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Article

Institutional dilemmas and legal responses in the green development of commercial space activities in China

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Abstract: The expansion of commercial space activities in China has heightened environmental risks from launch emissions, space debris, orbital collisions, and atmospheric reentry. International space law sets out principles of environmental protection and State responsibility, but their implementation depends on more specific domestic rules. China's current regulatory framework for space activities has introduced preliminary rules on registering space objects, licensing civil space launches, mitigating and protecting against space debris, and administering satellite projects. However, the framework lacks a dedicated national law governing space activities and relies largely on ministerial rules and other normative documents. Provisions addressing commercial operations and environmental protection remain fragmented, and the responsibility and liability regime is underdeveloped. To meet the practical demands of green development in the commercial space sector, China should enact dedicated space legislation to establish a basic framework for green development, implement environmental requirements through life-cycle regulation and a coherent system of standards, strengthen the environmental obligations and risk accountability of commercial space actors through a clear responsibility and liability regime, and advance governance of the outer space environment through international coordination and multifaceted cooperation. Through these measures, China can better reconcile the high-quality development of commercial space activities with the protection of the terrestrial and outer space environments and the long-term sustainable use of outer space.

Keywords: commercial space activities; green development; protection of the outer space environment; space debris; legal safeguards; China

1. Introduction

In recent years, growing market demand and increased capital investment have created significant opportunities for the rapid development of China's commercial space industry, which has increasingly been prioritized as a strategic emerging industry in the country's national development agenda. The 2024 "Government Work Report" expressly identified commercial spaceflight as a "new growth engine" for the first time. Beijing, Shanghai, and other localities subsequently introduced dedicated action plans for the commercial space sector. In 2025, the China National Space Administration issued the "China National Space Administration Action Plan for Promoting the High-Quality and Safe Development of Commercial Space (2025–2027)" (China National Space Administration, 2025a), marking a significant advance in the development of China's commercial space industry. As an important component of the strategic emerging industries, the commercial space sector constitutes a vital vehicle for fostering new quality productive forces in the space domain.

The Fifth Plenary Session of the Eighteenth Central Committee of the Communist Party of China incorporated "green development" into China's framework of new development concepts, emphasizing the need to coordinate economic development with ecological and environmental protection throughout the process of modernization. At the eleventh group study session of the Political Bureau of the 20th CPC Central Committee, Xi Jinping further emphasized that "green development is the defining feature of high-quality development, and new quality productive forces are green in nature" (Xi, 2024). Accordingly, the cultivation of new quality productive forces cannot be divorced from the orientation towards green development. It should facilitate the transformation of development models towards greener and lower-carbon pathways.

Green development is an essential requirement for new quality productive forces. In terms of their underlying dynamics, new quality productive forces and green development do not have a unidirectional relationship of promotion. Rather, they form a mutually causal, interdependent, and dynamically reinforcing relationship (Chen & Wan, 2025). On the one hand, by relying on the development of new technologies, new energy sources, and emerging industries, new quality productive forces provide continuous support and impetus for green development. On the other hand, the objectives of resource conservation, environmental protection, and low-carbon transformation embodied in green development establish the normative direction and practical guidance for the development of new quality productive forces (Du & Ye, 2024).

The development of the commercial space industry should therefore not be assessed solely by the number of launches, the scale of satellite constellations, or the level of capital-market activity. It must instead be examined within a framework that aligns high-quality development with green development. In other words, while the commercial space industry should serve as an important force for fostering new drivers of growth and creating new competitive advantages, it must also comply with the fundamental requirements of resource conservation, environmental protection, low-carbon development, and sustainable use. Only in this way can industrial development and environmental sustainability be pursued in a coordinated and mutually reinforcing manner.

At the international-law level, the existing corpus of outer space law sets out general principles in three areas: protection of the space environment, the common interests of humankind, and State responsibility. First, with respect to protection of the space environment, existing outer space law sets out general requirements governing States' exploration and use of outer space. Article IX of the Outer Space Treaty requires States Parties to conduct the exploration and use of outer space, including the Moon and other celestial bodies, in accordance with the principles of cooperation and mutual assistance and with due regard to the corresponding interests of all other States Parties. (United Nations, 1967, Article IX). It further requires States to pursue studies of outer space and conduct their exploration so as to avoid the harmful contamination of outer space and celestial bodies, as well as adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter. Article 7(1) of the Moon Agreement similarly requires States Parties to take measures to prevent disruption of the existing balance of the lunar

environment, whether through adverse alterations to that environment, its harmful contamination by the introduction of foreign matter, or by any other means (United Nations, 1979, Article 7(1)). It also requires States Parties to prevent the harmful alteration of the Earth's environment through the introduction of extraterrestrial matter or otherwise.

Second, under the principle of the common interests of humankind, the existing outer space treaty regime places the exploration and use of outer space, the Moon, and their natural resources within a framework directed towards the interests of all humankind. At the same time, it incorporates an intergenerational dimension by requiring consideration of the interests and needs of both present and future generations (United Nations, 1967; United Nations, 1979).

Third, in relation to State responsibility, Article VI of the Outer Space Treaty expressly establishes the international responsibility of States for national activities in outer space and their obligation to exercise continuing supervision over such activities. In addition, the United Nations Committee on the Peaceful Uses of Outer Space has defined the "long-term sustainability of outer space activities" as the ability to conduct space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the peaceful exploration and use of outer space, meets the needs of present generations, and preserves the outer space environment for future generations (United Nations Office for Outer Space Affairs [UNOOSA], n.d.).

In the field of space-debris governance, the international community has primarily relied on normative instruments such as the IADC Space Debris Mitigation Guidelines (Inter-Agency Space Debris Coordination Committee [IADC], 2021a) and the Space Debris Mitigation Guidelines of the UN Committee on the Peaceful Uses of Outer Space (United Nations, 2007). These instruments have progressively established standards of conduct for limiting debris released during normal operations, minimizing the risks of on-orbit breakups and collisions, and implementing post-mission disposal measures. International law has therefore already established general requirements for the protection of the space environment. As an important component of space activities, commercial space activities must likewise be subject to those requirements. For these principles to operate effectively in commercial space practice, however, they must be further translated into specific rules of domestic law capable of ensuring their effective implementation.

Nevertheless, commercial space activities differ from traditional space programmes, which are predominantly State-led and centred on technological breakthroughs and the accomplishment of strategic missions (Sheng et al., 2025). These differences are also reflected in financing structures, operational models, and the range of participating actors. As the commercial space sector continues to develop towards lower costs, greater diversification, and large-scale operations (Qu, 2020), it has contributed to higher launch frequencies, the dense deployment of satellites in low Earth orbit, and an increase in re-entry activities. These developments have, in turn, raised green-development concerns, including the growing generation of space debris, launch-related emissions and their potential effects on atmospheric chemistry and stratospheric ozone, and the deposition of

aluminium and other metallic particles in the upper atmosphere during spacecraft re-entry.

In addressing these challenges, the green development of commercial space activities cannot rely solely on policy guidance, industry self-regulation, and technological improvements; it must also be underpinned by the rule of law. The role of law is not limited to affirming the normative objectives of green development. It must also regulate commercial space activities through specific institutional mechanisms, including market access requirements, licensing review, operational oversight, and the attribution and enforcement of legal responsibility. China's existing regulatory framework has begun to respond to these concerns. However, viewed as a whole, it remains characterized by the relatively low hierarchical status of the applicable rules, the fragmentation of regulatory norms, insufficient incorporation of green-development requirements, and inadequate coordination among different components of the regulatory system.

Existing scholarship relevant to this study has developed along several interrelated yet largely distinct strands. First, legal scholarship on commercial space activities has examined how national legal frameworks respond to the growing commercialization of space activities and the diversification of participating actors, with particular attention to legislative models, licensing and market access, registration, liability and indemnification, insurance, safety, ongoing governmental supervision, and enforcement mechanisms (Bo, 2012; Dempsey, 2016; Su, 2021). This body of research has mainly focused on establishing the basic institutional framework necessary for the orderly development of commercial space activities.

