

Secure World Foundation
Preprint Series

PP26.06

Chapter 23 in The Oxford Handbook
of the New Space Economy

Responsible Investment
Considerations for
Space Sustainability

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About Secure World Foundation

The Secure World Foundation (SWF) is a private operating nonprofit foundation dedicated to promoting the secure, sustainable, and peaceful uses of outer space, ensuring its preservation for future generations.

As the only organization devoted entirely to space sustainability, SWF collaborates with international partners in governments, industry, and civil society to foster policies and practices that enhance the protection of the space domain. Recognizing the rapid increase in the number of actors in outer space and the urgent need to promote norms of behavior and best practices to ensure sustainable activities in space, SWF is committed to facilitating dialogue, informing policy decisions, and fostering international cooperation in the peaceful uses of outer space. Through these efforts, SWF strives to ensure that space remains an accessible, safe, and stable operating domain for commercial, military, and civil use by all nations.

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Doc. #PP26.06

Last Update: February 13, 2026

Published in The Oxford Handbook of the New Space Economy,
Anthony P. D'Costa (ed.), 27 January 2026
<https://doi.org/10.1093/oxfordhb/9780198881049.013.0036>



The Oxford Handbook of the New Space Economy

Anthony P. D'Costa (ed.)

<https://doi.org/10.1093/oxfordhb/9780198881049.001.0001>

Published: 18 December 2025

Online ISBN: 9780191990526

Print ISBN: 9780198881049

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CHAPTER

23 Responsible Investment Considerations for Space Sustainability

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<https://doi.org/10.1093/oxfordhb/9780198881049.013.0036> Pages 461–479

Published: 27 January 2026

Abstract

Space-based information and services form part of the critical infrastructure of many countries. The societal benefits of space activities are increasingly being provided by commercial operators in the context of a rapidly expanding space economy that is fueled by private sector investment. However, commercial space actors operate in a globally shared orbital domain, which is a limited natural resource that must be used rationally, equitably, and responsibly. This requires responsible investment decisions and practices by investors. This chapter discusses the concept of space sustainability, the role of investors in creating a sustainable space economy, what constitutes responsible investment in the space domain, the benefits of responsible investment practices in space, and the risks of not pursuing responsible investment practices. The chapter closes with a discussion of the elements of responsible investment practices in space and provides guidance to investors on a responsible approach to space investing.

Keywords: [space activities](#), [space sustainability](#), [responsible investment](#), [space economy](#), [space investment](#), [circular space economy](#)

Subject: [International Economics](#), [Macroeconomics and Monetary Economics](#), [Economics](#)

Series: [Oxford Handbooks](#)

Collection: [Oxford Handbooks Online](#)

1. Introduction

The term “new space economy” is loosely defined, but just about any definition of this term would include reference to growth in commercial space activities fueled by private capital and entrepreneurial innovation and dynamism. In this chapter we focus on the role of investment in growing the space economy in a responsible and sustainable manner. The new space economy has evolved in a series of successive waves of investment. The first wave demonstrated that private capital and entrepreneurial efforts could succeed in markets that had formerly been the exclusive preserve of governments and a few large established aerospace prime contractors to governments. One of those markets was launch. The first wave saw the development of reusable launch vehicles that dramatically reduced the cost of launch. This set the scene for the second wave of investment, characterized by a significant expansion of private capital flows into the space sector that financed a surge of entrepreneurial efforts across the space economy. Some of this growth was fueled by optimistic projections from various institutions in the late 2010s that space would grow into a trillion-dollar economy by 2030 (Crane et al. 2020). Government agencies also began to look to commercial New Space providers of space capabilities to meet their needs. This led to a broadening of the number of participants and the emergence of new commercial space-based applications and services, the most prominent of which are the large low-Earth orbit satellite constellations comprising tens of thousands of satellites. Peaking in 2021, investments in the second wave declined during 2022 and 2023, partly in response to global economic headwinds and their damping effect on all markets, but also partly due to investor expectations being tempered by the realization that “space is hard,” as evidenced by the significant number of companies funded at the beginning of the second wave that failed to meet investor expectations.

After waning for several years, investor interest in the space economy is gradually on the rise again, building up to a third wave of investment in the space economy that will pave the way for the development of in-orbit logistics and servicing, which will be foundational capabilities for an orbital economy where goods and services are produced in space for customers in space. The rapid growth of the commercial space sector in recent years has been fueled by a great influx of private sector capital that rivals the collective investments of national governments during the first decades of the Space Age. Investors are attracted to the space sector by the lure of potential profits and because they want to be part of creating the new space economy. While investors understand and accept that investments in space are riskier than investments in other more mature terrestrial sectors, they are generally less aware of the potentially serious consequences of failure of space investments.

