behaviour and even generate oscillation.⁸³⁴ The scientists point out that time lags between the occurrence in the change of a leading variable (such as the use of orbital positions) and the impact on subsequent variables (including collision risk, debris density, or even long-term economic viability of satellite operations) can produce complex, non-linear dynamics that require numerical modelling to understand and anticipate long-term impacts.⁸³⁵ Altogether, the holistic sustainability approach enables the incorporation of additional feedback loops and the recognition of delays, producing more accurate and comprehensive assessments and measurements. It also creates, according to the scientists, opportunities to connect orbital governance with broader global efforts to “tackle emissions, to reach net zero [targets], and work towards developing a circular economy”.⁸³⁶

⁸³⁰ Megan Perks, Hugh Lewis and Nina Vaidya, ‘A holistic systems thinking approach to space sustainability via space debris management’ (2024) 11(3) *Journal of Space Safety Engineering* 532, 533. An important side-note – contradicting the assumptions of Perks et al. – comes from a recent 2025 MIT study, which projects that climate change-induced contraction of the upper atmosphere will significantly reduce natural orbital drag, thereby lowering the carrying capacity of the most heavily used regions of LEO by an estimated 50-66 percent by 2100. See: Jennifer Chu, ‘Study: Climate change will reduce the number of satellites that can safely orbit in space’ (*MIT News*, March 2025) (https://news.mit.edu/2025/study-climate-change-will-reduce-number-satellites-safely-orbit-space-0310?utm_source=chatgpt.com) accessed 20 October 2025.

⁸³¹ It may be worth comparing the two causal loop diagrams: Virendra Verma, Rajan Gangadhari and Pramod Pandey, ‘A re-examination of the space debris problem using systems thinking’ (2023) 2 *Space Mission Planning and Operations* 28, 36; and Megan Perks, Hugh Lewis and Nina Vaidya, ‘A holistic systems thinking approach to space sustainability via space debris management’ (2024) 11(3) *Journal of Space Safety Engineering* 532, 533.

⁸³² A feedback loop is a repeating pattern in a closed system, where a stock influences actions or rules, which in turn change the flows that increase or decrease that stock. See: Donella H Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 25-27.

⁸³³ Megan Perks, Hugh Lewis and Nina Vaidya, ‘A holistic systems thinking approach to space sustainability via space debris management’ (2024) 11(3) *Journal of Space Safety Engineering* 532, 532.

⁸³⁴ Donella H Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 54-58.

⁸³⁵ Megan Perks, Hugh Lewis and Nina Vaidya, ‘A holistic systems thinking approach to space sustainability via space debris management’ (2024) 11(3) *Journal of Space Safety Engineering* 532, 534.

⁸³⁶ *Ibid.*, 537.

From a systems thinking perception, this dissertation adopts the more holistic sustainability approach to orbital space, in line with the perspective advanced by Perks et al. Consequently, when addressing the problem of orbital overexploitation, it is essential for broader understanding to situate the issue within the larger framework of space sustainability and its underlying tendencies, as outlined in the first chapter of this thesis. Furthermore, at the technical level, Earth-orbit processes such as atmospheric drag shall be incorporated into orbital debris models, since they determine the lifetime and collision risk of objects in low Earth orbit especially below the altitude of 600 km in human timescale.⁸³⁷ Accurate measurements of deorbiting would be impossible without such factors. In addition, effective governance requires attention to qualitative mitigation strategies or policies functioning as balancing loops – such as regulation, the safety of space operations, public awareness, capacity-building, and research and development – as set out in the 21 Guidelines for the Long-term Sustainability of Outer Space Activities. Yet, from a functionalist perspective, this dissertation also emphasises that the corrective effect of balancing loops is far too weak and slow to counteract the dominant reinforcing loops driven by human activity – particularly the continual replacement and expansion of constellation networks and their indirect consequences, such as collisions and fragmentation that generate further debris in LEO. Paradoxically, these limited balancing loops, operating as delays, can foster a false sense of resilience. By buying time in the short term, they reduce incentive to invest in pre-emptive limits, while in reality allowing the reinforcing loops of congestion and debris-growth to intensify. Thus, while this analysis begins from a broader sustainability perspective, it ultimately draws a limit to the border of its analysis, to treat orbital capacity as a finite, *nested subsystem*. This narrowing is necessary because without prioritizing the immediate constraints of satellite proliferation and debris growth, governance efforts risk being diluted by broader but less urgent dimensions of space sustainability. At the same time, this functional boundary is not fixed; it can be expanded

⁸³⁷ See for example: Viasat, ‘White Paper – Self-cleaning Orbit Myth’ (December 2021) 2 <<https://www.viasat.com/content/dam/us-site/corporate/documents/Viasat-White-Paper-Self-Cleaning-Orbit-Myth-20211220.pdf>> accessed 20 October 2025; Aaron C. Boley and Michael Byers, ‘Satellite mega-constellations create risks in Low Earth Orbit, the atmosphere and on Earth’ (2021) 11(1) *Science Reports* 1, 3; OECD, ‘Earth’s Orbits at Risk, The Economics of Space Sustainability’ (OECD Publishing, 2022) 29 <https://www.oecd.org/content/dam/oecd/en/publications/reports/2022/09/earth-s-orbits-at-risk_d8902e97/16543990-en.pdf> accessed 20 October 2025.

whenever the focus shifts to the wider framework of space sustainability, or to parallel fields relevant to orbital space activities, such as terrestrial climate mitigation.

Furthermore, a pivotal concept in system thinking is the use of *archetypes*. Archetypes are recurring, recognisable pattern of behaviour that occur across systems and reveal the underlying structures that drive them.⁸³⁸ Systems thinkers use archetypes to explain and anticipate characteristic system behaviour, making them powerful tools for analysing complex dynamics such as orbital overexploitation. Additionally, Meadows describe “perverse” archetypes, – systems structured to produce deeply problematic behaviour – as *system traps*, and argues that merely understanding these problem-generating structures is insufficient; tolerating them is impossible, hence they must be changed.⁸³⁹ System traps, however, are not only obstacles, but also opportunities for change; system traps may be escaped in various ways, such as by reformulating goals, modifying (including strengthening or weakening) feedback loops, or introducing new ones.⁸⁴⁰

In their analysis of space debris, Verma et al. identify two key system traps: the limits-to-growth archetype and the tragedy-of-the-commons archetype.⁸⁴¹ Examining these traps is important for our understanding, since they offer a structured framework of the systemic dynamics of orbital overexploitation. Moreover, both archetypes are well-established in terrestrial environmental governance, underscoring that the challenges in orbit follow patterns already observed on Earth.

3.a The limits-to-growth archetype

A central principle of systems thinking is the limits to grow archetype.⁸⁴² In a closed, or otherwise constrained environment, no physical system can expand indefinitely. Growth persists only until it encounters inherent limits, at which point it must inevitably slow, stabilize,

⁸³⁸ Virendra Verma, Rajan Gangadhari and Pramod Pandey, ‘A re-examination of the space debris problem using systems thinking’ (2023) 2 *Space Mission Planning and Operations* 28, 35.

⁸³⁹ Donella H Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 111-112.

⁸⁴⁰ *Ibid.*, 111-112.

⁸⁴¹ Virendra Verma, Rajan Gangadhari and Pramod Pandey, ‘A re-examination of the space debris problem using systems thinking’ (2023) 2 *Space Mission Planning and Operations* 28, 35.

⁸⁴² In systems thinking literature, this archetype is also described as „Limits to Success”, underscoring how initial progress eventually generates the constraints that restrain it. See: Daniel Kim and Virginia Anderson, *Systems archetype basics: from story to structure* (Pegasus Communications 2007) 43-61.

or collapse.⁸⁴³ According to this archetype, in systems theory, the dynamics of both resource – and pollution-constrained systems follow similar patterns. A resource stock is finite and becomes depleted as inflows are consumed, eventually reaching a point where growth can no longer be sustained. Pollution operates in the opposite direction: it accumulates as an outflow, with the environment serving as a sink. Where the environment has some capacity to absorb or neutralize the pollutant, the system functions as a renewable sink – though only up to a threshold. If the capacity is absent or exceeded, pollution becomes effectively non-renewable, persisting indefinitely and undermining the system’s stability. On both cases, the system encounters limits to growth, whether through exhaustion of resources or through accumulation of wastes that cannot be removed. The same dynamics apply to the orbital environment. Usable orbital slots can be seen as a finite resource stock, depleted as more satellites are launched and operated. At the same time, orbital debris functions as a form of pollution. This tendency is strongly supported by a scientific research from 2021 with estimates suggesting that between one-third and one-half of LEO’s long-term capacity to sustain space activities has been already saturated.⁸⁴⁴ In fact, the so-called “critical density” – the tipping point of space debris, a concept first introduced by Donald Kessler – has already been exceeded in LEO at altitudes above 700 km.⁸⁴⁵ This means that even if all new launches into these higher LEO altitudes were suspended, the debris population would still continue to grow, due to the self-sustaining debris growth, a condition known as Kessler syndrome.⁸⁴⁶

After Verma et al., the limits-to-growth archetype exemplifies, how satellite constellations are expanding rapidly, driven by falling launch costs, mass-production of

⁸⁴³ The resulting behaviour depends on the character of the limit and the delays in feedback: the system may level off smoothly, oscillate, or overshoot and collapse. See: David Collste, et al., ‘Polycrisis patterns: applying system archetypes to crisis interactions’ (2025) 8(17) *Global Sustainability* 1, 3 <https://doi.org/10.1017/sus.2025.21>, accessed 20 October 2025.

⁸⁴⁴ Carmen Pardini and Luciano Anselmo, ‘Evaluating the impact of space activities in low earth orbit’ (2021)184 *Acta Astronautica* 11, 11.

⁸⁴⁵ Donald J Kessler, ‘Collisional cascading: limits of population growth in low Earth orbit’ (1991) 11(12) *Advances in Space Research* 63, 63–66. Since this critical density has already been exceeded, it has been argued that it can no longer serve as a meaningful limiting threshold, instead density values tied to specific short-term environmental consequences may provide more practical reference points. See: Carmen Pardini and Luciano Anselmo, ‘Evaluating the impact of space activities in low earth orbit’ (2021)184 *Acta Astronautica* 11, 20.

⁸⁴⁶ J.-C. Liou, ‘An Active Debris Removal Parametric Study for LEO Environment Remediation’ (2011) 47(11) *Advances in Space Research* 1865, 1865.

satellites, and efficiency gains in deployment.⁸⁴⁷ The reinforcing loop growth is clear: more satellites create more connectivity and dependence, which stimulates further demand for satellites. Satellites launches are currently increasing at an exponential rate. While exponential growth initially appears sustainable, any system subject to physical constraints reaches its limits surprisingly quickly. In the orbital environment, this growth ultimately activates balancing feedback loops driven by finite orbital capacity, rising interference risks, and increasing collision probabilities. However, these natural constraints are increasingly counteracted by technological efficiency gains that allow operators to continue expanding deployment despite escalating systemic risks.

Importantly, advances in satellite design, launch technology, and novel operational methods do not necessarily resolve the above constraints. On the contrary, while such innovations increase efficiency, they may accelerate resource depletion by undermining the natural corrective mechanisms that would otherwise limit orbital use, thereby pushing orbital resource stocks toward systemic collapse or even extinction. In systems terms, orbital capacity then becomes increasingly sensitive to disruption: each new launch not only occupies finite usable slots but also heightens the chance of collisions functional exhaustion, which further reduces capacity.⁸⁴⁸ Accordingly, advances in technology and harvesting efficiency can accelerate depletion, pushing resource stocks toward collapse or even extinction. This dynamic is closely tied to the *rebound effect*, often redescribed as *Jevons Paradox*, and in modern economics, the *Khazoom-Brookes Postulate*.⁸⁴⁹ These insights, now well established in both economics and behavioural research, show that efficiency improvements often reduce the cost of using a resource, which paradoxically stimulate greater overall consumption rather than conserving it. The historical record strongly challenges the widespread belief that access to

⁸⁴⁷ Virendra Verma, Rajan Gangadhari and Pramod Pandey, 'A re-examination of the space debris problem using systems thinking' (2023) 2 *Space Mission Planning and Operations* 28, 35-36.

⁸⁴⁸ A comparable dynamic is observable in fisheries, where advances in harvesting technology allow fleets to remain economically viable even at critically reduced stock densities. Rather than facilitating sustainability, this dynamic drives overshoot beyond ecological limits, culminating in the collapse of both the fish population and the dependent industry. In such circumstances, a renewable resource is effectively rendered non-renewable. See: Donella H Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 71.

⁸⁴⁹ The *Jevons paradox* illustrates how human responses to efficiency gains can paradoxically increase total resource use. See for example: Mona Mashhadi Rajabi, 'Dilemmas of energy efficiency: A systematic review of the rebound effect and attempts to curb energy consumption' (2022) 89(6-7) *Energy Research & Social Science* (2022) 1, 2.

new resources – whether terrestrial or extraterrestrial – will secure a sustainable high-technology civilization.⁸⁵⁰

Eventually, the limits-to-growth constrains slow or even reverse expansion. This demonstrates that, in the absence of deliberate governance intervention, the system is unlikely to stabilize at a sustainable equilibrium and instead faces the risk of collapse. In other words, unchecked expansion inevitably pushes the system against its limits,⁸⁵¹ and if the limits are not self-imposed, they will be *system-imposed*.⁸⁵² As a proposed response to the limits-to-growth trap, Verner et al. advocate the use of mitigation measures – such as satellite return mechanisms, mandatory deorbiting requirements, or active debris removal – that function as balancing loops, designed to slow, counteract, or even reverse the unchecked growth of orbital debris.