A second strand of scholarship has examined the environmental protection and long-term sustainability of outer space activities. One line of research has explored the application of environmental impact assessment and principles of international environmental law to space activities (Viikari, 2004; Dalledonne, 2021). Related scholarship further developed the concept of space sustainability by emphasizing the need to integrate environmental protection into present space activities without compromising the viability of future missions (Newman & Williamson, 2018). Yan (2019) further framed the long-term sustainability of outer space activities as an extension of sustainable development into the space domain, identifying intragenerational equity, sustainable use, intergenerational equity, integration, and peaceful purposes as its principal legal elements. A further body of scholarship has focused on the regulatory dimensions of space sustainability, including the implementation of the Guidelines for the Long-term Sustainability of Outer Space Activities (LTS Guidelines), compliance with non-binding standards, and their incorporation into national legal and regulatory frameworks (Yan, 2019; Martinez, 2019; Long & Li, 2023), as well as the legal and institutional challenges associated with space-debris mitigation and space traffic management (Feng, 2014; Yan, 2019; Bartóki-Gönczy et al., 2024). This literature has clarified important dimensions of space sustainability, but has tended to address them either at a general level or through discrete regulatory issues such as space debris, orbital safety, and space traffic management.

Third, within Chinese scholarship, an emerging body of research has examined the relationship between new quality productive forces and green development.

Existing studies have emphasized the inherently green attributes of new quality productive forces, the leading role of green technological innovation, the combined economic and environmental benefits of green industries, and development pathways that include green technology, energy conservation, emissions reduction, and renewable energy (Jiang & Qiao, 2024; Han et al., 2024). While this literature provides a conceptual basis for understanding green development as an integral dimension of emerging industries, it has not yet been systematically linked to the distinctive technological, environmental, and regulatory characteristics of commercial space activities.

Taken together, these strands of scholarship provide important foundations for understanding the legal regulation, environmental sustainability, and green-development dimensions of contemporary space activities. However, they have largely developed along parallel rather than integrated lines. Limited attention has been devoted to an integrated legal framework that links terrestrial environmental protection with outer-space sustainability across the full life cycle of commercial space activities, particularly in the context of China's rapidly evolving commercial space sector.

Against this background, this article examines the green development of commercial space activities in China from a rule-of-law perspective. It first identifies the principal ecological and environmental risks that are intensified by the expansion of commercial space activities. It then assesses the extent to which China's existing regulatory framework addresses those risks and identifies the principal institutional deficiencies that remain. On this basis, the article proposes a set of rule-of-law responses to incorporate green-development requirements into the legal governance of commercial space activities throughout their life cycle.

2. Environmental and operational risks associated with commercial space activities

Over the past six years, the number of commercial spaceflights and satellite launches has exceeded the total recorded during the preceding sixty years (United Nations Environment Programme [UNEP] & United Nations Office for Outer Space Affairs [UNOOSA], 2025). The European Space Agency's Space Environment Report 2025 documents the continued growth in the number and scale of satellite constellations in low Earth orbit. Driven by frequent launches, mass production, and rising private-sector investment, commercial space activities have spurred technological innovation and broadened the range of space-based services. At the same time, this rapid expansion has intensified environmental pressures, including launch emissions, space debris, collision risks, radio-frequency interference, energy-intensive manufacturing, and light pollution.

2.1. Risks arising from launch emissions

Rocket launches are one of the most visible contributors to space exploration's environmental impact. The immense energy required to propel spacecraft into orbit generates significant emissions (Olawade et al., 2025). As commercial space activities develop rapidly, the number of spacecraft launches worldwide continues to

increase. Emissions from rocket launches and spacecraft in the stratosphere, along with particulate matter generated during atmospheric reentry, are emerging as atmospheric environmental risks that cannot be ignored. These emissions not only contribute to air pollution but may also alter atmospheric chemical processes, with particularly adverse effects on the stratospheric ozone layer. (Ryan et al., 2022; Ferreira et al., 2024). They may consequently pose further risks to climatic processes and astronomical observations. Moreover, the atmospheric re-entry of spacecraft, including satellites, may release aluminium, lithium, copper, and other metals, compounds, and elements into the atmosphere (Murphy et al., 2023; NOAA Chemical Sciences Laboratory, 2023).

2.2. Risks arising from the rapid proliferation of space debris

Space debris is a by-product of human activities involving the exploration, development, and use of outer space. In the context of commercial space activities, the growing frequency of space operations has accelerated the rate at which space debris is generated and expanded the overall scale of the debris population (European Space Agency Space Debris Office, 2025). In particular, the rapid development of mega-constellations of small satellites has substantially increased the number of satellite deployments, replacements, failures, and post-mission disposal operations. These developments may result in the large-scale generation of space debris, thereby impeding the orderly conduct of space activities (IADC, 2021b). The growth of space debris produces significant cumulative and mutually reinforcing effects. As the debris population increases, the probability of collisions rises and the operational lifetimes of spacecraft may be shortened. Additional launches undertaken to replace damaged or non-operational spacecraft may, in turn, generate further debris and pollution. (UNEP & UNOOSA, 2025). This problem is particularly acute in the context of the rapid expansion of mega-constellations in low Earth orbit. As the density of space objects in orbital regions continues to increase, the risks posed by space debris and orbital collisions increasingly overlap and compound one another. Consequently, the safe operation of spacecraft in orbit remains under continuing threat, while the stability and orderly use of the outer space environment are seriously affected (Gong et al., 2024).

The hazards posed by space debris are not limited to the possibility that debris may re-enter the Earth's atmosphere and cause damage on the surface. Space debris also creates a continuing risk of collision with spacecraft, satellites, space stations, and other space objects in orbit. As the quantity of space debris continues to increase, so too does the risk of collisions both among debris objects and between debris and operational spacecraft. Such collisions may, in turn, generate additional smaller debris fragments, thereby producing a cascading growth effect. Even if no additional debris were introduced in the future, collisions among existing debris objects could continue to generate new fragments and further increase the overall orbital debris population.

Space debris therefore threatens not only the safe conduct of present-day outer space activities but also the long-term usability of low Earth orbit and geostationary orbit. It may consequently diminish the opportunities available to future generations

to explore, develop, and use outer space on an equitable basis. Although compliance with space-debris mitigation standards in the commercial space sector has improved in recent years, it remains insufficient to prevent continued growth in both the number and aggregate volume of debris objects (European Space Agency Space Debris Office, 2025). The governance of space debris therefore remains a pressing issue that must be addressed more effectively in order to advance the green development of commercial space activities.

2.3. Risks of collisions between space objects

As the number of actors engaged in outer space activities and the volume of such activities continue to increase, As the number of actors engaged in outer space activities and the volume of such activities continue to increase, the rapid deployment of mega-constellations in low Earth orbit and the growing congestion of orbital space have significantly heightened the risk of collisions among space objects. The rapid deployment of mega-constellations in low Earth orbit and the growing congestion of orbital space have significantly heightened the risk of collisions between space objects. This problem is particularly acute in low Earth orbit, where the density of space objects continues to rise and recurrent collision threats render collision-avoidance manoeuvres unavoidable in certain orbital regions (European Space Agency Space Debris Office, 2025). The risk of collisions between space objects therefore constitutes not merely a matter of operational safety but also an issue closely connected with the outer space environment, the utilization of outer space resources, and the long-term sustainability of outer space activities (Long, 2018).

The risks associated with collisions between space objects have pronounced cascading and compounding effects. According to the European Space Agency's Space Debris Office, nearly 130 million pieces of orbital debris generated by fragmentation events—including explosions and collisions—abandoned spacecraft, satellites, and rocket upper stages, mission-related operational debris, and deliberate destructive activities such as anti-satellite weapon tests pose an increasingly serious threat to space activities. At the same time, the large-scale deployment of mega-constellations further magnifies these risks. Once such constellations are deployed, the number of space objects increases sharply, the probability of orbital collisions rises substantially, and competition for orbital positions and radio-frequency spectrum resources intensifies.

