ENVIRONMENTAL IMPACTS OF ROCKET LAUNCH ACTIVITIES ON SURROUNDING COMMUNITIES AND ECOSYSTEMS: ASSESSING LIABILITY AND REGULATORY GAPS UNDER SPACE LAW

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ABSTRACT

With the increase of rockets being launched into outer space, many questions are being raised recently. What does this process of rocket launching do to the local environment and ecosystem? What effects does it have on the atmosphere due to the rocket exhaust being injected directly into the stratosphere? Does the body of law regulating space activity even touch upon those topics? This paper attempts to address these questions by going through scientific studies that are published on the topic at hand. The paper reviews evidence relating to possible harmful environmental impacts of launching rockets, such as noise pollution, chemicals release, damage to the local habitat and atmospheric emission. Then the paper examines key international space law legal instruments such as the Outer Space Treaty of 1967 and Liability Convention of 1972, and their adequacy to environmental protection in the course of outer space exploration. Finally, national legislation, with US case study being chosen as an example, is discussed. The outcome of this examination shows that there is a reasonable case for updating the current legal regime, even if the precise path forward is not yet clear.

Keywords: Rocket launches, environmental impact, Atmospheric emissions, space law, Outer Space Treaty, Liability Convention.

1. Introduction

It is worth pausing, now and then, to think about what has changed in the space industry. For most of the twentieth century, rocket launches were rare events. They were expensive, conducted by governments, and counted in the dozens per year globally. That picture has changed quite dramatically.

In 2019, there were 102 orbital launches worldwide. By 2024, that number had risen to 261. In 2025, it reached 330 (Wikipedia, 2024 in spaceflight; Wikipedia, 2025 in spaceflight). A single company, SpaceX, accounted for roughly 95% of all US launches in 2024 (Payload Space, 2025). Some estimates suggest that by 2050, there could be as many as 1,000 launches per year (Ang et al., 2024). Whether or not that figure turns out to be accurate, the direction of travel seems clear enough.

All of this raises a question that deserves more attention than it has typically received. What are the environmental consequences of so many launches? The communities living near launch sites, the wildlife in surrounding areas, and the atmosphere itself may all be affected in ways that are not yet well understood. The legal framework that governs space activities was put together decades ago. It was not written with any of this in mind.

It is important in this paper to critically examine what the current science says about the potential for environmental harm from rocket launches, and what the present legal framework for outer space might be capable or incapable of accomplishing in regard to this issue. This analysis seeks to avoid reaching conclusions based on insufficient evidence. Instead, the goal is to provide a mapping of the problem and consider how knowledge and regulation may be lacking.

2. Environmental Impacts: What the Evidence Suggests

2.1 Rise in Launch Activity

However, it is useful to take note of the sheer number of rocket launches before addressing their environmental impact in more detail. Figure 1 below provides data on the total number of orbital launches carried out annually between 2015 and 2025. This information has been taken from the Wikipedia annual spaceflight summary reports, and is based on established databases such as Space-Track.org and Jonathan McDowell’s catalogue.