3.b The tragedy-of the commons archetype

The tragedy of the commons, as explained earlier, arises when individuals overuse a shared resource while disregarding the environmental harm that their actions generate. This harm constitutes a negative externality, since the associated costs are displaced onto others – present and future users – rather than being internalized by those directly responsible. For a systems perspective, the tragedy of the commons is considered a system trap, and comes about when there is escalation, or just simple growth, in a commonly shared, erodible environment. A clear illustration to this system trap is climate change: while it is in every actor's short-term interest to continue relying on fossil fuels, the CO₂ released at every stage of the fossil fuel

⁸⁵⁰ This line of reasoning exemplifies a recurrent strand of technological optimism. See for instance: Saara Reiman, 'Is space an environment?' (2009) 25:2 *Space Policy* 81, 83, where the author states that "It is probable that the path to a sustainable high technology civilization would be far less rocky if we had access to the resources of near space". Such claims implicitly assume that access to additional resources alleviates scarcity and sustainability pressures, while overlooking rebound effects, intensified exploitation, and the absence of effective governance mechanisms that would prevent new resources from reproducing existing patterns of overuse.

⁸⁵¹ A real challenge in managing a non-renewable (or quasi-non-renewable) resource, such as usable orbital positions, lies in deciding whether to maximise short-term gains at the cost of rapid depletion, or to accept more moderate benefits in exchange for long-term sustainability. See: Virendra Verma, Rajan Gangadhari and Pramod Pandey, 'A re-examination of the space debris problem using systems thinking' (2023) 2 *Space Mission Planning and Operations* 28, 35.

⁸⁵² Donella H Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 103.

cycle contributes to the accumulation of greenhouse gases that drive global warming and generate harmful pollutants, producing widespread and long-lasting environmental damage.⁸⁵³

As a response to this systemic trap, behavioural economics and system thinking provide complementary perspectives on governance, deepening and extending the classic pathways identified in law and economics for addressing the tragedy of the commons. While Hardin highlighted regulation and privatization as primary solutions, Meadows added another dimension: the role of education and moral exhortation. From a systems-thinking perspective, these latter, soft interventions are not merely ancillary but can alter feedback loops by shaping actors' perceptions, norms, and adaptive capacities, thereby influencing behaviour in ways that neither market mechanisms nor top-down regulation alone can achieve. Furthermore, while privatization is unlikely to be applied in global commons, regulation or *mutual coercion*, *mutual agreed upon* arrangements limit the freedom to abuse a commons, through different forms, while preserving the freedom to use it.⁸⁵⁴ For such instruments to be effective, however, they must be accompanied by credible enforcement through monitoring and sanctions. In systemic terms, regulation operates as an indirect feedback loop: information about the state of the resource is collected by regulators, interpreted, and then translated into rules that shape user behaviour. For this feedback mechanism to function properly, regulators require both the technical capacity to monitor and assess the condition of the commons and the institutional authority to deter violations. Crucially, they must also be able to act in the collective interest; if regulators are weak, uninformed, or vulnerable to capture and corruption, the regulatory feedback loop breaks down, undermining the effectiveness of governance.

Recognising these systemic archetypes underscores why governance responses must extend beyond technical “fixes” to address the deeper behavioural and structural dynamics that drive overuse of global commons such as orbital space. Some behavioural patterns persist over long periods of time despite repeated technological or policy interventions, leaving the system

⁸⁵³ Shaye Wolf, Robert Bullard, Jonathan J Buonocore, Nathan Donley, Trisia Farrelly, John Fleming, David J X González, Naomi Oreskes, William Ripple, Robin Saha, Mary D Willis, ‘Scientists’ warning on fossil fuels’ (2025) 5(1) *Oxford Open Climate Change* 1, 1 <<https://doi.org/10.1093/oxfclm/kgaf011>> accessed 20 October 2025.

⁸⁵⁴ Everyday life is full of “mutual coercion” arrangement. A familiar example is the traffic light at a busy intersection: drivers are not free to cross whenever they wish, but when it is their turn, they can proceed more safely and efficiently than would be possible in an unregulated free-for-all. In this sense, regulation does not eliminate freedom of use but conditions it in ways that make the common space functional and sustainable. This analogy may be particularly relevant to current initiatives on space traffic management.

locked in cycles of degradations – a phenomenon known as *policy resistance*. From a behavioural economics perspective, this arises because actors, whether individuals or states, operate with bounded rationality: they pursue their own goals within narrow information horizons, often ignoring long-term externalities or the interests of others. Systems thinking makes this dynamic visible, showing how what appears “rational” at the level of a single actor or subsystem can create unintended, even harmful, outcomes for the system as a whole. Overcoming such traps requires moving beyond local or short-term perspectives and adopting a system-wide view that integrates interdependence, feedback loops, and long-term sustainability into governance design.⁸⁵⁵

Elinor Ostrom’s influential work on common pool resources provides one pathway out of such systemic traps. In order to avoid the tragedy of the commons, Elinor Ostrom – awarded the Nobel Prize in Economics in 2009 – demonstrated through extensive field research across diverse regions, that common pool resources can be sustainably managed when governance is organized around eight core design principles.⁸⁵⁶ Where these principles are respected, the economist argued, local communities are often able to prevent the tragedy of the commons through self-management, in other words without a centralized government or private property regime. In her work, Ostrom challenges the mid-20th century orthodoxy in economics and international relations that saw only two governance options for collective-action problems (in terms of common pool resources): markets: (for private goods) or centralized states (for public

⁸⁵⁵ Donella H Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 108.

⁸⁵⁶ The eight principles by Ostrom are: (1) Clearly defined boundaries: The boundaries regarding the use of shared resources (including what kind of individuals can use them) are clear; (2) Local conditions: The rules for permitting the use of shared resources and allocating resources are based on local conditions and provision rules; (3) Collective choice arrangements: most individuals affected by the operational rules should be able to participate in the making of the operational rule; (4) Monitoring: It is possible to monitor whether the users of the shared resource adhere to the operational rules of the self-government system; (5) Graduated sanctions: Sanctions for the users of the commons who violate the rules of self-government management must be gradually implemented, depending on the content; (6) Conflict resolution mechanism: If there is a conflict between the users, there should be a low-cost local forum where the members can resolve the conflict; (7) Minimal recognition of rights to organize: Permissions from an external government agency are not required to apply the rules of self-government; (8) Nested enterprises (for commons that are part of larger systems): Self-government is organized and managed in multiple layers of nested enterprises. See: Elinor Ostrom, *Governing the commons: The evolution of institutions for collective action* (Cambridge University Press 1990) 90.

goods).⁸⁵⁷ Ostrom argues that this dichotomy is both empirically inaccurate and normatively limiting. Through extensive empirical fieldwork on water management in California and irrigation systems in Nepal, as well as large-scale meta-analyses of case studies on forests, fisheries, and other common pool resources, she demonstrates that communities are capable of creating durable, self-organized systems without a Leviathan central coercion or full privatization. These systems often involve *polycentric governance* – that is, multiple, overlapping centres of authority (local, regional, national, international) that are formally autonomous but functionally interdependent. Contrary to the assumption that such multiplicity produces chaos, her research shows that overlapping jurisdictions can yield greater adaptability, efficiency, and resilience.⁸⁵⁸

Moreover, although traditional rational-choice games assume actors respond solely to costs and benefits, behavioural experiments show that people – and, by analogy, states – evaluate whether actions are perceived as cooperative or exploitative, fair or selfish, based on the motives they attribute to others.⁸⁵⁹ This is especially significant in relation to *sanctioning*. While rationalist models treat sanctions as mere “sticks” that alter payoffs, behavioural research demonstrates that their effectiveness depends on whether they are perceived as *fair*. Fair sanctions, such as those targeting clear cases of defection in public goods or common-pool-resource games, can sustain cooperation by reinforcing trust and reciprocity. By contrast, sanctions seen as arbitrary, excessive, or self-serving tend to backfire, undermining legitimacy and eroding collective action. This behaviour insight resonates with Ostrom’s design principles for successful common-pool resources governance. Ostrom emphasizes that sustainable “self-

⁸⁵⁷ Ostrom’s work was, in part, a direct critique of Hardin’s proposed solutions to the tragedy of the commons – mainly the privatization of the commons or the creation of a Leviathan-style central authority to impose and enforce rules. Ostrom challenges this logic, emphasizing that while such centralized governance might be possible within states, it is largely absent at the international level, where no overarching global government exist. Instead, she demonstrated that communities can and do develop self-governing institutions capable of sustainable managing shared resources without relying on either private property regimes or a hierarchical sovereign authority. Thus, according to Ostrom, the trap of the tragedy of the commons can be escaped. See: Elinor Ostrom, ‘Beyond Markets and States: Polycentric Governance of Complex Economic Systems’ (2010) 100(3) *American Economic Review* 641, 649.

⁸⁵⁸ *Ibid.*, 649-650.

⁸⁵⁹ Anne van Aaken, ‘Behavioral international law and economics’ (2014) 55(2) *Harvard International Law Journal* 421, 434-435. Ostrom’s research also showed that communications, trust, reputation, local monitoring, and graduated sanctions consistently increase cooperation in common-pool resources settings – findings that challenge the predictions of strict rational-choice models. See: Elinor Ostrom, ‘Beyond Markets and States: Polycentric Governance of Complex Economic Systems’ (2010) 100(3) *American Economic Review* 641, 643–653.

governance” depends not only on rules that limit access and use, but also on fair allocation of rights, graduated sanctions proportionate to violations, and accessible conflict-resolution mechanisms.⁸⁶⁰ In other words, both behavioural economics and Ostrom’s institutional analysis converge on the idea that legitimacy and fairness are indispensable for sustaining cooperation in the long run. Potentially applied to the orbital commons, the parallel is clear. Debris-mitigation measures or penalties for non-compliance will only foster durable cooperation if they are collectively perceived as legitimate and equitable. If technologically advanced states impose strict sanctions without addressing equity – for instance, by restricting access to LEO while continuing to benefit from their existing dominance – such measures risk being viewed as self-interested and illegitimate, leading to resistance and non-compliance. Conversely, enforcement mechanisms designed around fair allocation, graduated sanctions, and credible conflict-resolution forums – reflecting differences in capacity and responsibility – are more likely to align individual state incentives with the collective interest in sustainable orbital use.

A key limitation of Ostrom’s framework is that it was originally derived from a small-scale, local commons, raising doubts about whether her principles can be applied to global commons such as outer space.⁸⁶¹ However, subsequent work by Ostrom and others has shown that these principles are relevant even for large, complex commons, provided they evolve through what is termed, “*adaptive governance*”.⁸⁶² This concept emphasizes not static rules but flexible, evolving institutions that can preserve collective goods under conditions of uncertainty. According to Weeden and Chow, for example, adaptive governance is particularly relevant to orbital space, where satellite launches are multiplying, new actors are emerging,

⁸⁶⁰ See: Elinor Ostrom, ‘A Behavioral Approach to the Rational Choice Theory of Collective Action—Presidential Address of the American Political Science Association, 1997’ 92(1) *American Political Science Review* (1998) 1, 8 and 17.

⁸⁶¹ When scaling the cooperative solutions to larger, more heterogeneous groups, it remains a formidable challenge to apply a polycentric governance, as coordination costs rise and conflicts of interest intensify. See for example: Steven C Hackett, Edella Schlager and James Marvin Walker, ‘The role of communication in resolving commons dilemmas: experimental evidence with heterogeneous appropriators’ (1994) 27(2) *Journal of Environmental Economic Management* 99, 99–126; Hao Zhao and David Porter, ‘Vote and trade: An efficient mechanism for common-pool resource management with stock externalities’ (2025) 249 *Journal of Public Economics* 1, 1; and Charles F Mason and Owen R Phillips, ‘Mitigating the Tragedy of the Commons through Cooperation: An Experimental Evaluation’ (1997) 34(2) *Journal of Environmental Economics and Management* 148, 148–172.

⁸⁶² Thomas Dietz, Elinor Ostrom and Paul C Stern, ‘The struggle to govern the commons’ (2003) 302(12) *Science* 1907, 1908–1909.

and technologies rapidly evolve.⁸⁶³ Thus the sustainable management of orbital space requires institutions capable of continuous adaptation – balancing efficiency with political and practical feasibility while responding to emerging challenges. A valuable illustration of such adaptable governance is provided by the ITU’s binding, technical Radio Regulations, which are revised every three to four years at the World Radiocommunication Conferences. This periodic review process ensures that regulatory rules evolve in step with technological and systemic change, a feature that is particularly vital for the management of radio frequencies and geostationary orbital slots.

On the same note, governance theory highlights that policies are encouraged to build learning and adaptability into their design to escape uncertainty. This is particularly important where uncertainty and information asymmetries are severe, as in the case of orbital debris dynamics. Adaptive regulation, however, requires not only feedback loops (where rules respond to observed changes in the resource), but also meta-feedback loops that enable adjustment of the rules themselves as knowledge evolves.⁸⁶⁴ The Montreal Protocol offers a striking precedent: when adopted in 1987, scientific uncertainty about ozone depletion was still high. The treaty nonetheless set initial reduction targets, but crucially mandated periodic scientific review and reconvening of parties to adjust commitments. By 1990, when damage was revealed to be far worse than expected, states agreed to accelerate phase-outs and expand the list of banned substances.⁸⁶⁵ This capacity for continuous adjustment was central to its success – and offers a model for the governance of orbital space, where uncertainties about debris creation, collision risks, and technological solutions are profound, and where static rules are unlikely to remain adequate over time.

Elinor Ostrom’s conception of polycentric governance-systems offers a valuable lens for thinking about orbital space. From a narrow Law and Economics perspective, the central challenge of the orbital environment lies in the coexistence of multiple market failures: negative externalities, common-pool resource pressures, information asymmetries and

⁸⁶³ By applying Ostrom’s framework to outer space, Weeden and Chow demonstrate how each of Ostrom’s eight design principles for governing common-pool resources can be adapted to the orbital environment as a global commons. See: Brian Weeden and Tiffany Chow, ‘Taking a common-pool resources approach to space sustainability: A framework and potential policies’ (2012) 28(3) *Space Policy* 166, 166-172.

⁸⁶⁴ Thomas Dietz, Elinor Ostrom and Paul C Stern, ‘The struggle to govern the commons’ (2003) 302(12) *Science* 1907, 1908-1909.