Against this background, the risks posed by space debris and orbital collisions are closely intertwined. Their interaction continually exposes operational spacecraft to impact risk and seriously disrupts the orderly conduct of outer space activities. Moreover, an increased risk of collision may not only cause the direct destruction of spacecraft and the failure of space missions but may also generate additional space debris, shorten the operational lifetimes of spacecraft, and necessitate further replacement launches, thereby creating additional sources of pollution. Existing studies estimate that annual losses attributable to collisions amount to approximately US$86 million to US$103 million, further underscoring the urgency of adopting effective mitigation measures and strengthening space traffic coordination (UNEP &

UNOOSA, 2025). The risk of collisions between space objects is therefore not merely a conventional operational-safety concern; it also constitutes a significant ecological and environmental risk that urgently requires effective legal regulation.

2.4. Risks arising from disruption of the radio-frequency environment

The rapid deployment of large commercial satellite constellations may also disrupt the radio-frequency environment. The radio-frequency spectrum constitutes an indispensable resource for satellite communications, navigation, Earth observation, and scientific research. Article 44 of the Constitution of the International Telecommunication Union (ITU) recognizes radio frequencies and associated satellite orbits as limited natural resources that must be used rationally, efficiently, and economically (International Telecommunication Union [ITU], 2023, art. 44). As commercial satellite constellations expand in number and scale, the increasing density of satellite transmissions may intensify aggregate radio-frequency interference arising not only from intended communications signals but also from out-of-band and spurious emissions and unintended electromagnetic radiation generated by onboard electronic systems. Unlike many terrestrial sources of radio-frequency interference, satellites traverse extensive geographical areas, thereby limiting the effectiveness of geographic separation and terrestrial radio-quiet zones as protective measures.

Radio astronomy is particularly vulnerable to such interference because astronomical radio signals received on Earth are extremely weak in comparison with anthropogenic radio emissions. Recommendation ITU-R RA.769 establishes protection criteria and threshold levels for interference detrimental to radio astronomical observations (ITU, 2003). Empirical observations using the Low Frequency Array (LOFAR) have detected unintended electromagnetic radiation from Starlink satellites at frequencies between 110 and 188 MHz, well below their assigned transmission frequencies of 10.7–12.7 GHz (Di Vruno et al., 2023). Subsequent observations of second-generation Starlink satellites found substantially stronger unintended electromagnetic radiation, with measured emission levels exceeding the numerical protection thresholds recommended in ITU-R RA.769-2 for the 150.05–153 MHz frequency band allocated to radio astronomy (Bassa et al., 2024). These findings demonstrate that the radio-frequency risks associated with large constellations are not confined to interference caused by authorized communications transmissions, but may also arise from unintended emissions and their cumulative effects.

From the perspective of green development, disruption of the radio-frequency environment should be understood as part of the broader environmental and sustainability implications of large-scale commercial space activities. As satellite populations continue to grow, cumulative radio-frequency interference may impair the “quiet sky” required for astronomical observation and diminish the scientific utility of portions of the radio-frequency environment. The preservation of a usable radio-frequency environment should therefore be considered alongside physical forms of environmental harm, such as launch emissions, space debris, and orbital

congestion, when assessing the environmental risks associated with the expansion of commercial space activities.

2.5. Other ecological risks

In addition to launch emissions, space debris, and collisions between space objects, commercial space activities may pose other ecological risks, including light pollution and the degradation of the outer space environment.

First, as the number of satellite constellations in low Earth orbit, orbital debris objects, and associated particulate matter increases, their effects on the night-sky environment are becoming increasingly apparent. Satellites and debris reflect sunlight, producing large numbers of rapidly moving points of light across the sky. Satellite flares and brightness variations further increase fluctuations in night-sky luminance, alter the natural appearance of the night sky worldwide, and interfere with ground-based astronomical observations (International Astronomical Union [IAU], 2022; Barentine et al., 2023). As commercial space activities expand, the night sky should no longer be viewed solely as a natural landscape or scientific resource; its protection should increasingly be treated as a distinct regulatory concern within broader frameworks of environmental protection and the public interest.

Second, the development of commercial space activities may further exacerbate conventional forms of pollution of the outer space environment. As the frequency of commercial space operations continues to increase, however, the scope of what constitutes pollution of the outer space environment is also expanding. In the absence of science-based and coherent regulation, the growing frequency of outer space activities will cause the associated pollution risks to accumulate further, thereby diminishing humankind's capacity to continue exploring, developing, and using outer space.

In summary, the ecological risks associated with the green development of commercial space activities encompass not only conventional risks, such as direct emissions and space debris, but also damage to the night-sky environment, disruption of the radio-frequency environment, and the broader degradation of the outer space environment. These risks are both long-term and cumulative. They affect not only the safe conduct of contemporary space activities but also the ability of future generations to use outer space sustainably. Accordingly, any discussion of the green development of commercial space activities must incorporate these additional ecological risks into the framework of legal regulation.

3. China's regulatory framework and its limitations

3.1. The existing legal and regulatory framework

China's existing framework for the environmental regulation of commercial space activities comprises norms at both the international and domestic levels. At the international level, a framework of general principles has developed around the foundational outer space treaties, liability rules, the registration regime, and space-debris mitigation guidelines. At the domestic level, commercial space activities are subject to a preliminary regulatory framework comprising rules governing the

registration of space objects, the licensing of civil space launches, space-debris mitigation and protection, satellite-project management, and the general legal regime for ecological and environmental protection.

3.1.1 Relevant provisions of international law

At the international level, the five principal United Nations treaties on outer space constitute the institutional foundations of contemporary space law. As a State Party, China is bound by the international conventions to which it has acceded. Within this treaty framework, provisions on the protection of the space environment are expressed primarily in general, broadly formulated terms, most notably in Article IX of the Outer Space Treaty and Article 7 of the Moon Agreement. Article IX of the Outer Space Treaty establishes a general principle of environmental protection in outer space by requiring States, when conducting outer space activities, to exercise due regard for the corresponding interests of other States. Article 7 of the Moon Agreement imposes obligations concerning the protection of the lunar environment, including the prevention of disruption to its existing environmental balance and the prevention of harmful effects on the Earth's environment. The indeterminacy of certain provisions of the Moon Agreement, together with its limited number of States Parties, has constrained the Agreement's practical normative reach, although its provisions continue to carry interpretative and normative significance. The international liability regime applicable to environmental damage arising from space activities is principally derived from Articles VI and VII of the Outer Space Treaty and further elaborated in the Liability Convention. Article VI of the Outer Space Treaty establishes the principle of State responsibility in space law, under which each State Party bears international responsibility for its national activities in outer space, including the Moon and other celestial bodies, irrespective of whether those activities are conducted by governmental agencies or non-governmental entities. Article VII further establishes the principle of liability by requiring a launching State to bear liability for damage caused by its space objects. Articles II and Ⅲ of the Liability Convention further elaborate this principle by establishing a distinctive regime of State liability for damage caused by space objects. In the context of environmental protection, the concept of "damage" under the Liability Convention has frequently been interpreted as capable of encompassing environmental harm. This interpretation received further support from the practice of the Soviet Union and Canada in resolving the claims arising from the re-entry of Cosmos 954 (Li, 2006). Nevertheless, the relevant treaty provisions remain broadly formulated and lack sufficient specificity, thereby limiting their practical applicability to environmental damage caused by contemporary commercial space activities (Hou, 2011).

With respect to the protection of the outer space environment, the identification of the responsible State presents distinctive difficulties arising from the particular characteristics of outer space activities. As private capital has entered the space sector and commercial space activities have expanded, an increasing proportion of such activities is conducted by enterprises and other non-governmental entities. The identification of the State responsible for those activities has therefore assumed considerable importance (Liu, 2019). The question of which State should bear

responsibility for the activities of a non-governmental entity has long remained a focus of debate within the international community.

A widely adopted approach is to identify the relevant State by reference to the territoriality and nationality principles of public international law (Freeland, 2012, p. 21). Under this approach, a State exercises jurisdiction over activities conducted within its territory and over activities conducted abroad by its nationals, including both natural and legal persons, and bears the corresponding responsibility. In international practice, the domestic space legislation of many States adopts a similar approach by extending regulatory authority both to space activities conducted within national territory and to activities conducted abroad by their nationals or legal persons. This institutional arrangement is particularly significant for commercial space activities because it ensures that the relevant State remains subject to the obligations of authorization and continuing supervision and continues to bear international responsibility for the activities concerned.