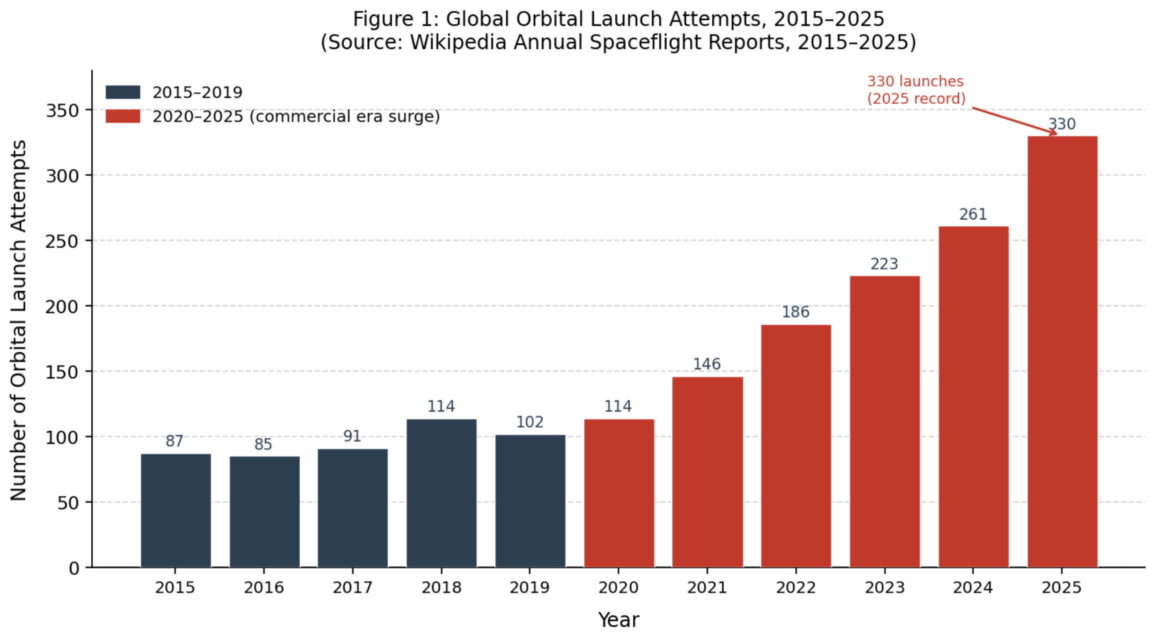

Figure 1. Global Orbital Launch Attempts, 2015–2025. Pre-2020 launches shown in dark grey; the commercial-era surge from 2020 onwards shown in red. Sources: Wikipedia Annual Spaceflight Reports (2015–2025), compiled from Space-Track.org and McDowell (2024).

The trend shown in Figure 1 is remarkable. While in 2015 there was only 87 orbit launches in the world, by 2025, there were already 330 orbit launches worldwide - more than three times the number for the ten years. This increase in orbit launch activity is mainly attributed to the commercial satellite constellation projects, including the Starlink project. Each orbit launch contributes to the cumulative impact of air pollution, sound pollution, and physical disturbance on and off the orbit launch site. The issue of environmental concern is not the individual orbit launch but all of these happening year after year in the same place.

2.2 Atmospheric Emissions and What They May Do to the Ozone Layer

Rocket engines burn fuel. That produces exhaust. And unlike aircraft, which release their exhaust in the lower atmosphere, rockets push their combustion products directly into the stratosphere and mesosphere. The stratosphere is where the ozone layer sits. It is also a region where chemical compounds can linger for a long time.

Different propellant types produce different kinds of exhaust. Solid rocket motors, which use ammonium perchlorate combined with aluminium, release hydrogen chloride and reactive chlorine compounds when they burn. These are ozone-depleting substances. Liquid-fuelled rockets burning kerosene release black carbon soot particles along with carbon dioxide and water vapour. Black carbon in the stratosphere is particularly concerning. It absorbs solar radiation, warms the surrounding air, and in doing so appears to drive chemical reactions that destroy ozone (Maloney et al., 2022).

Ryan et al. (2022), writing in the journal Earth's Future, used an atmospheric chemistry model to assess the likely effects of current and projected rocket emissions. They found that ozone losses from current launch levels are probably modest. But they also found that if space tourism and high-cadence commercial launches grow substantially, the effect on the Arctic upper stratosphere could become significant. The ozone layer has been slowly recovering since the Montreal Protocol reduced the use of chlorofluorocarbons. That recovery could be put at risk.

More recent work makes this concern feel more pressing. Ryan et al. (2025), publishing in npj Climate and Atmospheric Science, modelled two different scenarios for how launch activity might grow towards 2030. Figure 2 below shows what they found.