⁸⁶⁵ Donella H Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing 2008) 177-178.

uncertainties, and risks of monopolization. Traditional regulatory strategies grounded in welfare economics – such as centralized caps or Pigouvian taxes – struggle in the international domain, where no supranational Leviathan exists to impose and enforce binding rules. Ostrom’s framework points to a different pathway: instead of a single hierarchical authority, governance of the orbital commons could be built on a nested, adaptive structure that combines multiple layers of decision-making. At the global level, COPUOS, the *corpus juris spatialis*, as well as the ITU regime provide mechanisms for coordination and norm-setting across states and their private operators. However, these regimes have also remained largely ambiguous and vague, offering little normative precision and enforceability to protect the LEO environment.

A central difficulty in governing LEO is that, despite growing scientific concern about congestion and debris, actors lack incentives to define or respect meaningful limits on use. Under the current first-come, first-served logic, technologically advanced states and their private operators benefit most by rapidly filing, launching, and occupying orbital shells, effectively engaging in strategic rent-seeking that secures long-term advantages while externalising costs onto others. In Ostrom’s terms, this dynamic illustrates a failure of the first design principle: the absence of clearly defined boundaries. Locals and global commons succeed when users recognise limits and craft rules to manage them; in LEO by contrast, actors avoid acknowledging such limits, due to physical constraints and because doing so would constrain profitable expansion.

In economic analysis and behavioural sciences, however, what matters is not the formal delimitation in international law, but the establishment of functional boundaries that define the resource’s sustainable use. Chow and Weeden, by reacting to the first principle of Ostrom, also argue following the functionalist perspective that for effective governance of the orbits, what matters is not a precise technical altitude marking where airspace ends and LEO begins.⁸⁶⁶ What is crucial is a shared regulatory and operational understanding among states about where one regime ceases to apply and another takes over. Climate governance, for example, may offer again a useful analogy: although the atmosphere has no legally fixed boundary, international cooperation – most prominently through the IPCC, the Kyoto Protocol, and the Paris Agreement – has nevertheless been organized around functional boundaries, such as carbon

⁸⁶⁶ Brian Weeden and Tiffany Chow, ‘Taking a common-pool resources approach to space sustainability: A framework and potential policies’ (2012) 28(3) *Space Policy* 166, 168.

budgets and temperature thresholds, which serve as proxies for the system's ecological limits.⁸⁶⁷ Similar logic can be applied the orbital commons. Even though outer space lacks a clear legal demarcation from national airspace, effective governance of LEO does not require resolving this longstanding legal boundary question. What is more urgent is agreement on functional measures of *carrying capacity* – such as maximum collision probabilities, density thresholds, or safe operational margins per orbital shell – that can serve as practical limits for sustainable use. From a Law and Economics perspective, such functional boundaries provide the necessary reference point for designing allocation and enforcement mechanisms, without demanding the creation of a centralized global authority or the resolution of politically intractable legal definitions. Yet, as experience from other global commons demonstrates, defining limits and allocation rules are not enough: monitoring and enforcement are indispensable. In the absence of central sovereign, this can only be achieved through adaptive, polycentric governance regimes that combine flexibility with credible oversight and sanctioning mechanisms.

In their 2019 article, Feichtner and Ranganathan suggested that the common-heritage of mankind (CHM) principle may provide a framework for integrating ecological sustainability with redistributive justice, offering a way to treat these objectives as complementary rather than mutually exclusive.⁸⁶⁸ In other words, managing global commons does not have to be a zero-sum struggle for national advantage; it could instead be reimagined as a cooperative, non-competitive regime, where states work collectively, guided by shared values of equity and stewardship. For international law, this means that the “paradoxical” nature of commons cannot be erased but can be managed more productively through frameworks that combine both ecological responsibility and fairness. However, as highlighted in the preceding Law and Economics analysis, realizing such regimes is not straightforward: market failures such as externalities, common pool resources, monopolization, and information asymmetries systematically distort incentives, while behavioural insights remind us that states, like

⁸⁶⁷ See: Valérie Masson-Delmotte, et al., ‘Global Warming of 1.5°C, IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty’ (Cambridge University Press 2019) 616.

⁸⁶⁸ Isabel Feichtner and Surabhi Ranganathan, ‘International Law and Economic Exploitation in the Global Commons: Introduction’ (2019) 30(2) *The European Journal of International Law* 541, 546.

individuals, often exhibit biases, short-termism, and fairness concerns that complicate collective action. Together, these perspectives underscore both the promise and the difficulty of operationalizing CHM-like governance in the orbital commons. However, achieving genuinely sustainable and equitable governance of the global commons demands nothing less than a fundamental paradigm shift. The following section therefore introduces five interdisciplinary approaches that push us to reconsider how we think about sustainability and equity in managing the orbital space environment, highlighting the need for a paradigm shift not only in the behaviour of decision-makers but also in the values and expectations of society as a whole.

D. Pathways to a paradigm shift: critical and interdisciplinary thoughts

*[The] “commons” become understood
in terms of an economy of interests
in which the rampant commercial exploitation of nature
is justified with the satisfaction of societal needs”.*⁸⁶⁹

1. Orbital space, an environment?

There is a growing recognition of orbital space as an environment, worthy of protection – a view increasingly advanced in academic literature and scholarly debate.⁸⁷⁰ While international law sources generally do not provide a single, universal definition of “environment”, following the various interpretation techniques established in Article 31 of the Vienna Convention on the Law of Treaties, the ordinary meaning the Oxford English

⁸⁶⁹ Isabel Feichtner and Surabhi Ranganathan, ‘International Law and Economic Exploitation in the Global Commons: Introduction’ (2019) 30(2) *The European Journal of International Law* 541, 543.

⁸⁷⁰ See for example: Claudia Cinelli, and Camilla Campodonico, ‘The duty of state to protect the orbital environment’ (2024) 11(2) *Journal of Space Safety Engineering* 318, 318-321; Andy Lawrence, Moriba Jah, et al., ‘The Case for Space Environmentalism’ (2022) 6 *Nature Astronomy* 428, 428-435; Alessandra Marino and Thomas Cheney, ‘Centring Environmentalism in Space Governance: Interrogating Dominance and Authority Through a Critical Legal Geography of Outer Space’ (2023) 63 *Space Policy* 1; Kaja Hopej and Katarzyna Malinowska, ‘Environmental law principles as guidelines for protecting the outer space’ 18(35) (2023) *Journal of Agricultural and Environmental Law* 18, 18-30; Benjamin J Richardson, ‘Space Matters: Environmental Law’s Spatial Character and Context’ (2022) 34(2) *Journal of Environmental Law* 379, 379-386.

Dictionary, the “environment” can be defined as “the natural world or physical surroundings in general, either as a whole or within a particular geographical area, especially as affected by human activity”.⁸⁷¹ A key question arises: can the term “environment” be meaningfully applied to orbital space itself, rather than limiting our perspective to outer space as a whole and framing it solely as a resource or a “domain” for human exploration – a view that has largely prevailed until recent years? After all, orbital space – part of outer space – contains no ecosystems, no biodiversity, and no natural processes of regeneration comparable to those found on Earth. Why, then, does it matter whether orbital space is classified as an environment?

Expanding humanity’s sphere of influence beyond Earth raises profound philosophical and ethical questions with far-reaching practical consequences. Acting responsibly in such novel domains requires determining how we conceptualize it – in this case, Earth’s orbital environment. Conceptualization is never neutral; it entails a commitment to certain values and to a particular lens through which we understand the world.⁸⁷² According to Reiman, “if we choose to understand space as an environment as opposed to a mere phenomenon for us to exploit, we lay the foundations for an ethics of space exploration that is very different from an ethics that treats space exclusively from the point of view of human interests”.⁸⁷³ Indeed, framing space as an environmental commons, shifts the discourse and focus toward long-term sustainability.

However, it is also important to recognize that the concept of environment has historically been framed in terrestrial and anthropocentric terms. Most of environmental law – particularly in its international dimension – has built on an anthropogenic foundation, treating the environment primarily as something to be protected because it underpins human survival, health, and economic prosperity, rather than as possessing value in its own right. This is very clear in international environmental law instruments, such as the Stockholm Declaration and the Rio Declaration, which frame environmental protection as essential for the “well-being of peoples” and “sustainable development”.⁸⁷⁴ Despite the gradual move away from a strictly

⁸⁷¹ ‘environment’ in Oxford English Dictionary

https://www.oed.com/dictionary/environment_n?tab=meaning_and_use#5307111, accessed 20 October 2025.

⁸⁷² Saara Reiman, ‘Is space an environment?’ (2009) 25:2 *Space Policy* 81, 81.

⁸⁷³ Ibid 81.

⁸⁷⁴ See for example Principle I of the Report of the United Nations Conference on the Human Environment, (1972), A/CONF.48/14/Rev.1 (Stockholm Declaration); and Principle 1, 4, 7, 8, 9, 12, 22, and 24 of the Report of the United Nations Conference on Environment and Development (1992) A/CONF.151/26 (Rio Declaration).

anthropocentric approach in terrestrial environmental law since the 1980s, no comparable shift has taken place in the governance of outer space.⁸⁷⁵ In the context of space,⁸⁷⁶ the LTS Guidelines – though a soft-law instrument – represent an important step by explicitly recognising Earth orbit as an environment in their preamble, to be preserved as a safe and stable domain for present and future space activities. This recognition is particularly in light of international law’s due diligence obligation, which extends state responsibility for preventing environmental harm even in areas beyond national jurisdiction,⁸⁷⁷ and thus provides a normative basis for attributing responsibility for space debris to states under OST.

Although Viikari’s 2008 observation on the legal protection of the space environment dates back almost two decades, it remains valid today. As she noted, “Needless to say, the prevention of a potentially harmful activity on purely ecological grounds, as well as compensation for such harm, is practically out of question on the context of the current international law of outer space”.⁸⁷⁸ In fact, Viikari continues, space law expressly permits states to “conduct a wide range of potentially environmentally detrimental activities on celestial bodies and in other areas of outer space, as long as they are peaceful and otherwise in accordance with international law”.⁸⁷⁹

It is crucial to highlight that the Moon Agreement (MA) presents an alternative trajectory that space law might have – or could – take(n), particularly in its framing of the principle of freedom of use and its emphasis on environmental protection. Notably, Article 7 (1) of the MA introduces a robust environmental safeguard, requiring states to avoid harmful impacts not only on the Earth’s environment but also on the lunar environment – including its orbital space.⁸⁸⁰ This is significant, as Cheney highlights, in that the MA acknowledges the

⁸⁷⁵ Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff, 2008) 14.

⁸⁷⁶ On emerging approaches that seek to reconceptualize the relationship between law and the environment beyond traditional frameworks, see, e.g.: Sarah Burch, et al, ‘New directions in Earth System Governance Research’ (2019) 1 *Earth System Governance* 1, 1-18; Louis Kotzé and Rakhyun Kim, ‘Earth system law: The juridical dimension of earth system governance’ (2019) 1 *Earth System Governance* 1, 1-12; Craig Kauffman and Pamela Martin, *The Politics of Rights of Nature – Strategies for Building a More Sustainable Future* (MIT Press 2021) 1-27.

⁸⁷⁷ ICJ, *Obligations of States in Respect of Climate Change*, Advisory Opinion of 23 July 2025 ICJ Reports 2025 para 134.

⁸⁷⁸ Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff, 2008) 112.

⁸⁷⁹ *Ibid.*, 112.

⁸⁸⁰ Pursuant to Article 1 (2) of the Moon Agreement, references to the Moon by the MA also includes its orbits and any other trajectories to or around it.

environment of the Moon and its surrounding orbital space, as worthy of protection in its own right, independent of its potential utility for human activity or scientific investigation.⁸⁸¹

Regardless of its prevailing anthropocentric orientation, an increasing number of scholars argue that environmental considerations remain significantly underexplored in contemporary debates on space activities. For the principles of the OST – particularly those concerning equitable use and the sharing of benefits – to be given real effect, environmental sustainability must be re-examined and integrated far more centrally into governance discourses. As Cheney observes, when concerns are raised about the environmental consequences of satellite megaconstellations – especially the risks of increased debris generation – they are often downplayed or overridden in light of prevailing geopolitical and commercial imperatives,⁸⁸² a dynamic that will be shortly examined below.

2. (Neo)extractivism and critical legal geography

Many of the territorial tendencies leading to environmental degradation and the climate crisis, are intertwined with or extensions of material use and extractivism.⁸⁸³ The term

⁸⁸¹ Thomas Cheney, 'Non-use of Space, Reconsidering Article I of the Outer Space Treaty and the Useability of Space Resources', in Solène Guggisberg and Catherine Blanchard (eds.) *Non-use Measures for Global Goods and Commons in International Law* (Brill 2025) 428, 438.

⁸⁸² Alessandra Marino and Thomas Cheney, 'Centring Environmentalism in Space Governance: Interrogating Dominance and Authority Through a Critical Legal Geography of Outer Space' (2023) 63 *Space Policy* 1, 2.