In addition to legally binding treaties governing outer space, the international community has further regulated the protection of the outer space environment through soft-law instruments and technical guidelines. In this context, soft-law instruments are normatively framed but non-legally binding. Although they do not create binding legal obligations, they can clarify and operationalize treaty principles, promote common standards of responsible conduct, guide national implementation, and contribute to the gradual development of international norms (Boyle, 2019; Tapio & Soucek, 2019; United Nations, 2019). The Guidelines for the Long-Term Sustainability of Outer Space Activities and the Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space therefore perform an important normative and guiding function. The Space Debris Mitigation Guidelines were endorsed in December 2007 and advocate measures to preserve the outer space environment from the present onward, reflecting a normative approach based on proactive limitation and self-restraint (Xiong, 2020). The Guidelines for the Long-Term Sustainability of Outer Space Activities, adopted in 2019, give more specific and operational effect to the principles embodied in the existing outer space treaties (Yin & Yan, 2016). Their definition of the long-term sustainability of outer space activities reflects the principles of intragenerational and intergenerational equity recognized in environmental law. The preamble defines long-term sustainability as the ability to conduct space activities indefinitely into the future in a manner that realizes the objectives of equitable access to the benefits of the exploration and use of outer space for peaceful purposes, meets the needs of the present generation, and preserves the outer space environment for future generations.

Moreover, the Guidelines apply throughout the entire life cycle of space activities. Their scope encompasses all planned and ongoing space activities and extends to every stage of a mission, including launch, operation, and end-of-life disposal. Although the Guidelines expressly provide for voluntary implementation by States within the existing framework of international law and create no new obligations under international law, they nevertheless supplement and elaborate upon treaty-based rules by providing guidance on how existing principles may be understood and implemented in practice, particularly through their incorporation into domestic legal and regulatory frameworks. In doing so, they encourage States to

translate the requirements of outer space environmental protection into more specific provisions of domestic law.

3.1.2 Relevant provisions of chinese domestic law

According to the activities they regulate, China's space legislation may be divided into two categories: military space legislation and civil space legislation. This article focuses primarily on the latter. China has not yet enacted a comprehensive law specifically governing civil space activities. The existing regulatory framework is composed principally of ministerial regulations and other normative documents, none of which is devoted specifically to commercial space activities. Certain technical standards and policy documents also form part of the existing regulatory framework.

The Measures for the Administration of Registration of Space Objects, issued in 2001, and the Interim Measures for the Administration of Licences for Civil Space Launch Projects, issued in 2002, established the preliminary institutional framework for the regulation of China's space activities.

China acceded to the Registration Convention on 12 December 1988. To fulfil its obligations as a State Party to the Convention and safeguard its legitimate rights and interests as a launching State, China promulgated the Measures for the Administration of Registration of Space Objects. As China's first domestic normative instrument concerning civil space activities, the Measures established a preliminary regulatory framework for the registration of space objects. Nevertheless, they remain subject to certain limitations. For example, they neither establish a procedure for amending registration information following a transfer of rights in a space object nor specify the legal consequences of failing to comply with the registration obligation (Su, 2021). In the context of commercial space activities, the significance of the registration regime extends beyond the formal fulfilment of registration obligations. Registration also provides information necessary for identifying space objects, tracking their orbital status, assessing collision risks, managing their re-entry or return, and determining responsibility and liability.

On 21 November 2002, the former Commission of Science, Technology and Industry for National Defence promulgated the Interim Measures for the Administration of Licences for Civil Space Launch Projects, marking China's initial transition towards the standardized regulation of civil space-launch activities. From the perspective of green development, the Measures already incorporate a preliminary environmental-protection requirement: an applicant must submit documentation demonstrating that the proposed project complies with national laws and regulations concerning environmental protection (Commission of Science, Technology and Industry for National Defense [COSTIND], 2002, art. 6(2)).

With the development of commercial space activities, China's civil space-launch licensing and space-object registration regimes have been supplemented by subsequent normative documents. For example, the materials submitted in support of a licence application must include a copy of a valid third-party liability insurance policy, a copy of the relevant space-station radio licence, a space-debris mitigation plan, and a survey report concerning the designated impact area or recovery site. In addition, where the status of a satellite or spacecraft undergoes a material change, an

amendment to its registration must be filed with the State Administration of Science, Technology and Industry for National Defence (State Administration of Science, Technology and Industry for National Defense [SASTIND], 2023, arts. 1, 6 – 7).

China regulates space-debris governance primarily through normative documents, technical standards, and policy instruments. The Interim Measures for the Administration of Space Debris Mitigation, issued in 2009, established, for the first time, requirements for the management and control of space debris during the spacecraft development phase. In 2017, China adopted a national standard on space-debris mitigation requirements, which prescribes general mitigation requirements for uncrewed space-system flight objects entering or traversing near-Earth space. Furthermore, the Notice on Promoting the Orderly Development of Small Satellites and Strengthening Safety Management, issued in 2021, requires that a space-debris mitigation plan be prepared before an application is submitted for a civil space-launch project license and before the relevant specialized review is conducted. Competent State authorities are required, within their respective areas of responsibility, to provide collision-warning services for small satellites in orbit, conduct safety reviews of collision-avoidance strategies, and perform collision-risk assessments. Where the owner of a small satellite identifies a risk of an on-orbit collision, it must take proactive measures to avoid the collision.

In recent years, China has begun treating commercial space activities as a distinct regulatory field. The 2025 Notice of the China National Space Administration on Strengthening Quality Supervision and Administration of Commercial Space Projects requires quality supervision and administration throughout the life cycle of commercial space projects, including research and development, production, testing, launch, operation, service provision, recovery, and end-of-life disposal. This life-cycle regulatory approach should likewise apply to environmental protection. The Notice further identifies the improvement of the industrial ecosystem as one of the principles governing the supervision and administration of commercial space projects (China National Space Administration [CNSA], 2025b, sec. I(1), (3)).

Moreover, the 2026 Commercial Space Standards System (Version 1.0), jointly released by the China National Space Administration (CNSA) and the State Administration for Market Regulation (SAMR) in April 2026, further demonstrates that China's regulatory framework for commercial space activities is becoming more standardized and systematic. Within its industry-governance standards, the Standards System establishes separate branches for "space environmental governance" and "energy conservation, emissions reduction, and environmental protection". The former encompasses space-debris mitigation and protection and space-debris warning, while the latter covers the conservation of energy and resources, green manufacturing, emissions of toxic and hazardous pollutants, hazardous-waste disposal, emergency response, and assessment (CNSA & State Administration for Market Regulation [SAMR], 2026). Although the Standards System does not itself impose legally binding obligations, it incorporates both protection of the outer space environment and broader green-development concerns into a unified standards framework for commercial space activities.

3.2. Regulatory deficiencies in the green development of China's commercial space activities

As discussed above, international and domestic law have laid a preliminary institutional foundation for the green development of commercial space activities. At the international level, the Outer Space Treaty, the Liability Convention, the Registration Convention, and the Guidelines for the Long-Term Sustainability of Outer Space Activities collectively establish a general normative framework for protecting the outer space environment and promoting the long-term sustainability of outer space activities. China's domestic space regulatory framework has responded, to a certain extent, to the development of commercial space activities through rules governing the registration of space objects, the licensing of civil space-launch projects, space-debris mitigation and protection, satellite-project management, and other related matters. Nevertheless, when assessed against the practical requirements of the green development of commercial space activities, a disparity remains between China's policy documents, which actively encourage the development of the commercial space sector, and its existing legal framework, which continues to exhibit a number of regulatory deficiencies.