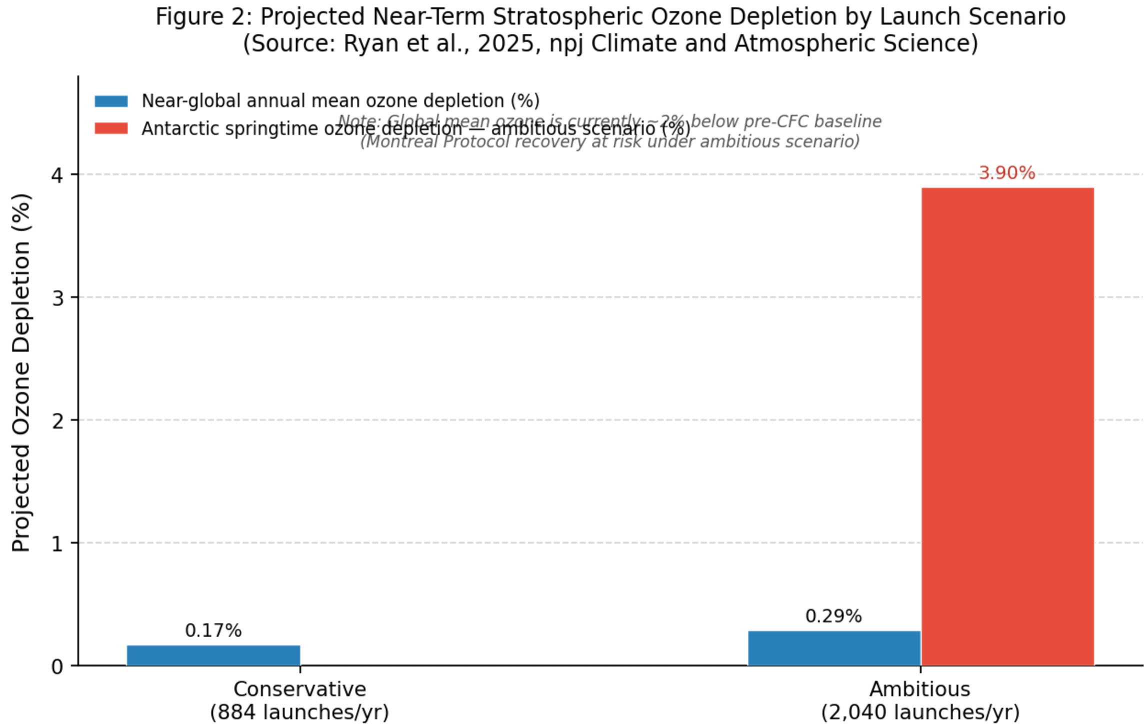

Figure 2. Projected Stratospheric Ozone Depletion by Launch Scenario. The conservative scenario assumes 884 launches per year; the ambitious scenario assumes 2,040 launches per year. Antarctic springtime depletion data available for the ambitious scenario only. Source: Ryan et al. (2025), npj Climate and Atmospheric Science.

The numbers in Figure 2 may look small at first. A 0.17% or 0.29% depletion in global ozone does not sound like much. But it is worth keeping in mind that global mean ozone is still around 2% below its pre-CFC baseline (Ryan et al., 2025). Any further depletion, on top of an already reduced layer, is not trivial. And the 3.9% Antarctic springtime loss in the ambitious scenario is larger potentially large enough to affect ultraviolet radiation reaching the surface in polar regions.

This is made more ominous by the timeline. According to Ryan et al. (2025), the conservative scenario which entails 884 launches per year might be realized or exceeded before 2030 based on present-day licensing rates. This is not some long-term forecast; rather, it is an imminent prospect when one considers the graph presented in Figure 1.

The situation at the local level, however, presents a slightly different atmospheric outlook. Following each launch, the combustion plume left by the rocket can lead to deposits of hydrogen chloride, aluminium oxides, and acidifying substances in the vicinity of the launch site. In a recent study of the Indian River Lagoon, Arata et al. (2025) detected what seemed like links between launch activities from nearby facilities and trace metal contamination and acidification of the lagoon. The authors make clear that their evidence is preliminary and that they have yet to prove definite causality. Nevertheless, further research is warranted.

2.3 Effects of Noise on Wildlife

It is known that Rockets create very loud sounds. Some types of transport emit noises greater than 200 dB SPL (Biology Insights, 2025) even at some distance from the point of launch. There is a rather substantial number of studies that prove that anthropogenic noise created by activities like seismic surveys, low altitude flights of military aircraft, etc., can lead to hearing loss in animals, disturbance of their feeding/migration activity, stress reactions, and so on. However, no research was done on the effects of the noises made at the moment of launching rockets on wildlife in the neighbourhood of launch sites, especially birds, fish and marine mammals. However, there is an evident need for it.

A paper by Ang et al. (2024) entitled "Rocket Launch Sites and Global Biodiversity" and published in the Communications Earth & Environment journal reveals several facts of great importance. Firstly, more than 62% of the existing launch sites are situated in or near protected territories. Secondly, threatened species of Tropical and Subtropical Moist Broadleaf Forests seem to be at particular risk. The authors propose that the species community composition around the launch areas is dependent on the biome type and distance from coastlines.