⁸⁸³ Between 2001 and 2020, the Amazon rainforest lost 42 million hectares of forest due to mining and agriculture expansion, primarily for soy and cattle farming. Indeed, the rate of deforestation is currently 45% higher than what is required to meet the 2030 forest goals of lasting deforestation and woodland region. Habitat destruction from deforestation also leads to species loss. The global extinction rate is estimated to be 1,000 times higher than the natural background rate, largely due to land-use changes. In 2023, global carbon emissions from fossil fuels reached a record high, with an increase of 0.8% compared to the previous year, adding approximately 330 million tons of CO₂ to the atmosphere. Fossil fuels accounted for 81.5% of the global energy mix in 2023, a slight decrease from 86% in 1995. As of 2023, humanity's demand for ecological resources exceeds Earth's ability to regenerate these resources by approximately 70%. This overconsumption leads to environmental degradation and resource depletion. Moreover, the ocean absorbs about 44% of human-caused CO₂ emissions annually, leading to increased acidification. This process alters marine ecosystems and affects biodiversity. The ocean's warming accounts for 40% of the increasing rapid rise in average sea levels, which have increased by around 9 centimetres over the past 30 years. Last but not least, monitored populations of wild animals had shrunk by 73% globally by 2020 compared with 1970 figures. For sources, see for instance: Forest Declaration Assessment, '2024 Forest Declaration Assessment: Forests under fire' (2024) <https://www.forestdeclaration.org/resources/forest->

extractivism defines a mode of appropriating nature, a pattern of colonial accumulation linked to the birth of modern capitalism.⁸⁸⁴ This concept can be traced back to the colonial era, when European powers exploited the natural wealth of colonies in Africa, Asia, and the Americas for the benefit of their imperial economies. It is based on a large-scale extraction of natural resources, for export and profit, often with minimal processing and little regard for ecological or social consequences.⁸⁸⁵ Today, traditional extractivism is often linked to neo-colonialism, where resource-rich countries, particularly in the Global South, continue to supply raw materials to industrialized nations, becoming heavily dependent on exporting raw materials, making them vulnerable to global market fluctuations and the “resource curse”, a phenomenon where resources wealth leads to economic instability, corruption, and conflict.⁸⁸⁶

Over time, extractivism has evolved through successive stages, with the latest trends marked by the intensive consumption of water, energy, and raw materials. *Contemporary neo-extractivism* is often described as a “development model based on the over-exploitation of increasingly scarce, largely non-renewable natural resources and on the extension of the limits of use to areas that were previously considered unproductive from a capitalist perspective”.⁸⁸⁷ By now, neo-extractivism is widely regarded as a major driver of climate change and

[declaration-assessment-2024](#) accessed 20 October 2025; Jake Spring, ‘Cop 16, From forests to oceans, nature in a dire state’ (*Reuters*, October 18, 2024) https://www.reuters.com/business/environment/cop16-forests-oceans-nature-dire-state-2024-10-18/?utm_source=chatgpt.com accessed 20 October 2025; Robert Harvey, ‘Fossil Fuel use, emissions hit records in 2023, report says’ (*Reuters*, June 20, 2024): https://www.reuters.com/business/environment/fossil-fuel-use-emissions-hit-records-2023-report-says-2024-06-19/?utm_source=chatgpt.com accessed 20 October 2025; Institute for Energy Research (IER), ‘2023 Set Records in Global Fossil Fuel Use and Carbon Dioxide Emissions’ (24 June 2024) https://www.instituteforenergyresearch.org/international-issues/2023-set-records-in-global-fossil-fuel-use-and-carbon-dioxide-emissions/?utm_source=chatgpt.com accessed 20 October 2025; NASA, ‘Emission from Fossil Fuels Continue to Rise’ (March 5, 2024) https://earthobservatory.nasa.gov/images/152519/emissions-from-fossil-fuels-continue-to-rise?utm_source=chatgpt.com accessed 20 October 2025; Martin Valo, ‘Ocean is warning at an “unprecedented rate” warns UNESCO’ (*Le Monde*, 5 June 2024) https://www.lemonde.fr/en/environment/article/2024/06/05/ocean-is-warming-at-an-unprecedented-rate-warns-unesco_6673831_114.html?utm_source=chatgpt.com# accessed 20 October 2025.

⁸⁸⁴ Maristella Svampa, *Die Grenzen der Rohstoffausbeutung: Umweltkonflikte und ökoterritoriale Wende in Lateinamerika* (Bielefeld University Press 2020) 19.

⁸⁸⁵ The term, extractivism was popularized by Latin American thinkers such as Eduardo Gudynas and Arturo Escobar, who criticized neoliberal economic policies and the reliance of Latin American countries on resource extraction, viewing as a continuation of colonial patterns of exploitation. See: Maristella Svampa, *Die Grenzen der Rohstoffausbeutung: Umweltkonflikte und ökoterritoriale Wende in Lateinamerika* (Bielefeld University Press 2020) 13.

⁸⁸⁶ Barbara Teixeira, ‘Underdevelopment, extractivism, and conflict in the Global South and the role of systemic alternatives’ 12(59) *Conjuntura Austral* (2021) 21, 22.

⁸⁸⁷ Maristella Svampa, *Die Grenzen der Rohstoffausbeutung: Umweltkonflikte und ökoterritoriale Wende in Lateinamerika* (Bielefeld University Press 2020) 19.

environmental degradation, imposing profound environmental and social costs. These include deforestation, pollution, biodiversity loss, community displacement, and labour exploitation, all of which highlight its fundamentally unsustainable nature. Neo-extractivism serves to sustain and accelerate capitalist growth by providing the raw materials needed for industrial production, infrastructure development, and global trade. Indeed, the rise in global GDP closely mirrors the increase in global resource use and extraction, reflecting a strong correlation between economic growth and resource material footprint.⁸⁸⁸

A more recent perspective, *critical legal geography* – applied to the space environment by scholars such as Cheney and Marino – emphasizes how legal regimes do more than regulate activities in space: they actively produce and shape the very spatial order of the orbital environment.⁸⁸⁹ This perspective resonates with debates on terrestrial (neo)extractivism, where law and governance frameworks present resource frontiers – whether forests, oceans, or mineral reserves – as “empty” or “open” for appropriation, while in practice facilitating large-scale extraction that disproportionately benefits powerful actors. Outer Space governance exhibits similar dynamics. The OST’s freedom principle and the ITU’s first-come, first-served allocation effectively function as legal devices that transform a formally non-appropriable commons into a system of de facto entitlements. By enabling prolonged and repeated satellite operations, this regime systematically reinforces early-mover advantages and privileges technologically advanced states. Critical legal geography helps explain this dynamic: law does not merely regulate space but actively produces its spatial order, shaping who can access, benefit from, or be excluded from the commons. The history of space law illustrates this point. While the OST proclaimed space the “province of all humankind, its ‘pro-use’ orientation and reliance on state self-implementation left environmental protection weak.⁸⁹⁰ This reveals how legal regimes can reproduce inequality and enable de facto appropriation, rather than ensuring sustainability. Just as terrestrial extractivist regimes have often justified resource exploitation

⁸⁸⁸ Jason Hickel, *Less Is More – How Degrowth Will Save the World* (William Heinemann 2020) 104.

⁸⁸⁹ Alessandra Marino and Thomas Cheney, ‘Centring Environmentalism in Space Governance: Interrogating Dominance and Authority Through a Critical Legal Geography of Outer Space’ (2023) 63 *Space Policy* 1, 1-10.

⁸⁹⁰ More ambitious proposals – such as Japan’s push for stronger environmental safeguards in Article IX OST or the redistributive vision of the 1979 Moon Agreement – were sidelined, largely because they threatened the interests of established powers. Alessandra Marino and Thomas Cheney, ‘Centring Environmentalism in Space Governance: Interrogating Dominance and Authority Through a Critical Legal Geography of Outer Space’ (2023) 63 *Space Policy* 1, 8.

under the banner of “development” while sidelining ecological limits and reproducing global inequalities, so too are environmental concerns in orbital space frequently dismissed in the face of geopolitical and commercial imperatives. From this perspective, as Cheney and Marino suggest, the orbital commons should be reimagined not only in terms of efficiency, but also through values of equity and ecological stewardship that sustainable governance of LEO requires deliberately designed institutions that can recognize environmental limits while ensuring fair distribution of opportunities and responsibilities. Seen through the lens of critical legal geography, orbital governance is not a neutral framework but a form of spatial ordering that risks reproducing neo-extractivist dynamics: treating orbital space primarily as a site of resource competition and commercial advantage.

3. Sustainable development between old Institutional economics and the limits to growth

*“The economy, in its physical dimensions, is a subsystem of the earth’s ecosystem”.*⁸⁹¹

Alongside the rise of neoclassical economics, a partial rejection of its abstract, formal assumptions emerged in the form of the *old Institutional economics*,⁸⁹² which replaced universalising market models with historically grounded empirically informed analyses of how law, institutions, culture, technological change and power shape economic behaviour over time.⁸⁹³ Old Institutional economists explicitly questioned efficiency and wealth maximisation as neutral evaluative standards. They argued that efficiency analysis embeds normative

⁸⁹¹ Herman E Daly, ‘Steady-state economics: avoiding uneconomic growth’ in Jeroen van den Bergh (ed.) *Handbook of environmental and resource economics* (Edward Elgar 1999) 635, 635.

⁸⁹² Walton H. Hamilton, ‘The institutional approach to economic theory’ (1919) 9(1) *American Economic Review* 309, 309–318.

⁸⁹³ To learn more about old Institutionalism, see for example: Malcolm Rutherford, ‘Institutionalism, Old’ in Matias Vernengo, Esteban Perez Caldentey, Jayati Ghosh (eds.) *The New Palgrave Dictionary of Economics* (Palgrave Macmillan, 2008) 1, 1–15 <https://doi.org/10.1057/978-1-349-95121-5_2747-1> accessed 20 October 2025; also See: Nicholas Mercuro and Steven G. Medema, *Economics and the Law* (2nd edn, Princeton University Press, 2020) 220.

assumptions, legitimises existing power relations, and disguises fundamentally distributive and political choices as matter of technical necessity rather than contestable social decisions.⁸⁹⁴

Building on this old Intuitionist critique of market-centred governance, the growth mentality – as previously described in relation to the limits-to-growth systemic trap – can be understood as a core feature of the current global economic system, namely capitalism. This paradigm prioritises a continuous economic expansion, typically measured through Gross Domestic Product (GDP), as the ultimate marker of development and progress.⁸⁹⁵ While economic growth under capitalism has led to improved living standards for many, the benefits are unevenly distributed and have contributed to persistent wealth inequalities.⁸⁹⁶ Critics of capitalism further argue that its fundamental objective is the extraction and accumulation of

⁸⁹⁴ Drawing on Robert Lee Hale's old Institutional economics critique of neoclassical economics, Samuels famously characterised efficiency-based economic analysis as obscuring its foundations in legal power relations rather than offering a value-neutral account of markets. See: Warren J Samuels, 'The economy as a system of power and its legal bases: the legal economics of Robert Lee Hale' (1973) 27(3-4) *University of Miami Law Review* 261, 262; Karl Polanyi, in his famous book, *The Great Transformation* famously emphasized that markets are not natural or self-regulating phenomena but are instead politically and legally constructed, and that attempts to organise society around a self-regulating market inevitably subordinate social relations to economic power, generating social dislocation and environmental (land) damages. Karl Polanyi, *The Great Transformation – The Political and Economic Origins of Our Times* (3rd edn, Beacon Press, 2001) (first published 1944) 193. This idea is highly relevant to ecological economics, explained below.

⁸⁹⁵ Welfare economic logic, where social "good" is defined as the sum of individual utilities, directly underpins Gross Domestic Product (GDP) as the central measure of progress. This measure has cemented economic growth as a policy priority, on the assumption that expanding production and consumption equates to rising welfare. Which interestingly does not add to any four welfare stands (hedonism, actual or ideal preference, or objective good), rather works as a constructed or imagined preference, one promoted by governments and institutions as the primary indicator of progress because it is simple to measure through GDP. This reliance on growth as a proxy for welfare has long been criticised in economic thought for obscuring externalities, inequality, and ecological limits (Stiglitz, Sen, Mazzucato). In fact, from an old Institutional economics point of view, GDP itself is an institutional construction that embeds particular normative values and political choices. The modern concept of GDP was first developed by economist Simon Kuznets in 1934, when he explicitly warned against its use as a measure of welfare, stating that "the welfare of a nation can scarcely be inferred from a measure of national income." See: Peter Vanham, 'A Brief History of GDP – and what could come next' (*World Economic Forum*, 13 Dec 2021) <<https://www.weforum.org/stories/2021/12/stakeholder-capitalism-episode-1-a-brief-history-of-gdp/>> accessed 20 October 2025. Yet, this growth logic disregard ecological and systemic limits: just as on Earth, where GDP growth has been correlated with resource depletion and environmental degradation, in orbital space the proliferation of satellites may expand the global space economy and register as GDP gains – appearing welfare-enhancing – while simultaneously generating debris risks and undermining long-term sustainability. See: Martin Elvis, and Tony Milligan, 'How much of the Solar System should we leave as wilderness?' 162 (2019) *Acta Astronautica* 574, 576.

⁸⁹⁶ In traditional economic thought, including environmental and resource economics, social externalities are understood primarily as the product of market failures – as discussed earlier – distortions that can, at least in principle, be corrected through adjustments within the existing market framework itself.

ever-increasing profits, often achieved by externalizing environmental and social costs.⁸⁹⁷ To sustain perpetual growth, extractive capitalism depends on ever-expanding frontiers of resources, waste, and labour. As old, terrestrial frontiers become exhausted, new ones must be opened – linking growth to cycles of extractivism and neo-extractivism. Within this logic, space becomes the ultimate “final frontier”.⁸⁹⁸ This dynamic is widely seen as a driving force behind environmental degradation, the climate crisis, and labour exploitation. Underpinning it is the prevailing belief that economic growth inherently results in societal progress. However, with this framework, growth operates with a “totalitarian logic”, establishing itself as one of the most hegemonic ideologies in modern history. Every industry, every sector, and every national economy is expected to grow perpetually, with no clear or identifiable endpoint in sight.⁸⁹⁹ Indeed, global GDP has been growing at an exponential rate of 2-3 % per year, effectively doubling the size of the economy approximately every twenty-three to thirty-five years.⁹⁰⁰ This growth is coupled with continuously increasing energy and resource consumption, as well as escalating waste generation each year. Former extractivist patterns remain prevalent today. However, rather than being taken by force, these resources are now extracted and sold at low prices by governments that have become reliant on foreign investment

⁸⁹⁷ Building on old Institutionalist insights, *social-ecological economics*, an interdisciplinary approach that integrates ecological limits and social justice into economic analysis, emphasizes that sustainability requires balancing environmental integrity with equitable human well-being. To learn more on the field see for example: Sebastian Berger, ‘Karl Polanyi’s and K. William Kapp’s arguments on social costs: is there a common “revolutionary” raison d’être?’ (2024) 219 *Ecological Economics* 1, 1-8.

⁸⁹⁸ Thomas Cheney, ‘Non-use of Space, Reconsidering Article I of the Outer Space Treaty and the Useability of Space Resources’, in Solène Guggisberg and Catherine Blanchard (eds.) *Non-use Measures for Global Goods and Commons in International Law* (Brill 2025) 428, 442.