At the international-law level, the protection afforded to the outer space environment under existing international treaties is framed primarily in general and overarching terms and must therefore be translated into specific regulatory provisions of domestic law. To date, China has adopted domestic implementing measures only in relation to the Registration Convention, pursuant to which it promulgated the Measures for the Administration of Registration of Space Objects. No corresponding domestic implementing legislation has yet been enacted for the other outer space treaties (Su, 2021). The Outer Space Treaty establishes the principle of State responsibility, under which each State Party bears international responsibility for its national activities in outer space and the consequences arising therefrom, irrespective of whether those activities are conducted by governmental agencies or non-governmental entities. The attendant and related obligations derived from this principle include the authorization and continuing supervision by the State of outer space activities conducted by its non-governmental entities, as well as obligations concerning the registration of space objects, protection of the outer space environment, liability for damage, the determination of responsibility and liability, and the exercise of rights of recourse. In the context of commercial space activities, where the range of participating actors has become increasingly diverse, it is all the more necessary for the State to establish authorization and regulatory mechanisms through domestic law. Otherwise, the general obligations imposed by international law cannot be effectively implemented within the domestic legal system, resulting in inadequate coordination between China's international obligations and its domestic regulation of the green development of commercial space activities.

From the perspective of domestic law, the principal deficiencies are as follows.

First, in terms of the hierarchy of legal norms, China has not yet enacted a comprehensive national space law, while legislation governing civil space activities remains limited in number and generally of low normative rank. The existing regulatory framework consists primarily of ministerial regulations and other

normative documents, rather than higher-level legislation. It is likewise necessary in the space sector to enact a comprehensive basic space law establishing general principles governing major aspects of space activities, including the principle of environmental protection. Such legislation should be supplemented by a comprehensive body of implementing regulations, administrative rules, and technical standards, thereby creating a coherent space-law system characterized by a clear normative hierarchy and orderly institutional coordination (Gao, 2011).

Second, in substantive terms, China's space legislation contains few provisions specifically addressing commercial space activities and green development, resulting in legislative delay and regulatory gaps. On the one hand, the rules governing commercial space activities remain limited in scope. China's current regulatory framework for the space sector consists primarily of ministerial regulations and lacks laws or administrative regulations specifically governing commercial space activities. Instruments such as the Measures for the Administration of Registration of Space Objects and the Interim Measures for the Administration of Licences for Civil Space Launch Projects are relatively concise and were not formulated to promote the commercialization and privatization of space activities (Bo, 2012). Subsequently, Article 42 of the Interim Measures for the Administration of Civil Satellite Projects provided that "commercial satellite projects shall, in principle, be governed by reference to these Measures". This provision marked the first appearance of the term "commercial space activities" in a Chinese normative legal document (Feng, 2017).

Overall, China's existing rules remain limited in regulating commercial satellite-launch services, liability for damage caused by space objects, and the protection of the outer space environment. They are therefore insufficient to meet the practical regulatory needs generated by the ongoing technological innovation and space activities in China. By comparison, other States have promoted the development of the commercial space sector through legislation and enhanced policy support. The United States, for example, has adopted the National Space Policy and enacted legislation such as the U.S. Commercial Space Launch Competitiveness Act to provide institutional support for commercial space activities. On the other hand, the regulation of green development remains largely confined to statements of principle and lacks specific, operational requirements. The environmental risks associated with commercial space activities may arise throughout the entire life cycle of a space project. The relevant provisions, however, remain fragmented and have not yet been developed into enforceable regulatory standards capable of addressing the risks confronting the green development of commercial space activities.

Third, the inadequacy of the existing responsibility and liability regime constitutes another significant regulatory obstacle to the green development of China's commercial space sector. Environmental damage in outer space possesses distinctive characteristics in terms of the interests affected, the actors causing the harm, and the identification and assessment of damage, and therefore differs from the ordinary forms of injury addressed by traditional regimes of international responsibility and liability. The distinctive features and complexity of damage arising from pollution of the outer space environment—including the constituent elements of liability, the identification of responsible actors, and the applicable bases

of liability —also create substantial challenges for the establishment of principles of responsibility for environmental protection in outer space and for the design of corresponding institutional mechanisms (Hou, 2011). At the same time, the composition of participants in China's space sector has gradually diversified from a relatively homogeneous group of State-owned entities within the traditional space-industrial system to a broader range of market-based actors. The allocation of legal responsibility among these actors has yet to be clearly defined (Zhao, 2007).

Overall, existing international space law has established fundamental principles concerning State responsibility and the protection of the outer space environment. These principles are, however, formulated in broad terms and require further elaboration through their incorporation into domestic law. Although China's existing space regulatory framework contains preliminary rules governing the registration of space objects, launch licensing, space-debris mitigation, and satellite-project management, it continues to exhibit several structural deficiencies. These include the absence of a basic space law, the relatively low normative rank of the existing rules, the fragmentation of regulatory provisions, the insufficiency of rules specifically governing commercial space activities, and the lack of sufficiently specific requirements concerning green development. The responsibility and liability regime is particularly in need of improvement, given both the diversification of actors involved in commercial space activities and the distinctive nature of environmental damage in outer space.

4. Legal pathways to greener commercial space activities

The 18th National Congress of the Communist Party of China established the goal of comprehensively advancing law-based governance. Against this background, the rule-of-law governance of the space sector constitutes an important component of China's broader efforts to advance the rule of law, with the central objective of modernizing the system and capacity for national governance in the space sector through legal institutions and regulatory mechanisms (He, 2015). China currently maintains an actively supportive policy towards the development of commercial space activities. The sustainable development of commercial space activities requires more than policy guidance. In particular, achieving green-development objectives depends on systematic and enforceable legal safeguards. Accordingly, it is necessary to explore a legal framework for the green development of commercial space activities in light of practical regulatory needs. Such a framework should focus on four principal areas: improving specialized space legislation, establishing a whole-process green regulatory mechanism, strengthening the responsibility and liability regime, and enhancing international co-ordination and co-operation.

4.1. Embedding environmental protection in dedicated space legislation

As a State Party to the Outer Space Treaty, China should, in accordance with the principle that treaties must be performed in good faith, transform the principle of environmental protection in outer space into rules of domestic law adapted to China's particular national circumstances. This is especially necessary in view of the green-development risks intensified by commercial space activities, including the

proliferation of space debris, orbital congestion, and pollution resulting from spacecraft re-entry. Nevertheless, ensuring the sustained and sound development of China's space sector cannot depend solely on ministerial regulations of relatively low normative rank or on adjustments made through space-policy instruments. Such an approach is insufficient to guarantee the binding force, stability, and authority of the applicable norms throughout their implementation (Su, 2021).

The enactment of a basic space law is, on the one hand, an inherent requirement for promoting the sustainable development of the space industry. Such legislation is particularly important for the protection of the outer space environment and would provide an institutional foundation for the sound and orderly development and green transformation of commercial space activities. On the other hand, the enactment of a space law is also an urgent requirement arising from China's broader economic development (Wang, 2012). As the commercialization of space activities continues to advance, the range of domestic actors participating in such activities has become increasingly diverse, with private entities and private capital entering the space sector. Against this background, comprehensive space legislation is needed to regulate the various legal relationships arising from space activities.

The experience of other jurisdictions demonstrates that some spacefaring States have regulated commercial space activities through specialized legislation or supporting institutional arrangements tailored to the practical development of their domestic commercial space sectors. Although national space legislation varies considerably among States, a common feature is the gradual transformation of "soft law", including guiding rules and government policy documents, into legally binding "hard law" (Wang, 2012). The United States, for example, has supported the development of commercial space activities through both policy measures and legislation, including the Commercial Space Act, the Commercial Space Launch Act, and the U.S. Commercial Space Launch Competitiveness Act. The United Kingdom enacted the Space Industry Act 2018 in response to the development of its domestic commercial space industry. The Act further specifies the responsibilities and powers of the authorities responsible for regulating space activities conducted by non-governmental entities. It also requires the regulator, in exercising its functions, to take into account environmental objectives set by the Secretary of State and any space debris mitigation guidelines issued by an international organisation in which the government of the United Kingdom is represented (United Kingdom, 2018, s. 2(2)(e), (h)). China's commercial space industry is currently undergoing rapid development. Drawing upon relevant foreign legislative experience, China should enact a basic space law that reflects its own space-administration system and green-development requirements.

China should therefore enact a specialized basic space law. Its general provisions should establish green development and the protection of the outer space environment as fundamental principles. The law should also provide for such matters as responsibility and liability, insurance requirements, restrictions on the exploitation of space resources, and environmental-protection measures. A legislative model centred on a basic space law and supplemented by implementing regulations and other supporting rules would provide stable institutional safeguards for the development of commercial space activities. It would also enable green-development

requirements to be dynamically integrated into every stage of the life cycle of commercial space activities.