Some examples will provide an indication of what occurs in practice. In April 2023, the Starship/Super Heavy rocket from the Boca Chica, Texas, exploded just four minutes after the liftoff event, causing widespread damage to coastal wetlands and initiating a fire in an area of roughly three acres. In September 2022, another test launch at the same place was reportedly responsible for burning about 68 acres of the Lower Rio Grande National Wildlife Refuge (Defenders of Wildlife, 2024). This is a real problem, not a speculative one. While there have been no detailed ecological studies conducted of the above-mentioned events, their extent cannot be disputed.

2.4 Chemical Contamination of Soil and Water

The materials that serve as rocket fuels and those that provide support during launches can be poisonous. Hydrazine, one of the propellants in some rockets and in satellites' thrusters, is an acute poison. Perchlorates, substances produced as a result of the decomposition of ammonium perchlorate in the exhausts of solid fuel rockets, can be accumulated in the soil and water. Studies suggest that perchlorate can prevent the thyroid gland from absorbing iodine, with possible health risks for humans, especially children (Newsweek, 2022).

The issue of contamination of the area of SpaceX's facilities in Boca Chica, Texas, got much public attention in 2024. According to the investigative reports based on the data provided by the Texas Commission on Environmental Quality and the US Environmental Protection Agency, SpaceX had been releasing industrial waste water from its deluge system into the surrounding wetlands without appropriate permits, while some of the samples contained increased concentration of mercury (Flying Magazine, 2025). SpaceX denied the allegations, claiming that the water in the deluge system was potable water approved by the regulatory agencies. However, it highlights the structural challenge, which is that the regulatory frameworks responsible for tracking water quality in areas surrounding commercial launch sites may be struggling to keep pace with operations.

Indeed, the FAA's own environmental assessment of the Boca Chica launch site has revealed trace amounts of arsenic, barium, fluoride, and nitrate in deluge water samples. These are believed to be at concentrations equal to those present in the source water (FAA, 2023). It remains to be seen whether this characterization will hold up over time as the number of launches increases.

2.5 Land, Debris, and Nearby Communities

The impacts of launching rockets on the land and communities around launch sites extend well beyond emissions and pollution. Debris from rocket boosters and payload fairing is regularly shed during the launches. While some is intentionally directed into the oceans in certain zones, others fall in more unexpected ways due to the failures of the vehicles. According to Arata et al. (2025), marine debris resulting from the launch includes metals, plastics, and carbon composite materials that eventually fragment into microplastics.

The impacts of commercial launches may be quite direct for people living in the vicinity of the launch sites. Road closings, evacuations, and access restrictions to beaches and lands have been observed near active commercial launch sites. The small village of Boca Chica Village in Texas was known to experience multiple disruptions because of SpaceX launches and some families even moved away. Indigenous peoples have also expressed their concerns regarding this issue. The Carrizo Comecrudo Tribe, whose sacred land includes the area around Boca Chica Village, and the Tigua Tribe claim that industrial launches have been taking place on and near sacred and spiritual sites without proper consultations (Space for Peace, 2024).

Ang et al.'s (2024) analysis provides another perspective to this issue. The fact that more than 62% of launch sites are located near protected areas is not a mere geographical coincidence. This is explained by the fact that launch sites tend to be placed in coastal and remote areas, which happen to be sensitive from ecological and cultural perspectives. Thus, without proper planning, future growth of the commercial launch industry will bring even more of these issues.

3. International Space Law: What It Covers and What It Misses

3.1 The Outer Space Treaty

The 1967 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, commonly known as the Outer Space Treaty or OST, is the foundation document of international space law. As of 2026, it has 114 contracting states. It was negotiated in the era of the Cold War for the purpose of preventing militarisation of space and establishing principles of sovereign equality among spacefaring countries.

The article that has relevance to environmental considerations is Article IX. It requires the states to carry out their activities "with due regard to the corresponding interests of all other States" and to avoid any "harmful contamination" of outer space and the Earth's environment. Moreover, it urges the states to consult one another when any one state thinks that the activities of other may lead to harmful interference.

In reality, there are many flaws in Article IX as an environmental protection instrument. First of all, it was written in the context of a quite particular threat – that of the biological contamination of either the Earth or any other celestial body. It was not meant to tackle the problem of industrial atmospheric emissions resulting from routine launches. It is an open debate among international lawyers whether it can be interpreted as imposing any obligations in such a situation (Reinert, 2022). There are no particular criteria, no monitoring needs, and no enforcement procedures associated with it.