⁸⁹⁹ Jason Hickel, *Less Is More – How Degrowth Will Save the World* (William Heinemann 2020) 20. In fact, according to Johan Rockström and Owen Gaffney, among the 9 planetary boundaries assessed until 2023 – that are climate change, novel entities, ocean acidification, land system change, atmospheric aerosol loading, freshwater change, modification of biogeochemical flows, biosphere integrity, and ozone depletion – 6 have been already crossed. These crossings are clear signs of the Earth’s declining resilience, pushing us closer to irreversible tipping points. See: Johan Rockström, and Owen Gaffney, *Breaking Boundaries – The Science of Our Planet* (Penguin Random House 2021) 74-88. To learn more on planetary boundaries, see: Stockholm Resilience Centre, ‘Planetary Boundaries’ <<https://www.stockholmresilience.org/research/planetary-boundaries.html>> accessed 20 October 2025.

⁹⁰⁰ For visual representation of the world GDP growth, see: World Bank, ‘Global GDP’ <<https://data.worldbank.org/indicator/NY.GDP.MKTP.CD>> accessed 20 October 2025; and for the domestic extraction of world by material group, see: University of Economics and Business, Vienna, ‘Material flows by material group, 1970-2024’ <<https://www.materialflows.net/visualisation-centre/data-visualisations/>> accessed 20 October 2020.

and constrained by the growth demands of global capitalism – as explained under the neo-extractivist tendencies.

Nonetheless, exponential (economic) growth ordinarily levels off at some point. In space as well, “We may not expect the space economy to consistently sustain a 10% growth rate even if it reaches such rate, or even higher, during its early stages. Beyond a certain stage in its development, the accumulation of new resources simply becomes more difficult”.⁹⁰¹ Marginal opportunities are costlier to exploit, domestic political pressures intensify, export demand fluctuates, and initial competitive advantages erode. Yet, “whether or not a system slowdown occurs early enough to avoid major growth-related problems is, however, a contingent matter”.⁹⁰² Although proponents frame expansion into outer space as opening transformative possibilities, reliance on space resources offers only a time-limited extension of the extractivist model of “endless” growth, as earlier suggested. The solar system’s resources may be vast, but they are not inexhaustible. Moreover, pursuing the path risks perpetuating the ecological harms of extraction on Earth, since the underlying paradigm of extractivism remains intact as explained by the Jevons paradox.

Although public international law provides binding legal frameworks for environmental protection both within state jurisdictions and in areas beyond national jurisdiction, environmental degradation persists, as economic growth is often prioritized through the *sustainable development* framework while environmental costs are externalized. Indeed, public international law has become closely linked to the concept of sustainable development, first articulated in the Brundtland Report, which frames it as a balancing exercise between the pursuit of economic development through resource use and the imperative of environmental protection.⁹⁰³ The core premise of sustainable development is the pursuit of a balance among its three pillars – economic growth, social equality, and environmental protection – framed as if they were of equal weight and mutually reinforcing. Notably, however, critics contend that “given the accelerating pace at which global social and environmental conditions are

⁹⁰¹ Martin Elvis, and Tony Milligan, ‘How much of the Solar System should we leave as wilderness?’ 162 (2019) *Acta Astronautica* 574, 576.

⁹⁰² *Ibid.*, 576.

⁹⁰³ The Brundtland report defines sustainable development as development that “meets the needs of the present without compromising the ability of future generations to meet their own needs”. The report imagines some kind of limit on technology for example, where “technology and social organization can be both managed and improved to make way for a new era of *economic growth*” [emphasis added]. See: Brundtland Report para 27.

deteriorating – outstripping the modest progress of mitigation efforts – the very notion of “sustainable development” risks becoming an oxymoron.⁹⁰⁴ In fact, the relationship between the three pillars of sustainable development is not static but both *temporal* and *physical*, reflecting both the sequencing of impacts over time and the hard constraints imposed by biophysical limits. The three pillars’ apparent equality holds only until Earth’s biophysical limits are respected; once ecological thresholds are crossed, as is already observable today, the foundations for future economic and social development becomes structurally impossible. Accordingly, sustainability is treated here as intrinsically tied to Earth’s biophysical limits, and proposals that envisage outer space as an alternative to addressing planetary ecological constraints fall outside the scope of this dissertation.⁹⁰⁵ Building on this understanding, space sustainability is not about escaping Earth’s limits, but rather as an extension of sustainability thinking to Earth-adjacent environments that are themselves finite, fragile, and vulnerable to irreversible harm.

As a response to the sustainable development narrative, a more realistic perspective may therefore be required, one that recognizes, even within a human-centred framework, that without a resilient and functioning Earth system to provide life-supporting conditions, neither a thriving society nor a viable economy can be sustained. In this sense, the environmental foundation is primary; social well-being depends on ecological stability, and the economy, in turn, is embedded within society as a tool to serve human needs rather than autonomous end in itself.

Moreover, it is important to highlight concerning the sustainability model that sustainable development often relies on the belief that *technological innovation* can and will provide solutions to the growing environmental crisis,⁹⁰⁶ thus it relies heavily on technological

⁹⁰⁴ See for example: Claiton Fyock, ‘What Might Degrowth Mean for International Economic Law? A Necessary Alternative to the (un)Sustainable Development Paradigm’ (2022) 12 *Asian Journal of International Law* 40, 41; Others also argue that the term, has been frequently used as a vague concept to justify continued economic growth while barely addressing environmental and social concerns without fundamentally challenging structures that allows resource extractivism. See: Anna Aseeva ‘(Un)Sustainable Development(s) in International Economic Law: A Quest for Sustainability’ (2 November 2018) 10(11) *Sustainability* 1, 1-3.

⁹⁰⁵ For a critical perspective on the space colonization discourses, see for example: Shannon Stirone, ‘Mars is a Hellhole’ (*The Atlantic*, 26 February 2021) <<https://www.theatlantic.com/ideas/archive/2021/02/mars-is-no-earth/618133/>> accessed 20 October 2025.

⁹⁰⁶ See for example: Paris Agreement article 10 para 5, stating: “Accelerating, encouraging and enabling innovation is critical for an effective, long-term global response to climate change and promoting economic growth and sustainable development”.

advancements to “decouple” economic growth from environmental harm (e.g., geoengineering).⁹⁰⁷ This perspective has allowed decision-makers to aim at reconciling the inherent tension by assuming that technology will ultimately save humanity – that innovation will render economic growth “green”.⁹⁰⁸ A similar logic is visible in space sustainability debates: when addressing the orbital debris problem, most research and policy discussions place disproportionate faith in active debris removal (ADR), while paying comparatively little attention to structural drivers of overuse.⁹⁰⁹ ADR is frequently presented as the inevitable technological fix that will “clean up” the orbital environment, despite the absence of proven, scalable systems and the significant costs involved and a technology that remains underdeveloped and unimplemented until today. Furthermore, there is still little concrete evidence on the long-term environmental impacts of large-scale deorbiting on Earth’s atmosphere, meaning that the potential harms may once again be externalised – shifting the social and ecological costs of technological solutions onto the shared terrestrial environment.⁹¹⁰

As a critical response to the sustainable development paradigm, the *degrowth* movement has emerged over the past decade as a rapidly expanding field of thought, drawing on insights from economics, ecology, sociology, anthropology, and related disciplines.⁹¹¹ Following the limit-to-growth trap, proponents of the so-called *de-growth movement*, argue that nature has a self-limiting logic to growth, thus, the economy cannot sustain perpetual economic expansion on a planet that is already nearing ecological collapse and exceeding its

⁹⁰⁷ This view can be also characterized by the philosophical notion of *ecomodernism*. Accordingly, humanity can address ecological challenges not by reducing growth or consumption, but by intensifying technological innovation decoupling human well-being from environmental impacts. See for example: Roel Veraart, Vincent Blok and Peter Lemmens, ‘Ecomodernism and the Libidinal Economy: Towards a Critical Conception of Technology in the Bio-Based Economy’ (2023) 36(18) *Philosophy & Technology* 1, 2 <https://doi.org/10.1007/10_2019_100> accessed 20 October 2025.

⁹⁰⁸ The transition to renewables for example requires a massive increase over existing levels of material extractions. Renewable technologies such as wind turbines, solar panels, and electric vehicles depend heavily on various minerals and metals, including lithium, cobalt, nickel, copper, and rare earth elements.

⁹⁰⁹ J.-C. Liou and A.K. Anil Kumar, et al., ‘Stability of the Future LEO Environment – An IADC comparison study’ (April 2013) 1, 6.

<https://www.researchgate.net/publication/266584674_STABILITY_OF_THE_FUTURE_LEO_ENVIRONMENT_-_AN_IADC_COMPARISON_STUDY> accessed 20 October 2025.

⁹¹⁰ See for example, University of Southampton, ‘First study to examine environmental impact of deorbited satellites’ (9 May 2024) <<https://www.southampton.ac.uk/news/2024/05/environmental-impact-of-deorbited-satellites.page>> accessed 20 October 2025.

⁹¹¹ See for example: Jason Hickel, et al., ‘Urgent Need for Post-Growth Climate Mitigation Scenarios’ (2021) 6(8) *Nature Energy* 1, 1-3; and Giorgos Kallis, Christian Kerschner and Joan Martinez-Alier, ‘The Economics of Degrowth’ (2012) 8 *Ecological Economics* 172, 172-180.

carrying capacity.⁹¹² It argues that reliance on GDP or GNP as the primary indicators of progress entrenches unsustainable material throughput, driving resource depletion and environmental destruction while simultaneously worsening global inequalities. From this perspective, “green growth” and efficiency improvements are insufficient, since growth itself is structurally tied to escalating consumption. Furthermore, in addressing the role of technology, the de-growth movement advances the more radical claim that confronting the planetary crisis and realizing distributive justice requires an absolute downscaling global production and consumption, rather than simply “greening” existing growth-oriented models.⁹¹³ It is notable, however, that degrowth – and the author of this dissertation – does not reject technology altogether. Rather, technological innovation is viewed as a valuable tool for reducing environmental harm, but not as a substitute for the urgent and absolute reduction of resource use and consumption, particularly in light of the rebound effect.

A central economic foundation of the degrowth movement lies, alongside old Institutional economics, in *ecological economics*, which departs from mainstream environmental and resource economics by placing ecological limits and system integrity at the centre of analysis.⁹¹⁴ From the standpoint of (neo)classical economists, however, this approach is often judged as “extreme”, insofar as it prioritises environmental conservation at the expense of economic activity.⁹¹⁵ While environmental and resource economics remains rooted within the disciplinary framework of welfare economics – seeking to correct market failures and optimize efficiency – ecological economics is grounded in ecology as a natural science,

⁹¹² Jason Hickel, *Less Is More – How Degrowth Will Save the World* (William Heinemann 2020) 20.

⁹¹³ Ibid. 124-164.

⁹¹⁴ Since economics is a field that analyses human economic activities, resource and environmental economics analyse environmental problems from a human-oriented perspective. Thus, in the mainstream welfare economic and common-pool resource perspectives, the central problem lies in market failure: pollution is framed as a negative externality to be internalized through taxes, liability, or tradable permits, while overuse is treated as a coordination challenge to prevent depletion. In both cases, the underlying assumption remains that growth and efficiency are desirable and that the role of law, policy as well as technology is to correct distortions so that markets can continue to function. By contrast, in ecology, environmental problems are examined from a nature-oriented perspective. Ecological economics rejects the premise that economic growth throughput is physically bounded on a finite planet, and growth-oriented model – even one that corrects for externalities – ultimately drives ecological overshoot. Whereas environmental and resource economics seeks to fix markets so they can better steward resources, steady-state economics calls for a paradigm shift away from growth as the central objective, placing ecological integrity and distributive justice above the pursuit of ever-expanding GDP. See: Aruga, Kentaka, *Environmental and Natural Resource Economics* (Springer 2022) 8.

⁹¹⁵ See for example: “(...) some ecologists who support *extreme* ecosystem conservation have called for the conservation of ecosystems at the expense of economic activity” [emphasis added]. See: Kentaka Aruga, *Environmental and Natural Resource Economics* (Springer 2022) 8.

emphasizing biophysical limits and the embeddedness of human economies within finite planetary systems.⁹¹⁶ Moreover, within the ecological economy movement, Herman Daly introduced the concept of the *steady-state economy*, in which material and energy throughput remains within the regenerative and absorptive capacities of the Earth's ecosystems.⁹¹⁷ This vision rests on two simple yet radical principles: never extract more resources than ecosystems can regenerate, and never emit more waste than ecosystems can safely absorb.⁹¹⁸ Indeed, for Daly, sustainability demands establishing biophysical limits on extraction and emissions first, allowing markets to operate within those constraints. Extending ecological economics to the governance of Earth's orbits may appear extreme in contemporary discourse; in fact, it is *radical* only in the original sense of addressing problems at their structural and systemic roots.

E. Towards an integrated governance – Chapter Conclusion

*“Not everything that can be done may be worth doing”.*⁹¹⁹

1. A virtuous Anthropocene

This dissertation builds on Viikari's observation that all values attributed to outer space – as with any environment or entity – are ultimately human values, since even claims to

⁹¹⁶ In other words, from Daly's vision, traditional welfare economics focuses on relative scarcity that assumes that price adjustments (e.g., correction by pollution taxes, or tradeable permits) can ensure efficiency within an otherwise boundless economy. “Since one man's price is another man's income”, aggregate growth cannot be curbed through prices alone. Hence, Daly argues that while such internalisation addresses allocation, it does not solve absolute scarcity – the physical limits of a finite planet. Consequently, even if all externalities were prices, continued growth in population and consumption would still expand total resource throughput beyond ecosystems' regenerative and absorptive capacities. See: Herman E Daly, *Steady-State Economics* (2nd edn, Island Press 1991) 43.

⁹¹⁷ “An economy in sustainable development, a steady-state economy, is one whose scale (or resource throughput, equal to population times per capita resource use) remains constant at a level that neither depletes the environment beyond its regenerative capacity, nor pollutes it beyond its absorptive capacity.” See: Herman E Daly, ‘Steady-state economics: avoiding uneconomic growth’ in Jeroen van den Bergh (ed.) *Handbook of environmental and resource economics* (Edward Elgar 1999) 635, 639.