4.2. Strengthening life-cycle regulation and environmental standards

Advancing law-based governance of the space sector is a systemic undertaking. Its central objective is to bring all categories of space activities and related regulatory action fully within a law-based framework, while co-ordinating progress in such key areas as space legislation, legal implementation, legal supervision, and institutional capacity for law-based governance (He, 2015). Similarly, in the context of a risk society, environmental risks in outer space are characterized by a high degree of uncertainty, while the ecological and environmental risks arising from commercial space activities may extend throughout the entire life cycle of those activities. The environmental effects of space activities include not only emissions generated during launch but also orbital debris produced or encountered during in-orbit operations. It is therefore necessary to establish a systematic and comprehensive governance framework covering the entire course of commercial space activities (Olawade et al., 2025).

Green-development requirements should accordingly be incorporated into every stage of space activities through a regulatory mechanism covering the full life cycle of commercial space projects. At the pre-activity stage, early-warning and risk-prevention mechanisms should be established to address pollution of the outer space environment. During the conduct of space activities, dynamic environmental monitoring should be strengthened, and environmental impact assessments should cover the entire operational process of space objects, from in-orbit operation and end-of-life disposal to atmospheric re-entry. Dynamic regulatory oversight should extend to launches, in-orbit operations, collision-avoidance manoeuvres, orbital changes, anomalous conditions, and space-debris risks. At the post-activity stage, a space-incident reporting mechanism should be established. Following a space incident, the entity exercising actual jurisdiction and control over the relevant space object should be required to report the incident and to notify the competent space authority, within a reasonable period, of the circumstances of the incident and its consequences.

Life-cycle regulation should also be integrated with the development of a coherent standards system. Standardization plays an important role in the development of commercial space activities. On the one hand, standards directly affect quality and should therefore be formulated and improved to ensure the quality of commercial space products and services (Tian et al., 2024). On the other hand, standards constitute an important basis for the orderly governance of commercial space activities. Laws and regulations generally establish overarching requirements at the macro level, but their effective implementation depends on more detailed technical and operational standards (Xu & Zhang, 2019). At present, China's commercial space sector continues to exhibit certain deficiencies in both industry standards and routine regulatory oversight. Given the large number of commercial space enterprises and their generally limited scale, government authorities should use standards to regulate market conduct and thereby promote the effective fulfilment of

corporate responsibilities. In the field of green development and environmental protection, mandatory standards should be formulated and accompanied by effective mechanisms for supervising their implementation.

4.3. Clarifying legal responsibilities and liability

A well-defined responsibility and liability regime is a crucial component of the legal framework for the green development of commercial space activities. At the international level, a State may incur international responsibility for commercial space activities conducted by its non-governmental entities. If domestic law fails to clearly define the environmental obligations of commercial operators and the scope of their responsibility and liability, a situation may arise in which the State bears international responsibility while the responsibility and liability of the operators concerned remain insufficiently defined under domestic law. China should therefore establish, through its space legislation, a responsibility and liability regime suited to the green development of commercial space activities, linking environmental protection obligations with liability for compensation and insurance arrangements.

Liability for damage arising from commercial activities in outer space differs from ordinary civil tort liability. It may therefore be inappropriate to determine such liability simply by applying the provisions on tort liability contained in the Civil Code of the People's Republic of China or other general rules of domestic law. Accordingly, the institutional framework governing compensation for damage caused by commercial space activities should be further improved (Su, 2021). Commercial space activities may cause various forms of damage, including damage to third parties on the surface of the Earth, damage resulting from in-orbit collisions, re-entry damage, and environmental harm. The law should clearly define the liable parties, the applicable standards of liability, the scope of compensation, liability limits, and insurance requirements for each category of damage. In particular, the third-party liability insurance regime should be further elaborated within the launch-licensing system, with clear rules governing the minimum amount of coverage, the scope and duration of insurance, and the State's right of recourse after it has paid compensation. Such arrangements would not only strengthen remedies available to victims but also use insurance mechanisms to incentivize commercial operators to improve their risk-prevention and risk-control capacities. Although current technological capabilities do not yet make it practicable to establish a liability regime for damage to the outer space environment caused by space debris generated by commercial space activities, the finite nature of space resources suggests that such a regime will ultimately become an important area of development in future space legislation.

In addition, the system for the registration of space objects should be linked to mechanisms for determining and enforcing responsibility and liability. Registration is not merely a means of fulfilling obligations under the Convention on Registration of Objects Launched into Outer Space; it also provides an essential basis for identifying space objects, determining the entities exercising control over them, tracking their operational status, and attributing responsibility and liability. China should therefore further improve its system for the registration of space objects by

clearly identifying the persons or entities subject to registration obligations, broadening the scope of registrable information and objects, refining the rules governing amendments to and cancellation of registrations, and prescribing the legal consequences of failure to register, delayed registration, or the submission of inaccurate registration information. In the context of commercial space activities, the liable party can be accurately identified following a collision, the generation of debris, re-entry damage, or the emergence of an environmental risk only when information concerning the identity, orbital status, and operator of each space object is clear, accurate, and readily traceable.

4.4. Enhancing international coordination and cooperation

The green development of commercial space activities is not merely a matter of domestic law; it is also an important issue of global outer space governance. Outer space has a global public character, and risks arising from space debris, orbital congestion, collisions between space objects, pollution caused by re-entry, and the degradation of the outer space environment are not confined within the borders of any single State. Many of the challenges affecting the long-term sustainability of outer space activities cannot be effectively addressed by individual States acting alone. Whether in relation to the mitigation of space debris, the use of the geostationary orbit, or the prevention and control of pollution in the outer space environment, an effective response requires stronger international coordination and cooperation (Yin & Yan, 2017). In the context of globalization, modern risks have transcended traditional national boundaries. The protection of the outer space environment therefore depends, to an even greater extent, on collective governance by the international community (Hou, 2011). Accordingly, while strengthening its domestic regulatory framework for the green development of commercial space activities, China should also participate actively in international coordination and cooperation concerning the protection and long-term sustainable use of the outer space environment.

As a major space-faring nation, China should not only fulfil its existing international obligations but also participate actively in the governance of the outer space environment. In doing so, China should contribute more actively to the development of relevant international rules. More specifically, China may promote cooperation in four principal areas: technology, law, institutional coordination, and funding. The challenges affecting the long-term sustainability of outer space activities can be substantially alleviated only if the international community develops a coherent and collective approach. Such an approach requires cooperation at the global, regional, multilateral, and bilateral levels in relation to space technologies, legal and regulatory frameworks, institutional coordination, and financial support (Yin & Yan, 2017). Through international cooperation across these fields, China can both discharge the international responsibilities commensurate with its status as a major space-faring nation and help secure a more stable, open, and sustainable international legal and institutional environment for the green development of commercial space activities.

5. Conclusion

The rapid expansion of commercial space activities has created new opportunities for the development of the space industry, while at the same time intensifying ecological and environmental risks across both terrestrial and outer space environments. This article has shown that, although existing international space law provides fundamental principles concerning environmental protection, State responsibility, and the long-term sustainability of outer space activities, these principles remain broadly framed and require further implementation through domestic legal and regulatory mechanisms. In China, existing rules on space-object registration, launch licensing, space-debris mitigation, satellite-project management, and commercial-space standardization have established an initial regulatory foundation. However, the current framework remains constrained by the absence of a basic space law, the low normative rank and fragmentation of existing rules, insufficient provisions on commercial space activities and green development, and an underdeveloped responsibility and liability regime.Addressing these deficiencies requires a more systematic rule-of-law approach that combines specialized space legislation with life-cycle environmental regulation and a coherent standards system, clarifies the responsibility and liability of commercial space actors, and strengthens international coordination and cooperation. A more coherent and enforceable legal framework would therefore provide a stronger institutional basis for coordinating the continued development of China's commercial space sector with environmental protection and the long-term sustainable use of outer space.