The OST also focuses on states. Private companies are not directly addressed. Article VI places responsibility on each state for the national activities of its non-governmental entities, which means states must authorise and supervise commercial operators. But how they do this, and how rigorously, is left largely to each state's own domestic arrangements. This creates obvious variation in the level of environmental oversight that applies to commercial launches across different countries.

3.2 The 1972 Liability Convention

The Convention on International Liability for Damage Caused by Space Objects, in force since 1972, builds on Article VII of the OST. It sets up two liability rules. Under Article II, a launching state is absolutely liable meaning it does not need to be shown to have been at fault for damage caused by its space objects on the surface of the Earth or to aircraft in flight. Under Article III, liability for damage occurring elsewhere (say, in orbit) is fault-based.

The convention has only ever been formally invoked once. That was in 1978, when the Soviet nuclear satellite Kosmos 954 came down over Canada. The two governments eventually reached a diplomatic settlement (Reinert, 2022).

The convention defines "damage" as loss of life, personal injury, or loss of or damage to property. Environmental harm the kind of diffuse, cumulative damage to ecosystems that might result from repeated launches does not fit easily into this definition. It is not clear that an ecosystem has a "owner" in the legal sense. It is also not clear that gradual degradation from many launches over time would qualify as "damage" under the convention's terms (Reinert, 2022).

Moreover, there is also the issue of practice. Actions under the Liability Convention may be initiated only by one state against another state. No individual, community, NGO, or environmental association can benefit from the treaty directly. For a community suffering damage to its land close to a commercial launch site, there is no possibility to turn to this convention. The community would have to rely on its government bringing the case on its behalf, which is associated with all the intricacies of diplomatic claims between states.

3.3 Other International Instruments

The Moon Agreement of 1979 forbids actions which could interfere with the Moon and other celestial body environment. However, the treaty has only 18 parties, and the main space-faring countries did not become parties to the treaty. Hence, its role in shaping present-day space governance remains insignificant.

Generally speaking, the international environmental law contains some universal principles recognized internationally, such as precautionary principle, polluter pays principle, and duty to prevent transboundary harm. These principles are not included in any space treaty expressly. Whether they apply by implication, as general principles of international law, is an argument that some scholars make but that is far from settled (Northwestern Journal of Law and Social Policy, 2023).

The UN COPUOS Long-Term Sustainability Guidelines, adopted in 2019, are the most recent international effort to address sustainable use of outer space. They are non-binding. They focus primarily on orbital sustainability and debris management rather than on the terrestrial and atmospheric effects of launch operations. The Artemis Accords of 2020, signed by a growing number of states, include transparency and interoperability provisions but say nothing specific about environmental standards for launch sites. The trend in recent space governance, in other words, has been to deal with what happens in orbit not what happens on the ground or in the lower atmosphere during and after a launch.

4. National Regulatory Frameworks: The United States as an Example

4.1 How the FAA Handles Commercial Launch Licensing

In the United States, the primary regulator for commercial rocket launches is the Federal Aviation Administration's Office of Commercial Space Transportation, usually referred to as FAA/AST. Under the Commercial Space Launch Act and its subsequent amendments, companies wanting to launch commercially need a licence from the FAA. Part of that process involves an environmental review under the National Environmental Policy Act, or NEPA.

NEPA is an important piece of legislation. It requires federal agencies, when they take a major action like issuing a launch licence to assess the likely environmental impacts of that action. The assessment can take different forms depending on the scale and significance of what is planned. The most thorough is a full Environmental Impact Statement, or EIS. A less intensive option is an Environmental Assessment, or EA. For very routine actions with well-understood and minor impacts, a categorical exclusion may apply.

Critics have argued that the FAA has sometimes opted for the EA route in situations where the scale and novelty of operations arguably warranted a full EIS. The Boca Chica case is often cited in this context. Starship/Super Heavy is the largest and most powerful rocket ever built. It is being launched repeatedly from a site surrounded by sensitive wetlands, near an endangered species corridor, and close to communities with limited political voice. Nonetheless, despite this, the FAA opted for an EA rather than a proper EIS, something that advocacy organizations claimed to be illegal (Space for Peace, 2024).

Moreover, there have been concerns regarding the capabilities of the FAA to cope with the growing number of licensing actions it performs. The 2023 report of the Commercial Space Transportation Advisory Committee identified a shortage of relevant skills in the FAA to evaluate the newly invented compliance measures, essentially placing the responsibility on operators (Congress.gov, 2025). As of August 2024, there were 158 employees at the commercial space office of the FAA who worked mostly on licensing actions. Given the annual growth of the launches, this number of personnel might prove inadequate to perform environmental reviews.