⁹¹⁸ Herman E Daly, *Steady-State Economics* (2nd edn, Island Press 1991) 15-49; Herman E Daly, ‘Steady-state economics: avoiding uneconomic growth’ in Jeroen van den Bergh (ed.) *Handbook of environmental and resource economics* (Edward Elgar 1999) 635, 635-642; and Herman E Daly, *Steady-State Economics* (2nd edn, Island Press 1991) 15-49.

⁹¹⁹ Saara Reiman, ‘Is space an environment?’ (2009) 25:2 *Space Policy* 81, 85.

“intrinsic value” are necessarily mediated through human perspectives.⁹²⁰ This observation is particularly relevant in international law, where states are not abstract actors but collective expressions of human societies and their references. Understanding why actors may behave unsustainably therefore requires looking beyond formal rules to the dynamics of human behaviour itself – an area where both theoretical frameworks and empirical studies provide important guidance.

Drawing on a 2014 behavioural study by Harvard and Yale researchers, for example, which examined how people manage finite resources across generations, the findings revealed that many participants chose to act out of fairness and responsibility toward future generations rather than pursuing narrow self-interest.⁹²¹ Although, economists traditionally predict that individuals act “rationally” by exhausting resources in the present, since future generations cannot reciprocate, yet the behavioural experiments showed the opposite: 68% of participants chose to use their share sustainably, allowing regeneration for future generations.⁹²² The problem was the 32% who opted for short-term profit, quickly depleting the pool and leaving future generations with nothing – a pattern strikingly similar to today’s environmental crisis. When decisions were made collectively through direct democracy, however, the selfish minority was overruled. Even short-term actors shifted towards sustainability, and resources were maintained indefinitely across up to fifteen simulated generations.⁹²³ This behavioural experiment provides strong empirical support for a long-standing insight of the old Institutional economics tradition: that the primary obstacle to sustainability lies not in human nature as such, but in the political systems and institutional structures that shape collective decision-making. It demonstrates that contemporary democracies often fail to translate widely shared societal preferences for long-term sustainability into effective action, as decision-making is often captured by economic elites and shaped by geopolitical interests rather than guided by sustainability and equity.⁹²⁴ As a conclusion to this experiment applied to degrowth, Hickel suggests the application of clear caps on resource use and waste.⁹²⁵ Furthermore, a degrowth-

⁹²⁰ Lotta Viikari, *The Environmental Element in Space Law* (Martinus Nijhoff, 2008) 15.

⁹²¹ Oliver Hauser, David Rand, Alexander Peysakhovich, and Martin Nowak, ‘Cooperating with the future’ (2014) 511 *Nature* 220, 220-223.

⁹²² *Ibid.*, 220.

⁹²³ *Ibid.*, 221.

⁹²⁴ Jason Hickel, *Less Is More – How Degrowth Will Save the World* (William Heinemann 2020) 244.

⁹²⁵ *Ibid.*, 234.

informed international order would move beyond the internal contradictions of sustainable development, placing ecological sustainability and global distributive justice as primary objectives. Rather than seeing growth as the baseline “good”, it prioritises ecological integrity and distributive justice, even at the expense of reduced output.⁹²⁶ Degrowth, paired with ecological economics, thus not only critiques the failures of growth-centric governance – mirrored in the overexploitation of orbital space under the freedom principle – but also provides a normative framework for reimagining the orbital commons as an environment to be preserved through absolute limits and equitable distribution of access. This positions degrowth as a genuine restraint, one that integrates ecological limits and embeds fairness at its core. With each passing year, it becomes increasingly clear that the global community requires a fundamental change in how the relationship between the three pillars, the economic, social, and environmental is understood and governed.

While the Harvard-Yale study suggests that, under the right institutional arrangements, actors are capable of agreeing on limits and rules that safeguard shared ecological resources, philosophical perspectives caution against treating institutions as the sole source of failure. In light of escalating environmental risks from collective inaction, they ask why individuals – and, by extension, states – so often default to short-term choices that jeopardize long-term survival, and why the necessary institutional transformation fail to materialize in the first place. Consequently, a revealing contrast emerges when the behavioural evidence is set alongside a critical philosophical account of the “libidinal economy”, developed by Bernard Stiegler and applied by Veraart et al.⁹²⁷ According to this philosophical take, our collective failures governing the global commons stem not merely from institutional gaps but from bounded rationality and a deeper corruption of human desire. Technological and economic systems have “short-circuited” long-term orientations towards sustainability, replacing them with drive-based impulses of instant gratification and perpetual consumption, reinforced by the promise of endless technological fixes.⁹²⁸ Even degrowth – the philosophers argue – though more

⁹²⁶ Claiton Fyock, ‘What Might Degrowth Mean for International Economic Law? A Necessary Alternative to the (un)Sustainable Development Paradigm’ (2022) 12 *Asian Journal of International Law* 40, 48-50.

⁹²⁷ Roel Veraart, Vincent Blok and Peter Lemmens, ‘Ecomodernism and the Libidinal Economy: Towards a Critical Conception of Technology in the Bio-Based Economy’, (2023) 36(18) *Philosophy & Technology* 1, 1 <https://doi.org/10.1007/10_2019_100> accessed 20 October 2025.

⁹²⁸ *Ibid.*, 10.

critical of the growth paradigm, falls short in this respect: it largely neglects how human “libidinal energy” and desire are themselves shaped by systemic dynamics, and thus cannot fully escape the logic of growth.⁹²⁹ Thus, restoring long-circuit orientations of care, attention, stewardship, and responsibility toward current and future generations requires more than institutional reforms or i-frame “nudges”. Instead, what is required, is a deeper *paradigm shift*⁹³⁰ in human consciousness and collective decision-making – one that reorients human desires and values away from short-term gratification and toward long-term sustainability, grounded in principles of equity.

When addressing the question of intrinsic values with respect to non-human environments, exposed to a short-circuited technological and economic environment, *virtue ethics* offers a promising lens for reorienting human values in light of the Anthropocene.⁹³¹ For Aristotle, virtue is not about pursuing limitless accumulation but about living well – cultivating moderation, balance, and purpose.⁹³² The pursuit of preserving or endlessly increasing wealth, driven by the desire for unlimited things, reflects no virtue, but a failure to distinguish between mere living and living well. Virtue, by contrast is the cultivation of stable character habits that enable individuals to act in accordance with reason, finding the mean between excess and deficiency, and orienting life toward the flourishing of self and community rather than endless accumulation. Additionally, it makes no difference whether our actions take place on Earth or in outer space – wherever we act, our conduct can and should be evaluated through the lens of

⁹²⁹ In Stiegler’s theory, libidinal energy refers to the deep, open-ended motivational force of human desire – our drive toward ideals like truth, beauty, and justice – that gives space to social, political, and economic systems but can be corrupted when reduced to short-term, consumptive urges. See: Roel Veraart, Vincent Blok and Peter Lemmens, ‘Ecomodernism and the Libidinal Economy: Towards a Critical Conception of Technology in the Bio-Based Economy’ (2023) 36(18) *Philosophy & Technology* 1, 9 <https://doi.org/10.1007/10_2019_100> accessed 20 October 2025.

⁹³⁰ As Thomas Kuhn famously argued, a paradigm shift entails such a decisive rupture from earlier modes of thought and practice that the new framework is no longer compatible with the old. See: Thomas Kuhn, *The Structure of Scientific Revolutions* (4th ed, University of Chicago Press 2012) 140.

⁹³¹ “If space exploration as a science treats ethical questions only in terms of human interests, can we really expect a future in which the exploration of space is capable of fulfilling the hopes humanity has placed on it? It is important to ask how our actions will shape us as a civilization and perhaps even as a species. This can be done by employing a framework of ‘virtue ethics’”. See: Saara Reiman, ‘Is space an environment?’ (2009) 25:2 *Space Policy* 81, 85.

⁹³² See for example: „[...] and they proceed on the supposition that they should either preserve or increase without limit their holdings of money. The cause of this condition is that they are serious about living, but not about *living well*; and since that desire of theirs is without limit, they also desire what is productive of unlimited things” Book 1, Chapter 9, Para 16, Aristotle, *Aristotle’s Politics* (2nd edn, University of Chicago Press 2013) translated by Carnes Lord.

virtue ethics.⁹³³ From a behavioural law and economics perspective, virtue ethics challenges the narrow reliance on incentives and enforcement by highlighting their limitations: legal rules risk rigidity and insensitive to context, while incentive-based instruments risk producing perverse effects or crowding out intrinsic motivations. Virtue ethics does not replace law but provides a complementary normative foundation by cultivating trust, reciprocity, and fairness – qualities that echo Ostrom’s design principles for common-pool resource governance,⁹³⁴ and reinforce the international law principle of *pacta sunt servanda*.

2. “Non-use” and the development law

Some argue that public international law has been called “development law” since the 1960s,⁹³⁵ resting on the idea of Rostow’s take-off theory, according to which every country should follow the great path of evolution and “growth” towards a society of mass consumption and productivism; what we would call a growth society.⁹³⁶ To curb resource exploitation and mitigate environmental harm – and thereby escape the tragedy of the commons – a growing body of international legal scholarship advancing *non-use* approaches argue that law must transcend its growth-oriented paradigm by recognising ecological limits and institutionalising non-use or strict caps as legitimate governance tools. This perspective closely aligns with ecological economics, which understands sustainability as requiring firm limits to resource use and exploitation rather than reliance on efficiency-based adjustments after harm has occurred. By the same token, understanding orbital governance as a new frontier of neo-extractivism – operating within the paradigm of unlimited growth – underscores the need to revisit not only

⁹³³ Saara Reiman, ‘Is space an environment?’ (2009) 25:2 *Space Policy* 81, 86.

⁹³⁴ See for example, design principles 7 and 8 of Ostrom’s governance theory. Eleonor Ostrom, *Governing the commons: The evolution of institutions for collective action* (Cambridge University Press 1990) 90.

⁹³⁵ Noémie Candiago, ‘The virtuous circle of degrowth and ecological debt, A new paradigm for public international law?’ in Laura Westra, Prue Taylor, Agnès Michelot (eds.) *Confronting Ecological and Economic Collapse* (Brill 2013) 423, 423; Also see for example: “sustainable development and international economy law share the same background assumptions of an entrenched globalized capitalism that is fully dependent on economic growth”. See: Clayton Fyock, ‘What Might Degrowth Mean for International Economic Law? A Necessary Alternative to the (un)Sustainable Development Paradigm’ (2022) 12 *Asian Journal of International Law* 40, 45.

⁹³⁶ The take-off stage of Rostow’s theory is the third stage in his five-stage model, which outlines a linear path of development of all economies. See: Whitman Rostow, *The Stages of Economic Growth: A Non-Communist Manifesto* (Cambridge University Press 1960).

allocation and enforcement mechanisms, but also the underlying normative assumptions that treat the orbital commons primarily as a site for competitive resource extraction rather than as an environment requiring equitable and sustainable stewardship.⁹³⁷

The non-use principle applied to global commons governance refers to prohibition or suspension of exploiting natural or spatial-extension resources.⁹³⁸ At the international level, such measures take various forms – bans, moratoria, abstentions, no-take zones, noctuaries, or closed seasons. While the label itself reveals little about their precise scope, key factors include the legal nature of the instrument, the extent to state participation, and their spatial and temporal application.⁹³⁹ In light of the repeated failures of resource management regimes – especially in areas beyond national jurisdiction – combined with growing demand for natural resources and the intensifying pressures of climate change, measures that limit use are gaining traction across legal regimes.⁹⁴⁰ Such measures are likely to become increasingly relevant, though also highly contested. Incorporating non-use into the governance toolbox can be justified not only as a pragmatic complement to existing conservation and management strategies, but also on the normative ground that, in the context of global goods, non-use is as legitimate of a governance

⁹³⁷ Cheney's invocation of the paradigm shift, for instance, is grounded primarily in the context of climate change and the broader Anthropocene, where the dominant growth-oriented economic model has driven ecological degradation. As he noted, "moving to space as the new frontier in order to source more resource falls squarely into the traditional economic model based on growth, enabling the same behaviour that has caused the current ecological catastrophe (...)". Even the 'climate friendly' visions of expanding into space in order to reduce pollution on the Earth environment and/or to enable the creation of renewable energies are not actually beneficial to solve the crisis facing Earth and humankind. From this perspective, outer space is not a limitless escape from terrestrial thresholds but a continuation of the same extractivist logic that generated the planetary crisis in the first place. Applied to LEO, the parallel is clear: framing orbital space primarily as a growth frontier reproduces patterns of over-appropriation, externalized harms, and inequitable access, rather than addressing the structural conditions that drive congestion and debris accumulation. This, Cheney's climate-based critique reinforces the argument that without a genuine shift in the underlying paradigm – from growth and exploitation to restraint, equity, and ecological stewardship – the governance of LEO will likely mirror the same unsustainable dynamics that have imperilled the Earth's environment. See: Thomas Cheney, 'Non-use of Space, Reconsidering Article I of the Outer Space Treaty and the Useability of Space Resources', in Solène Guggisberg and Catherine Blanchard (eds.) *Non-use Measures for Global Goods and Commons in International Law* (Brill 2025) 428, 445.

⁹³⁸ Catherine Blanchard and Solène Guggisberg, 'Introduction' in Catherine Blanchard and Solène Guggisberg (eds.) *Non-use Measures for Global Goods and Commons in International Law* (Brill 2025) 3, 3.

⁹³⁹ *Ibid.*, 24.

⁹⁴⁰ Existing non-use measures include the Montreal Protocol; the International Moratorium on Commercial Whaling; and The mining moratorium is provided for at Article 7 of the Environmental Protection to the Antarctic Treaty (Environmental Protocol).

choice as use.⁹⁴¹ Nevertheless, a non-use regime may impose strict bans in certain contexts while simultaneously permitting regulated use elsewhere, demonstrating that outright prohibitions and use-restricting measures can coexist within the same governance framework.