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References

Barentine, J. C., Venkatesan, A., Heim, J., Lowenthal, J., Kocifaj, M., & Bará, S. (2023). Aggregate effects of proliferating low-Earth-orbit objects and implications for astronomical data lost in the noise. Nature Astronomy, 7(3), 252-258. https://doi.org/10.1038/s41550-023-01904-2

Bartóki-Gönczy, B., Ganczer, M., & Sulyok, G. (2024). Space sustainability: Current regulatory challenges. Hungarian Journal of Legal Studies, 65(2), 260-281. https://doi.org/10.1556/2052.2024.00552

Bassa, C. G., Di Vruno, F., Winkel, B., Józsa, G. I. G., Brentjens, M. A., & Zhang, X. (2024). Bright unintended electromagnetic radiation from second-generation Starlink satellites. Astronomy & Astrophysics, 689, L10. https://doi.org/10.1051/0004-6361/202451856

Bo, S. S. (2012). The legal framework for the commercialization of China's space activities (Chinese). Journal of Beijing Institute of Technology (Social Sciences Edition), 14(3), 104-109, 131.

Boyle, A. (2019). The choice of a treaty: Hard law versus soft law. In: Chesterman, S., Malone, D. M., & Villalpando, S. (editors). The Oxford Handbook of United Nations Treaties. Oxford University Press. pp. 101-118. https://doi.org/10.1093/law/9780190947842.003.0007

Chen, X. H., & Wan, Y. T. (2025). Judicial safeguards for green development promoted by new quality productive forces (Chinese). Finance and Economy, (11), 73-82.

China National Space Administration. (2025a). Action Plan of the China National Space Administration for Promoting the High-Quality and Safe Development of Commercial Spaceflight (2025-2027) (Chinese). Available online: https://www.cnsa.gov.cn/n6758823/n6758839/c10719382/content.html (accessed on 24 September 2026).

China National Space Administration. (2025b). Notice on Strengthening Quality Supervision and Administration of Commercial Space Projects (Chinese). Available online: https://www.cnsa.gov.cn/n6758823/n6758839/c10690058/content.html (accessed on 27 September 2026).

China National Space Administration, & State Administration for Market Regulation. (2026). Commercial Space Standards System (Version 1.0) (Chinese). 24 April 2026. Available online: https://www.cnsa.gov.cn/n6758823/n6758839/c10741644/content.html (accessed on 27 September 2026).

Commission of Science, Technology and Industry for National Defense. (2002). Interim Measures on the Administration of Permits for Civil Space Launch Projects (Chinese). Order No. 12 of the Commission of Science, Technology and Industry for National Defense of the People's Republic of China. Available online: https://www.cnsa.gov.cn/n6758823/n6758839/c6796213/content.html (accessed on 26 September 2026).

Commission of Science, Technology and Industry for National Defense, & Ministry of Foreign Affairs. (2001). Measures for the Administration of Registration of Space Objects (Chinese). COSTIND Order No. 6. Available online: https://www.cnsa.gov.cn/n6758823/n6758839/c6796215/content.html (accessed on 28 September 2026).

Dalledonne, S. (2021). International environmental law and environmentally harmful space activities: Learning from the past for a more sustainable future. Journal of Property, Planning and Environmental Law, 13(2), 139-151. https://doi.org/10.1108/JPPEL-09-2020-0040

Dempsey, P. S. (2016). National laws governing commercial space activities: Legislation, regulation, & enforcement. Northwestern Journal of International Law & Business, 36(1), 1-44.

Di Vruno, F., Winkel, B., Bassa, C. G., Józsa, G. I. G., Brentjens, M. A., Jessner, A., & Garrington, S. (2023). Unintended electromagnetic radiation from Starlink satellites detected with LOFAR between 110 and 188 MHz. Astronomy & Astrophysics, 676, A75. https://doi.org/10.1051/0004-6361/202346374

Du, S. J., & Ye, X. X. (2024). Logical Reasoning, Value Implication and Practical Path of Green Development Empowered by New Quality Productivity (Chinese). Journal of Beijing Institute of Technology (Social Sciences Edition), 26(6), 52-61.

European Space Agency Space Debris Office. (2025). ESA Space Environment Report 2025. European Space Agency. Available online: https://www.esa.int/Space_Safety/Space_Debris/ESA_Space_Environment_Report_2025 (accessed on 4 August 2026).

Feng, G. D. (2014). International legal rules on space debris mitigation and control (Chinese). Journal of Beijing University of Aeronautics and Astronautics (Social Sciences Edition), 27(1), 31-37.

Feng, G. D. (2017). On the construction of China's legal system for commercial space activities (Chinese). Aerospace China, (9), 8-14.

Ferreira, J. P., Huang, Z., Nomura, K.-i., & Wang, J. (2024). Potential ozone depletion from satellite demise during atmospheric reentry in the era of mega-constellations. Geophysical Research Letters, 51(11), e2024GL109280. https://doi.org/10.1029/2024GL109280

Freeland, S. (2012). The development of national space law. In: Freeland, S., Popova, R., & Passy, S. (editors). Contemporary Issues for National and International Space Law: Commentary and Source Materials. AMG Publishing. pp. 12-35. Available online: https://researchers.westernsydney.edu.au/en/publications/the-development-of-national-space-law (accessed on 28 September 2026).

Gao, G. Z. (2011). Legislative safeguards for China's space activities and future prospects (Chinese). Journal of Beijing Institute of Technology (Social Sciences Edition), 13(4), 85-90.

Gong, Z. Z., Chen, C., & Zhang, P. L. (2024). Outer space security and environmental governance: Progress, challenges, and opportunities (Chinese). Journal of Space Science and Experiment, 1(1), 120-131.

Han, W. L., Dong, X. W., & Tang, X. (2024). The dialectical relationship between new quality productive forces and green development and its practical pathways (Chinese). Journal of University of Electronic Science and Technology of China (Social Sciences Edition), 26(3), 12-21.

He, P. Z. (2015). Reflections on and prospects for commercial space development—Yang Baohua, deputy general manager of China Aerospace Science and Technology Corporation (Chinese). Satellite & Network, (9), 16-18, 20-21.

Hou, R. X. (2011). Challenges facing outer space environmental protection and the necessity of a conceptual transformation (Chinese). Journal of Beijing Institute of Technology (Social Sciences Edition), 13(1), 84-87.

Inter-Agency Space Debris Coordination Committee. (2021a). IADC Space Debris Mitigation Guidelines (IADC-02-01, Revision 3). Available online: https://iadc-home.org/documents_public/file_down/id/5251 (accessed on 28 September 2026).

Inter-Agency Space Debris Coordination Committee. (2021b). IADC Statement on Large Constellations of Satellites in Low Earth Orbit. IADC-15-03 Rev. 1.1, July 2021. Available online: https://iadc-home.org/documents_public/file_down/id/5253 (accessed on 28 September 2026).

International Astronomical Union. (2022). Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference. Available online: https://cps.iau.org/about/ (accessed on 4 August 2026).

International Telecommunication Union. (2003). Recommendation ITU-R RA.769-2: Protection Criteria Used for Radio Astronomical Measurements. International Telecommunication Union. Available online: https://www.itu.int/rec/R-REC-RA.769-2-200305-I/en (accessed on 28 September 2026).

International Telecommunication Union. (2023). Constitution of the International Telecommunication Union. Article 44. International Telecommunication Union. Available online: https://www.itu.int/en/council/Documents/basic-texts-2023/Constitution-E.pdf (accessed on 28 September 2026).

Jiang, Y. M., & Qiao, Z. Y. (2024). New quality productive forces: An advanced form of productive forces consistent with the new development philosophy (Chinese). Southeast Academic Research, (2), 52-63, 246.

Li, W. F. (2006). A commentary on the 1979 Cosmos 954 crash case (Chinese). In: Zhao, H. F. (editor). Space Law Review. Harbin: Harbin Institute of Technology Press. pp. 197-204.

Liu, Y. Y. (2019). Development pathways for China's space law in the context of space commercialization (Chinese). Legal Forum, 34(5), 129-137.

Long, J. (2018). The international legal basis for the long-term sustainability of outer space activities: From the perspective of active space debris removal (Chinese). Journal of Beijing University of Aeronautics and Astronautics (Social Sciences Edition), 31(4), 91-99.