4.2 Where the Gaps Are

It might be beneficial to discuss specifically what kind of gaps in environmental protection seem to be the most problematic in the US.

First, NEPA review, without more, does not prevent harm. It requires government agencies to assess the environmental impacts and to disclose them. However, even the finding of significant impacts does not preclude implementation of the project under the law. The actual environmental protection occurs during the review process itself, which is largely dependent on the seriousness with which the reviewing agency fulfills its duties.

Secondly, those substantive statutory requirements for protection of the environment that exist, namely, the Clean Water Act, Clean Air Act, and Endangered Species Act, were not intended to address the issue of rocket launch operations in their specifics. Application of those Acts to such specific conditions as are present at the commercial rocket launch site is complicated, as the case of alleged water contamination at Boca Chica made clear, as well as the question of the adequacy of the coordination between EPA, FAA, and Army Corps of Engineers in the matter (Flying Magazine, 2025).

Thirdly, the issue of participation of local communities and indigenous people in environmental review process has been criticized. The Center for Space Policy and Strategy have highlighted the prevailing trend in congressional discourse on space regulatory reform which has focused on streamlining licensing in order to benefit operators, not strengthen protections for communities (Center for Space Policy and Strategy, 2024). If this continues, the holes will only continue to grow larger.

From a comparative perspective, it is also worth considering that the way that other nations deal with such issues is not necessarily the same. While some nations include requirements for environmental impact assessments in their national space licensing systems, others do very little. In general, it has been described by the Hungarian Journal of Legal Studies as quite a patchwork of different approaches (Hesterman and Woodburn, 2024). The importance of this issue stems from the fact that commercial launches now typically feature operators based in various jurisdictions, often for the purpose of a lighter regulatory environment.

5. Private Operators and the Issue of Accountability

One of the fundamental issues present within the current state of law has to do with private companies. The Outer Space Treaty imposes obligations on space activities on states. However, the people who are launching rockets in 2026 are private operators. The institutional infrastructure constructed in the name of states does not fit the reality where a single private firm is responsible for launching more rockets into space in a year than the majority of states has ever done in their history.

This situation is highlighted by Reinert (2022). Since the Liability Convention is based on the architecture of the state, the communities affected by private launches will have to contact the state to raise a claim through it. This will be politically unlikely for a number of reasons. For example, a local small community in Texas or an indigenous tribe in southern India located near the launch site do not have many diplomatic tools at hand.

However, national liability requirements will be of some help. In the United States, a license for launching spacecrafts requires carrying third-party insurance, but the amount will be insufficient in case of extensive environmental damage. Also, according to Clyde & Co. (2025), the space insurance sector is underdeveloped: out of 10,000 active satellites, no more than 300 are insured. First, for the period 2023-2024, there were claims greater than the premiums paid for insured satellites. This means that the risk pricing does not reflect yet the current situation.

Then, there is a problem of cumulative effects. A single launch might not exceed the threshold triggering a comprehensive review of its environmental effects. However, hundreds of launches per year from the same place, or even thousands of launches worldwide, would produce significant environmental effects. The licensing process as such might not be geared to identifying such cumulative damage because it is based on individual licensing decisions. A programmatic EIS would address this question better, but it is not mandatory according to current regulations.

6. How Things Can Be Done Otherwise

It should be admitted that there are certain limits to saying something sensible. Scientific understanding of the effects discussed is still evolving. Political climate concerning multilateral space regulation is complicated. And reform proposals should be elaborated carefully before advocacy. Taking all that into consideration, however, a few directions look promising.

At the international level, a protocol to the Outer Space Treaty addressing specifically environmental impacts from launches may be considered. It would include requirements to conduct environmental impact assessment prior to licensing, reporting requirements concerning atmospheric emissions, and provisions addressing transboundary environmental damage. The Northwestern Journal of Law and Social Policy has even suggested that something similar to the Montreal Protocol approach will become applicable at a certain point in time in order to address the atmospheric impacts of rocket propellants (Northwestern Journal of Law and Social Policy, 2023). The issue whether there is political will in the international arena to negotiate on such issues remains open.