Moreover, environmental law scholars argue that the ICJ's 2025 Advisory Opinion on climate change signals a broader *ecologisation of international law*, in which environmental protection is becoming constitutive element of legal reasoning rather than secondary concern.⁹⁴² An important element of this shift is the increasing application of the *precautionary principle*, which holds that, "where there are threats of serious or irreversible damage, lack of full scientific certainty should not be used as a reason for postponing such measures" –.⁹⁴³ Nevertheless, the precautionary principle aligns closely with the logic of non-use. Accordingly, it justifies temporary or permanent prohibitions on exploiting commons when scientific uncertainty persists, ensuring that the absence of full knowledge does not become an excuse for inaction in the face of potentially irreversible harm.⁹⁴⁴ From this it follows that, given the scientific uncertainty surrounding debris dynamics and LEO's carrying capacity, orbital governance should be guided by precautionary measures – grounded in Article III OST – that may justify limiting satellite deployment and mandate risk-mitigation even in the absence of complete scientific certainty. An orbital regime could, for instance, require states to commit to satellite and debris thresholds for specific orbital shells, thereby ensuring a continuing duty to take preventive measures against serious or irreversible harm to the orbital environment, which such thresholds subject to periodic revision as scientific knowledge advances.

⁹⁴¹ Beyond practicality, there is also a principled argument: in global commons governance, not using a resource is just as legitimate a choice as using it. International law often frames access and use as the default, but from a normative standpoint, preserving a fragile resource through non-use honours values like intergenerational equity and ecological integrity. See: Catherine Blanchard and Solène Guggisberg, 'Introduction' in Catherine Blanchard and Solène Guggisberg (eds.) *Non-use Measures for Global Goods and Commons in International Law* (Brill 2025) 3, 3.

⁹⁴² In acknowledging ecologisation of international law, it is argued that "This shift reinforces the normative foundation for planetary welfare and highlights the collective obligations and shared responsibility of the international community of states, thereby safeguarding the climate system as a global commons in the interest of present and future generations." See: Völkerrechtsblog, Symposia, 'Systemic Impacts and Structural Shifts: Climate Change and the Role of the ICJ Advisory Opinion' (September 2024) <<https://voelkerrechtsblog.org/symposium/symposium-on-the-icj-climate-change-advisory-opinion/>>; See also: Louise du Toit and Louis J. Kotzé, 'Reimagining international environmental law for the Anthropocene: An earth system law perspective' (2022) 11 *Earth System Governance* 1, 1-10.

⁹⁴³ United Nations Framework Convention on Climate Change, 9 May 1992, 31 ILM 849 (UNFCCC Framework Convention) art 3 para 3.

⁹⁴⁴ Pierre-Marie Dupuy and Jorge E Viñuales, *International Environmental Law* (2nd edn, Cambridge University Press 2018) 70-73.

3. The limitation of the freedom principle – from freedom to restrictive use

When addressing the governance of LEO, there are three interrelated challenges consistently recur. First are pollution externalities, most prominently the generation of debris, which imposes risks and costs on all users. Second, the overuse of the common-pool resource, as the finite carrying capacity of LEO creates risks of congestion and cascading collisions. Third, the question of distribution of use, reflecting a concentration of access and benefits among technologically advanced actors, who dominate filings and launches, while latecomers face mounting entry barriers. Different areas beyond national jurisdiction exhibit distinct governance challenges, and this diversity has led to the emergence of different institutional and legal responses. Various global commons regimes typically crystallize around two most pressing dominant challenges.⁹⁴⁵ These may involve pollution and environmental risks alongside distributive justice (as in the ozone regime or climate governance); rivalrous overuse and allocation disputes (as in the high seas fisheries); or distributive justice coupled with latent environmental risks (as in deep-seabed mining). By contrast, the governance of LEO concentrates all three dynamics simultaneously: stark first-mover advantages combined with immediate physical rivalry, de facto through occupation of orbital positions, and negative externalities arising from debris creation (environmental risks). This convergence renders LEO governance uniquely complex among global commons, as all three elements operate on short timescales and generate immediate consequences for new entrants – conditions largely absent, or far less acute, in other areas beyond national jurisdiction. An additional and particularly significant challenge is *scientific uncertainty*: unlike the relatively stable and well-defined geostationary orbit, the dynamics of LEO remain far less predictable, a factor that heightens the governance dilemma and brings its management into closer alignment with the climate commons, where uncertainty over thresholds and feedbacks is a defining feature.

In response to the foregoing economic analyses, one can differentiate between two distinct quantitative economic perspectives to the question of what constitutes a sustainable use – understood here as an *acceptable launch rate* –, which in turn shape fundamentally different

⁹⁴⁵ This classification does not deny the presence of all three elements across areas beyond national jurisdiction but rather distinguishes them according to the relative intensity and immediacy of their impacts.

conceptions of LEO as a global commons. From the neoclassical standpoint of environmental and resource economics, the goal is to identify the *socially optimal launch rate*. In this framework, orbital capacity is treated as a common-pool resource subject to negative externalities. The normative rule is that launches should continue up to the point where their marginal social benefit (MSB) is equal to the marginal social cost (MSC). The latter includes not only the operator's private costs, but also the externalised risks imposed on others through debris creation, collision probability, and higher avoidance costs. Policy instruments such as Pigouvian fees, tradable permits, or risk-based caps are then used to internalise these externalities, so that private incentives align with this equilibrium. In practice, such a model might still allow for significant growth in satellite constellation size if benefits are high and if debris risks can be priced and offset – for example, through the addition of ADR capacity. The underlying logic is welfare-maximization: launches are acceptable so long as the total gains outweigh the fully accounted losses.

By contrast, the steady-state economy paradigm, developed within ecological economics, begins from a different premise: that throughput of material and energy must remain within the regenerative and absorptive limits of the Earth system. Applied to LEO, this translates into a launch rate that does not allow the orbital debris stock to increase. In other words, launches should be limited to what can be safely balanced by natural orbital decay, controlled deorbiting (and active debris removal, once the technology is existent), minus additional fragmentation risks. Here the focus is not on equating marginal benefits and costs, but on respecting a biophysical ceiling. The priority is to keep the system stable and precautionary, even if this means foregoing profitable launches once the *assimilative capacity* is reached.⁹⁴⁶ The contrast between the two perspectives is therefore stark. The resource-economic approach allows the orbital environment to be exploited further, provided that externalities are properly internalised and compensated, mixed with growing scientific, technical, and regulatory uncertainties, while the steady-state approach insists on setting absolute limits first and only then distributing (or, where necessary, halting) use within those

⁹⁴⁶ In ecological economics, *assimilative capacity* means the maximum amount of pollution or waste that an ecosystem or environmental system can absorb, recycle, or neutralize without suffering irreversible damage or collapse. See: Purushottam Khanna, P. Ram Babu and M. Suju George, 'Carrying-capacity as a basis for sustainable development A case study of National Capital Region in India' (1999) 52(2) *Progress in Planning* 101, 110.

boundaries, subject to continuous review. On policy terms, the former relies primarily on economic instruments to “get the prices right,” whereas the latter calls for throughput caps and precautionary margins to prevent irreversible system collapse.

In contrast to GEO, where the ITU employs quantitatively specified coordination mechanisms to regulate access to orbital positions and radio-frequency spectrum, LEO lacks any equivalent institutional framework providing numerical coordination or allocation. While spectrum coordination, national licensing, and qualitative soft-law debris guidelines apply to LEO – including obligations of due regard under Article IX OST and binding principles of international environmental law – none of these instruments establish numerical limits, allocate orbital space *a priori*, or manage aggregate congestion and debris risks at the international level. These instruments, however, remain insufficient to directly address the threefold, growing challenges of distribution, overuse, and pollution, leaving the core risks of orbital congestion and debris largely unmanaged. While the adoption of a strict non-use regime for LEO satellites is highly improbable under current and economic political conditions, this dissertation argues that a radical shift away from the prevailing inaction remains essential, pointing toward the need for a hybrid governance mechanism that can secure support from both spacefaring and developing nations.

Drawing on Ostrom’s insights into common-pool resource governance, and informed by the decentralised, polycentric institutional model developed in high seas fisheries governance, several key priorities emerge for the governance of LEO:

1) A future LEO governance regime would most plausibly be negotiated under the auspices of UNCOPUOS, potentially through a dedicated working group with interdisciplinary expertise and culminating in the adoption of a binding *implementation agreement* analogous to the UNFSA Agreement and the BBNJ Agreement.⁹⁴⁷ The implementation agreement would

⁹⁴⁷ Both the UNFSA, like the recently adopted BBNJ Agreement, constitute an implementing agreement under UNCLOS, illustrating how framework obligations can be progressively operationalised through sector-specific regimes in response to scientific uncertainty and commons governance. A prospective LEO agreement would be situated under the normative framework of 1967 OST and the wider corpus juris spatialis, functioning as an implementing instrument that gives concrete effect to their foundational principles in the specific context of orbital congestion and debris.

establish precautionary obligation; duty to remain within orbital capacity; require to cooperate through shell-specific management bodies; and a scientific review mechanism;⁹⁴⁸

2) *LEO's carrying capacity* should be centrally assessed and quantified to provide a baseline for sustainable use, under the auspices of UNCOPUOS and informed by an independent scientific and technical process with option for periodic review.⁹⁴⁹ This approach aligns with the ecological economics tradition, which highlights the primacy of setting ecological limits to resource use.

3) a *precautionary approach*, inspired by the UN Fish Stocks Agreement (UNFSA)⁹⁵⁰ should be incorporated by embedding additional hard limits within an adaptive risk-management framework. These limits would aim to prevent serious or irreversible harm under conditions of persistent scientific uncertainty.⁹⁵¹ Such precautionary limits could be applied separately to individual *LEO shells* – defined by altitude and inclination – each characterised by distinct congestion, collision, and debris dynamics. The scientifically grounded carrying-capacity limits for individual LEO shells should be established centrally, at the international level.⁹⁵²

⁹⁴⁸ The *legal justification* for a new implementation agreement on LEO rests on three interrelated grounds. First, the existing governance framework, relying on voluntary guidelines and first-come, first-served filing system, without any slotting mechanism in LEO – has proven unsustainable, as it lacks clear quantitative limits to prevent congestion and debris proliferation, while proposed technological remedies such as active debris removal remain largely underdeveloped. Second, the principle of reciprocal equality enshrined in Article I OST, together with the duty of due regard under Article IX, supports the claim that all states share both rights and responsibilities in safeguarding orbital space as a safe and sustainable commons. Hence, third, pursuant to Article III OST, the foundational principles of international environmental law – including the no-harm rule, the precautionary approach, and the duty of due diligence – further require proactive measures to prevent irreversible harm in LEO. Taken together, these principles provide a strong legal basis for negotiating a dedicated LEO implementation agreement.

⁹⁴⁹ See on the topic for example: Amilla Colombo, Peter Martinez, Francesca Letizia, Benedetta Cattani, Emmanuelle David, Diego Escobar, Satomi Kawamoto, Robert Rovetto, Ivan Sumelzo, 'Space capacity management and its interaction with space traffic management' (2025) 233 *Acta Astronautica* 223, 223.

⁹⁵⁰ Straddling Fish Stocks Agreement art. 5(c)–(e) and 6.

⁹⁵¹ This allows to translate debris dynamics and collision risk per LEO shell into numerical carrying-capacity limits, rather than remaining at the level of abstract "due regard".

⁹⁵² The central limit setting per LEO shell departs from the UNFSA fisheries model, where TACs are typically determined at the level of individual fish stocks within RFMOs for several reasons. Unlike fish stocks governed under UNFSA, LEO shells cannot be treated as ecologically or functionally independent management units. Fish stocks are biologically distinct and, in principle renewable, allowing total allowable catches to be determined at the stock level within RFMOs. By contrast, LEO shells are physically interconnected: debris generated in one shell can mitigate across altitudes, triggering cascading collision risks that undermine the integrity of the entire orbital environment. Moreover, orbital degradation in LEO may become difficult to reverse on human timescales once debris densities exceed critical thresholds, and scientific uncertainty regarding debris dynamics carries system-wide consequences.

4) To prevent a “derby system” following the establishment of shell-specific hard caps, a *shell-specific allocation mechanism* should be introduced in the form of tradable, time limited usage quotas. Shell-level coordination bodies (functionally analogous to RFMOs) could administer these quota systems by allocating defined usage shares to operators or entities, while permitting controlled trading among participants.⁹⁵³ Analogous to tradable emission allowances in climate governance, such a system could reduce incentives for speculative filings and “paper satellites” by tying access rights to clearly defined and transferable entitlements.⁹⁵⁴ Furthermore, limited authorizations, coupled with periodic review, would further prevent de facto appropriation of orbital slots and radio-frequency spectrum. This design reflects the dynamic nature of orbital space and allows for regular adjustments as technology evolves and scientific knowledge of debris dynamics and carrying capacity improves, consistent with the adaptive governance logic exemplified by the ITU’s periodic revision of the Radio Regulations. Such a mechanism would introduce flexibility and economic efficiency without undermining the underlying ecological capacity limits of each orbital shell.

5) Beyond the necessary political decisions taken within UNCOPUS, the technical tasks of allocation, coordination, and ongoing orbital management should be delegated to the ITU, building on its established expertise in orbital and radio-frequency spectrum coordination, notification procedures and compliance monitoring. In turn, regional space agencies, such as APSCO, the African Space Agency, ESA, and the Latin American and Caribbean Space Agency (ALCE) – should play a complementary role in implementing and administering allocations within their membership once global and shell-specific ceilings are established. By doing so, they could enhance the bargaining power of developing states, facilitating the pooling of technical and regulatory expertise, and enable more effective coordination of monitoring, compliance, awareness-raising and capacity-building efforts. This arrangement would further allow strict and enforceable bring-into-use requirements to be monitored more effectively,

⁹⁵³ In order to avoid the first-mover advantage, a new, mixed equitable distribution system may be set up within the quota system through, for example, equal per-capita rights (giving each state an entitlement proportional to population); grandfathering (allocation based on past launch records); capacity-based differentiation (granting developing states additional room or financial/technical assistance, etc).