Long, J., & Li, X. D. (2023). Implementation of and responses to the Guidelines for the Long-term Sustainability of Outer Space Activities: The practice of the United Kingdom (Chinese). Journal of Beijing University of Aeronautics and Astronautics (Social Sciences Edition), 36(2), 143-154.

Martinez, L. F. (2019). Legal regime sustainability in outer space: Theory and practice. Global Sustainability, 2, e26. https://doi.org/10.1017/sus.2019.21

Murphy, D. M., Abou-Ghanem, M., Cziczo, D. J., Froyd, K. D., Jacquot, J., Lawler, M. J., Maloney, C., Plane, J. M. C., Ross, M. N., Schill, G. P., & Shen, X. (2023). Metals from spacecraft reentry in stratospheric aerosol particles. Proceedings of the National Academy of Sciences of the United States of America, 120(43), e2313374120. https://doi.org/10.1073/pnas.2313374120

Newman, C. J., & Williamson, M. (2018). Space Sustainability: Reframing the Debate. Space Policy, 46, 30-37.

NOAA Chemical Sciences Laboratory. (2023). NOAA scientists link exotic metal particles in the upper atmosphere to rockets, satellites. Available online: https://csl.noaa.gov/news/2023/388_1016.html (accessed on 27 September 2026).

Olawade, D. B., Ijiwade, J. O., & Wada, O. Z. (2025). Toward net-zero in space exploration: A review of technological and policy pathways for sustainable space activities. Science of the Total Environment, 972, 179145. https://doi.org/10.1016/j.scitotenv.2025.179145

Qu, X. F. (2020). Innovative applications and expansion of the commercial space market (Chinese). Satellite Application, (3), 1.

Ryan, R. G., Marais, E. A., Balhatchet, C. J., & Eastham, S. D. (2022). Impact of rocket launch and space debris air pollutant emissions on stratospheric ozone and global climate. Earth's Future, 10(6), e2021EF002612. https://doi.org/10.1029/2021EF002612

Sheng, Y. H., Shi, H. T., Wang, Y. J., & Fan, H. T. (2025). Research on the construction and innovation strategies of the commercial space system (Chinese). Aerospace Shanghai (Chinese & English), 42(S1), 29-35.

State Administration of Science, Technology and Industry for National Defense. (2016). Interim Measures for the Administration of Civil Satellite Projects (Chinese). Kegong Yisi [2016] No. 986. Available online: https://www.cnsa.gov.cn/n6758823/n6758839/c6796155/content.html (accessed on 28 September 2026).

State Administration of Science, Technology and Industry for National Defense. (2021). Notice on Promoting the Orderly Development of Small Satellites and Strengthening Safety Management (Chinese). Kegong Yisi [2021] No. 466. Available online: https://www.sastind.gov.cn/n10086167/n10086216/c10401866/content.html (accessed on 28 September 2026).

State Administration of Science, Technology and Industry for National Defense. (2023). Notice on Strengthening the Administration of Licenses of Civil Space Launch Project (Chinese). 23 February 2023. Available online: https://www.cnsa.gov.cn/n6758823/n6758839/c10006475/content.html (accessed on 27 September 2026).

Su, H. F. (2021). Construction of China's legal framework for commercial activities in outer space (Chinese). Yinshan Academic Journal, 34(6), 89-95.

Tapio, J., & Soucek, A. (2019). National implementation of non-legally binding instruments: Managing uncertainty in space law? Air & Space Law, 44(6), 565-582. https://doi.org/10.54648/AILA2019035

Tian, L., Xu, D. Y., & Dai, J. (2024). Reflections on promoting the high-quality development of commercial space activities through standardization in the new era (Chinese). Aerospace Standardization, (1), 1-4.

United Kingdom. (2018). Space Industry Act 2018, c. 5. Available online: https://www.legislation.gov.uk/ukpga/2018/5/contents/enacted (accessed on 27 September 2026).

United Nations. (1967). Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies. United Nations Treaty Series, 610, 205. Available online: https://treaties.un.org/Pages/showDetails.aspx?objid=0800000280128cbd (accessed on 24 September 2026).

United Nations. (1972). Convention on International Liability for Damage Caused by Space Objects. United Nations Treaty Series, 961, 187. Available online: https://treaties.un.org/pages/showdetails.aspx?objid=08000002801098c7 (accessed on 28 September 2026).

United Nations. (1974). Convention on Registration of Objects Launched into Outer Space. United Nations Treaty Series, 1023, 15. Available online: https://treaties.un.org/Pages/showDetails.aspx?objid=0800000280036 1b4 (accessed on 28 September 2026).

United Nations. (1979). Agreement Governing the Activities of States on the Moon and Other Celestial Bodies. United Nations Treaty Series, 1363, 3. Available online: https://treaties.un.org/Pages/showDetails.aspx?clang=_en&objid=080000028003b946 (accessed on 24 September 2026).

United Nations. (2007). Space Debris Mitigation Guidelines of the United Nations Committee on the Peaceful Uses of Outer Space. Available online: https://www.unoosa.org/documents/pdf/spacelaw/sd/COPUOS_space_debris_mitigation_guidelines.pdf (accessed on 28 September 2026).

United Nations. (2019). Report of the Committee on the Peaceful Uses of Outer Space, Sixty-second Session (12-21 June 2019). General Assembly Official Records, Seventy-fourth Session, Supplement No. 20, A/74/20. Annex II: Guidelines for the Long-term Sustainability of Outer Space Activities of the Committee on the Peaceful Uses of Outer Space. United Nations. Available online: https://digitallibrary.un.org/record/3824351/files/A_74_20-EN.pdf (accessed on 27 September 2026).

United Nations Environment Programme, & United Nations Office for Outer Space Affairs. (2025). Safeguarding space: Environmental issues, risks and responsibilities. Available online: https://www.unep.org/resources/emerging-issues/safeguarding-space-environmental-issues-risks-and-responsibilities (accessed on 4 August 2026).

United Nations Office for Outer Space Affairs. (n.d.). Long-term Sustainability of Outer Space Activities Information Repository. Available online: https://lts.unoosa.org/unoosa_lts/ (accessed on 28 September 2026).

Viikari, L. E. (2004). Environmental Impact Assessment and space activities. Advances in Space Research, 34(11), 2363-2367. https://doi.org/10.1016/j.asr.2004.01.016

Wang, G. Y. (2012). On the necessity and feasibility of enacting China's Space Law (Chinese). Journal of Beijing Institute of Technology (Social Sciences Edition), 14(6), 101-108.

Xi, J. (2024). Advancing New Quality Productive Forces Is Essential and a Key Priority for Fostering High-Quality Development. Available online: https://en.qstheory.cn/2024-11/12/c_1043431.htm (accessed on 24 September 2026).

Xiong, C. Y. (2020). The impact of outer space law on mega-constellation deployment and corresponding countermeasures (Chinese). Journal of Beijing University of Aeronautics and Astronautics (Social Sciences Edition), 33(3), 101-105.

Xu, A. M., & Zhang, G. T. (2019). A preliminary discussion of establishing China's commercial space regulatory system (Part II) (Chinese). Aerospace China, (9), 34-40.

Yan, Y. (2019). Maintaining Long-Term Sustainability of Outer Space Activities: Creation of Regulatory Framework to Guide the Asia-Pacific Space Cooperation Organization and Selected Legal Issues. Space Policy, 47, 51-62. DOI: 10.1016/j.spacepol.2018.06.002.

Yin, Y. H., & Yan, Y. L. (2016). Challenges to the long-term sustainability of outer space activities and corresponding countermeasures (Chinese). Journal of Beijing University of Aeronautics and Astronautics (Social Sciences Edition), 29(2), 20-25.

Yin, Y. H., & Yan, Y. L. (2017). A preliminary analysis of international cooperation concerning the long-term sustainability of outer space activities (Chinese). Journal of Beijing University of Aeronautics and Astronautics (Social Sciences Edition), 30(2), 37-45.

Zhao, H. F. (2007). Reflections on China's space legislation (Chinese). Heilongjiang Social Sciences, (5), 148-151.