An alternative international approach would consist in widening the COPUOS sustainability framework to include the impacts of launches on both atmosphere and Earth surface. The Space Debris Mitigation Guidelines may serve as an example – they are not legally binding but receive quite widespread compliance. Guidelines concerning environmental monitoring in the vicinities of launch sites and propellant preferences may prove possible to develop even without negotiating a treaty. In terms of the national approach in the United States, some additional specific actions may also appear sensible. Requiring the performance of an EIS for any commercial company that intends to perform a certain threshold of launchings annually at a particular location would address the problem related to cumulative effects. The clarification of jurisdictions and improving inter-agency cooperation among the FAA, EPA, and other agencies in a formal inter-agency agreement would solve the issue of unclear jurisdictions revealed by the Boca Chica case. The increase in the number of personnel and technical skills of the FAA/AST is the more general and fundamental need that is generally recognized, yet remains to be done.

Another issue that can be discussed is the redefinition of the term "damage" used in the Liability Convention. The provision of such damage that will include environmental damage and the right of sub-state actors to receive compensation will make the convention more realistic in light of the needs of today. Reinert (2022) stresses the challenges of modifying the international agreements in the current political climate. However, model legislation or even interpretive guidance can be a less complicated solution.

7. Discussion

Reviewing the data and the analysis above, several trends seem clear even as it may be advisable to be cautious in stating their strength.

First, there appears to be an increasing environmental problem here. As can be seen from the data in Fig. 1, there is a worrying trend which has become quite noticeable. The projections in Fig. 2, developed by Ryan et al. (2025), suggest that the atmospheric effect will become noticeable in the very near future under realistic conditions of further license issuance. The incidents of environmental degradation in the vicinity of Boca Chica including the scorched wildlife refuge, wetlands pollution, and wastewater allegations are examples of actual problems, the scale of which exceeds that assessed during the course of the environmental review procedure.

However, the factual basis for our assessment seems to be far from complete. In particular, the atmospheric assessments are based primarily on model projections. It is also difficult to draw any definitive conclusions regarding causality between individual launches and changes in the ecology due to the data gathered through observation. The IRL research performed by Arata et al. (2025) is refreshingly honest in recognizing this difficulty. What emerges is an image of a toolbox ill-suited for the modern world. The Outer Space Treaty and the Liability Convention were developed without keeping in mind the issues of rapid-fire launches by private companies or the atmospheric impacts of rocket emissions. These conventions were created back in the 1960s and 1970s and thus embody all the preoccupations of that time military applications of outer space, questions of liability between states, the issue of sovereignty of the Moon.

There are national systems that can partially compensate for the insufficiency of the international legal framework, at least in more developed regulatory systems. However, these systems have limitations too. NEPA can be analyzed minimally. It lacks enforcement capabilities. Interagency cooperation is not perfect. And there is political pressure to make the licensing process quick and lightweight in order to facilitate the growth of an industry.

International component is also important here in a way no purely domestic change could ever compensate for. Ozone layer does not know borders, so do launch emissions. Biodiversity hot spots pointed out by Ang et al. (2024) in South and East Asia are vulnerable to emerging space powers which might still be working on the development of their environmental governance regimes in the space sector domestically. One single improvement in regulation of one such country would hardly address this problem.

8. Conclusion

The space industry is developing rapidly. The available scientific evidence shows that its growth has certain environmental consequences which have not been taken seriously enough yet. These include both the negative effect on habitats in the vicinity of the launch site and the potential damage to the stratospheric ozone layer.

The existing legal regime in this field is outdated. The Outer Space Treaty and Liability Convention adopted in 1967 and 1972 respectively were not prepared for the realities of commercial space exploration where flights occur hundreds of times each year. The environmental regime established by these documents is quite general; moreover, its enforcement mechanisms are insufficient and focused on interstate relations.

Additional coverage is provided by national regimes. The case of the US illustrates a process which is fraught with tension; a situation where environmental impact assessments may not always be comprehensive enough, when the coordination between agencies fails, and where public opinion, especially indigenous, is not being considered all the time.

As one can see from Figure 1, the number of launches is growing very fast indeed. Figure 2 indicates that the results of that growth in terms of effects on ozone layer might start showing themselves within the next 5 to 10 years. Thus, it appears that the need for addressing this problem in a timely fashion arises. It is not the intention of this article to provide any one answer to this issue. A lot of thought would have to go into that. Yet what does seem clear is that the current situation cannot be sustained for a long time to come.

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