⁹⁵⁴ Tradability would allow major spacefaring states to adjust efficiently while potentially enhancing the bargaining position of smaller states, including through coordinated participation via regional organizations. This model fundamentally departs from neo-extractivist logic: even where trading among shell quotas is permitted, access rights would be temporary and revocable, subject to renewal only upon ecological review.

ensuring that allocated capacity translates into genuine and responsible utilisation. The resulting subsidiarity-like set-up would mirror Ostrom's principle of nested, polycentric governance, in which multiple layers of authority coordinate to balance global limits with regional implementation and equitable participation.⁹⁵⁵

⁹⁵⁵ Although this structure may increase Coasean transaction costs relative to a centralised model, Ostrom's work demonstrates that polycentric governance systems outperform centralized systems in managing complex common-pool resources – such as LEO – by improving information flows, trust, monitoring, and long-term compliance. See for example: Eleonor Ostrom, *Governing the commons: The evolution of institutions for collective action* (Cambridge University Press 1990).

CHAPTER V. Conclusion

*“For any physical entity in a finite environment,
perpetual growth is impossible.
Ultimately the choice is not to grow forever
but to decide what limits to live within”.⁹⁵⁶*

Despite the well-established physical and regulatory limits of LEO discussed throughout this dissertation, current practice continues to move in the opposite direction: satellite deployment is expanding at an exponential pace, and with it the volume of orbital debris. The contradiction is striking. On the one hand, scientific modelling makes clear that LEO has a finite carrying capacity and the uncontrolled growth risks triggering cascading collisions; on the other hand, commercial and geopolitical pressures are driving ever larger LEO constellation projects, with limited regard for these systemic constraints. The result is a widening gap between what sustainability in LEO would require and the actual trajectory of human activity in space, underscoring both the urgency of developing a robust governance framework and the inadequacy of relying on voluntary, non-binding measures.

The governance challenge of the LEO environment is best understood as a systemic problem shaped by two interrelated system traps: the growth trap and the tragedy of the commons trap. The *growth trap* applied to LEO reflects the structural pressure on states and private operators to continuously expand satellite deployments in pursuit of economic, strategic, and technological advantage, even as cumulative risks intensify. *The tragedy of the commons*, in turn, arises because orbital space is accessible to all yet finite and congestible, encouraging actors to maximise individual use while externalising debris, collision, and congestion risks onto others and onto future generations. Importantly, system traps are not merely obstacles to be overcome; they also reveal leverage points for institutional change. By making the structural sources of overexploitation visible, they highlight where governance

⁹⁵⁶ Donella H Meadows, *Thinking in Systems – A Primer* (Chelsea Green Publishing, 2008) 103.

interventions – such as binding limits, redesigned incentives, and collective rule-making, can redirect behaviour toward sustainable outcomes.

While the adoption of the five core UN space treaties and the establishment of the ITU regime represented major achievements in the early decades of space exploration, they were designed for a context in which human presence in orbit remained limited. Today, however, the unprecedented rise of large LEO satellite constellations and the accelerating risk of debris proliferation present new governance challenges – challenges that cannot be addressed through reinterpretation of existing treaties or the continued reliance on non-binding, qualitative guidelines implemented at the national level.

Developments in international environmental law – most notably the climate regime and the management of high seas fisheries – demonstrate that even under conditions of scientific uncertainty, the international community has been able to define and operationalize functional thresholds, such as carbon budgets, temperature targets, and total allowable catches, to delimit humanity's "room for manoeuvre" within ecological threshold. Although the ITU successfully established a quantitative allocation system for the geostationary orbit and spectrum, no comparable limit-setting mechanism has yet been formally proposed for the management of LEO. This raises a critical question: why, despite mounting evidence of congestion and debris risk, has the international space community so far avoided even recommending a collective framework for defining and distributing LEO's carrying capacity?

To analyse the growing challenges in LEO, this dissertation applied an interdisciplinary Law and Economics approach, which is employed to analyse the persistent governance gap in LEO and to formulate *de lege ferenda* proposals addressing the growing challenges associated with its use. Under the *neoclassical, rational-choice* framework, for example, the first-come, first-served rule functions as an incentive structure that entrenches early-mover advantages. By allowing initial users to secure *de facto* priority access, it encourages technologically advanced states and their private operators to expand their large satellite constellations strategically, rather than to support collective sustainability and equitable access. Additionally, according to this view, complemented by insights from *old Institutional economics*, institutional inertia results in continued reliance on non-binding qualitative guidelines. The Coasean transaction costs of negotiating binding international limits – including scientific uncertainty, political bargaining, and institutional complexity – are perceived by many states to outweigh the short-term benefits of reform. As a result, actors continue to rely on voluntary compliance and self-enforced practices rather than pursuing binding, quantitative mechanisms capable of

constraining aggregate behaviour.⁹⁵⁷ *Behavioural economics* further illuminates the reluctance to engage in limit-setting: present bias favours the immediate commercial and strategic gains of rapid satellite deployment, while status quo bias reinforces the existing permissive freedom principle of international space law. Perceptions of fairness further complicate negotiations: developing states advocate more equitable access to LEO, whereas established space powers resist redistributive arrangements that might dilute their existing advantage, as illustrated by the limited acceptance of the Common Heritage of Mankind Principle in the Moon Agreement. Finally, from a geopolitical standpoint, major powers have little incentive to create binding limits in LEO, given that orbital infrastructure – especially broadband large LEO constellations – carries significant security and strategic value.

When comparing governance approaches for LEO and GEO, it is important to recognize that although the ITU regime has contributed to the long-term stability of the geostationary orbit, environmental protection of GEO has largely emerged as an incidental by-product of technical coordination, rather than as an explicit autonomous regulatory objective. The distinct physical characteristics of GEO – fixed orbital positions, high scientific certainty, and immediate operational feedback – enable operators to directly internalise the costs of inefficient use, interference, or collision risk. In contrast, the LEO environment is characterised by diffuse congestion, probabilistic collision dynamics, and delayed system-wide impacts. As a result, LEO operators can rationally increase launch rates and constellation sizes while externalising debris, congestion, and collision risks to other users and to future generations, weakening incentives for restraint under an efficiency-based coordination framework. Accordingly, rather than drawing primarily on GEO governance, this dissertation turns to climate governance and high seas fisheries governance as more instructive analogies for managing the delayed, cumulative, and externalised risks characteristic of the LEO environment. These regimes address common-pool resources characterised by high scientific uncertainty, delayed and potentially irreversible harm, free-riding incentives, and profound distributional conflicts between early movers and latecomers. Both climate and fisheries, with mixed success, have therefore developed institutional responses, such as precautionary limit-setting, aggregate caps, adaptive management, polycentric enforcement, structures, or tradable quotas. These

⁹⁵⁷ See: Elinor Ostrom, *Understanding Institutional Diversity* (Princeton University Press 2005) 63-64.

mechanisms appear to be better suited to managing complex, congestible, and fragile commons like LEO.

From a legal perspective this dissertation has sought to identify a normative position between Article I OST, which guarantees the freedom of exploitation and use of outer space – including the exploitation of its resources – and Article II OST, which prohibits unlawful appropriation. Drawing on the reasoning of De Man and Jakhu, it has been argued that international space law, in particular the common interest clause of Article I OST and the due regard principle under Article IX, requires that space activities be conducted in an *inclusive manner*. Where such activities effectively exclude others – whether late-comer states or, potentially future generations – they may amount to a violation of international space law. Following this logic, it can be argued that several contemporary space practices are already in tension with the common interest clause. These include the effective monopolization of certain LEO shells, slot warehousing (including the filing of “paper satellites”) and prolonged and repeated satellite operations. Taken together these practices systematically entrench early-mover advantages, and privilege technologically advanced states, thereby undermining the inclusive use of outer space envisaged by international space law. Given the fragile and highly complex nature of the Earth’s orbital environment, such as LEO, the obligation of *due regard* under Article IX OST operates in conjunction with the duty of *due diligence*. Where scientific uncertainty surrounds debris dynamics, exponential growth in satellite stocks, and LEO’s carrying capacity, the combined obligations of due diligence and due regard trigger the application of a precautionary approach aimed at preventing serious or irreversible harm. The problem, therefore, is not the absence of applicable legal principles, but their insufficient operationalisation. Read together, the precautionary principle and the obligations of due diligence and due regard justify, and in conditions of systemic risk, require, the adoption of *preventive limits on the freedom principle*, without waiting for exclusionary effects to crystallise or prolonged uses to mature into de jure appropriation.

To render Earth’s orbits – as well as the climate – truly sustainable, and to apply the precautionary principle in practice, however, a paradigm shift is necessary, both in mindset, and in economic method. This shift is supported by the ecological economics tradition, closely associated with old Institutional economics, which recognises that the first task of governance is to identify and respect manageable ecological limits. Within those limits, welfare-economic tools can then be used to organise allocation, manage trade-offs, and enhance efficiency. Indeed, ecological economics does not reject neoclassical economics outright; rather it reorders its application. In this sense, neoclassical economics helps to manage the existing environment,

while ecological economics defines the boundaries within which such management may legitimately occur. Applied in LEO, this logic points toward a hybrid governance model. At the system level, aggregate limits on collision and debris risks require s-frame mechanisms – global ceilings, robust monitoring, and burden-sharing arrangements that address the structure of incentives itself. At the operational level, quality-based standards, such as the LTS Guidelines, ISO norms, and IADC Guidelines, can be advanced, through i-frame techniques embedded in domestic licensing and compliance regimes. Together, these approaches allow global physical limits to be respected while preserving flexibility in implementation, balancing system coordination with operational adaptability.

In terms of implementation, translating the insights elaborated in this document, requires not a single institutional fix, but a carefully sequenced, polycentric governance architecture that aligns scientific knowledge, legal authority, and political incentives. At the international level, UNCOPUOS remains the most appropriate forum to anchor reform. Its universal membership, normative authority under the OST, and experience in developing sustainability-related soft law instruments make it the natural locus for initiating a shift from qualitative guidance toward binding quantitative governance. A dedicated interdisciplinary working group could be mandated to assess LEO's carrying capacity overall and per LEO shell, define precautionary thresholds, and elaborate governance options, with the drafting of an implementation treaty. Scientific uncertainty could be addressed through the establishment of an independent scientific advisory body, similar to the IPCC or ICES,⁹⁵⁸ tasked with modelling debris dynamics, collision risks, and shell-specific carrying capacities. Crucially, however, scientific assessments should not merely inform political deliberations within the UNCOPUOS Scientific and Technical Subcommittee, but be institutionally linked to legal decision-making, ensuring that precautionary limits are triggered by defined risk thresholds rather than postponed by political disagreement. Within this institutional framework, the ITU would retain a central operational role, but one that is clearly delimited. Rather than defining ecological limits, the ITU would implement allocation and coordination within ceilings established through

⁹⁵⁸ The IPCC (Intergovernmental Panel on Climate Change) informs governments and policymakers about the state of knowledge on climate change. The ICES (The International Council for the Exploration of the Sea) is a leading multidisciplinary scientific forum for the exchange of information and ideas on all aspects of marine sciences. See: IPCC <https://www.ipcc.ch> accessed 20 October 2025 and ICES <https://www.ices.dk/about-ICES/who-we-are/Pages/Who-we-are.aspx> accessed 20 October 2025.

UNCOPUOS-based processes, building on its established expertise in spectrum and orbital coordination and its practice of adaptive regulatory revision. Additionally, a shell-specific coordination arrangement, similar to RFMOs in fisheries governance, as part of a decentralised allocation mechanisms, would operate within the hard limits set by UNCOPUOS. These arrangements could administer time-limited usage rights or quotas to operators or entities, potentially allowing controlled trading, while preserving flexibility. Time-limited and reviewable rights would help prevent de facto appropriation, curb speculative filings and limit the entrenchment of first-mover advantages. Additionally, regional space agencies, such as ESA, APSO, the African Space Agency, and ALCE, would play a complementary role in administering allocations within their memberships once global and shell-specific ceilings are set, reflecting Ostrom's principle of polycentric governance.

Given political sensitivities surrounding binding reform, progress is most plausibly achievable through a stepwise legislative strategy. An initial step, the environmental dimension of the due regard obligation under Article IX OST, read in conjunction with Article III OST and the applicable principles of international environmental law governing areas beyond national jurisdiction, could be clarified through UNGA resolutions and authoritative interpretative practice, analogous to recent developments in the interpretative evolution of international climate law. This could be followed by the drafting and adoption of an implementation agreement under the OST – similar in function to the UN Fish Stock Agreement and the BBNJ Agreement – designed to operationalise precautionary limits, review mechanisms, and institutional responsibilities without reopening the Outer Space Treaty itself.

This dissertation has sought to provide a grounded and interdisciplinary account on how legal analysis, law-and-economic scholarship (including behavioural insights), and critical theoretical perspectives can inform the governance of the low Earth orbit as a complex and rapidly deteriorating global commons. The physical dynamics of LEO, including accelerating launch rates, cumulative debris, and the risk of cascading effects, mean that regulatory delay is not neutral: it actively entrenches first-mover advantages and locks in unsustainable patterns of use. As congestion intensifies, the space for legal and political choice narrows. The central challenges therefore no longer whether limitations on the freedom principle can be justified, but how they can be articulated, operationalised, and institutionalised in a manner that remains both legally legitimate and politically feasible. The decision question is whether the international community will seize the opportunity to act sustainably while meaningful choices remain, before exclusionary practices become entrenched and system-wide harm becomes unavoidable. How LEO is governed will thus serve as a critical test case for the capacity of

international law to address global commons problems characterised by planetary-scale risk and scientific uncertainty, before collapse rather than after it. As Cheney aptly warned, “the time to define the scope of the freedom of use is now”.⁹⁵⁹

⁹⁵⁹ Thomas Cheney, ‘Non-use of Space, Reconsidering Article I of the Outer Space Treaty and the Useability of Space Resources’, in Solène Guggisberg and Catherine Blanchard (eds.) *Non-use Measures for Global Goods and Commons in International Law* (Brill 2025) 428, 452.

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