Unlike failed investments on Earth that usually only impact the investors and those directly concerned with a given enterprise, failures in space can have unpredictable and long-lasting consequences for many other space actors and people on Earth with no connection to the failed investment. This difference stems from operating in the orbital environment, where everything is in rapid motion, compared to operations on Earth, which are either stationary or moving at much lower velocities. Therefore, to preserve space as a safe, stable, and predictable operating domain for commercial space actors, their space activities must be carried out in a responsible manner that is sustainable and minimizes harm to the space environment and risks to the safety of space operations.

When investment decisions are made with regard to commercial space activities, one of the criteria used is that of financial sustainability. It is important to understand that, while a given commercial space activity may be financially sustainable and profitable in the short to medium term, it may be carried out in a manner that is ultimately unsustainable in the long term, especially if multiple actors behave in the same unsustainable way. Thus, from an investment perspective, space sustainability is strongly correlated with the *collective* long-term financial sustainability of commercial ventures in space. In other words, achieving a sustainable space economy will only be possible if space actors conduct their space activities in a sustainable manner. This

paradigm is widely accepted for commercial activities on Earth, but it applies equally to commercial activities in space.

This chapter discusses the role of investors in creating a sustainable space economy, what constitutes responsible investment in the space domain, the benefits of responsible investment practices in space, and the risks of not pursuing responsible investment practices. To set the scene for our discussion, Section 2 begins by defining the terms “space sustainability” and “responsible investment” as used in the context of this chapter. Section 3 describes the challenges to space sustainability that have arisen from the rapid expansion of the space economy, namely orbital congestion with active satellites, the proliferation of space debris, and the contestation of limited orbital resources. Section 4 discusses the evolution of space sustainability as a concept and draws connections between space sustainability and sustainable development on Earth. With this sustainability framing in place, the second half of the chapter focuses on the connection between responsible investment in space and space sustainability. Section 5 addresses the role of investors in developing a sustainable space economy. Section 6 describes what responsible investment means in the space context, outlining both the benefits of responsible investment in space activities and the consequences of not making responsible space investment decisions. Section 7 weaves together the various strands of the preceding sections to discuss the elements of responsible investment practices in space and ends by offering guidance to investors on the elements of a responsible approach to space investing. Section 8 concludes, followed by an epilogue.

2. Definitions of Space Sustainability and Responsible Investment

As the focus of this chapter is on responsible investment for space sustainability, it is instructive to begin our analysis with a brief discussion of what we mean by the terms “responsible investment” and “space sustainability,” because there is no single, universally accepted definition of either concept.

p. 463 “Space sustainability” is a term that has entered the vocabulary of the space community only within the last ten years or so and it has been understood in different ways by different actors. In Section 4, we will trace the emergence and evolution of the concept of space sustainability and its connection to the broader narrative of sustainable development on Earth, but at this point it would be helpful to give a general, high-level definition for the purpose of our discussion. At the time of this writing (June 2024), there are more than 10,000 active satellites orbiting the Earth that provide tangible social, scientific, and economic benefits to billions of people on Earth. Yet, the ability to continue providing these benefits is threatened by a number of challenges, such as orbital congestion, space debris, and contestation of economically valuable orbits. These challenges are discussed in Section 3. For the purposes of our discussion, simply put, *space sustainability is about ensuring that all of humanity can continue to use outer space for peaceful purposes and socio-economic benefit, now and in the long term.*

The concept of responsible investment is well established in the investment community, even if there are different interpretations of what this term means. The origins of the concept can be traced back hundreds of years,¹ but it was the emergence of the mass environmental movement of the 1960s that brought it into the modern age. The first manifestations appeared in the investment and disinvestment decisions of major multinational corporations in the chemical and petroleum sectors, based initially on environmental considerations, but then later expanded to include social issues as well, which ultimately led to actions such as widespread disinvestment from South Africa during the apartheid era. Since the early 2000s, climate action has been a major focus of responsible investment philosophies.

A growing number of people (and investors in particular) want companies to act responsibly in addition to delivering financial returns. The terms “environmental, social, and governance (ESG) investing,” “responsible investing,” and “impact investing” are often used interchangeably, but have important differences that we will

not discuss here.² For our discussion, we can say that *responsible investment is about selecting or disqualifying investments based on specific ethical or environmental impact criteria, in addition to the traditional financial analysis and portfolio construction techniques, and about influencing portfolio companies to adhere to stated responsible investment principles and goals through active ownership*. Responsible investment is premised on the notion that long-term profitability and long-term sustainability are intimately linked to each other. This is expressed in the “triple bottom line” concept—people, planet, profit—introduced by John Elkington (1994). This chapter makes the case that this sort of thinking needs to be extended to space activities, which have not traditionally featured in sustainable development narratives, and that the investment community has an important role to play in ensuring space sustainability.

With this basic framing of the concept of space sustainability in place, in Section 3 we will delve into the main challenges for space sustainability before proceeding to connect space sustainability to the broader concept of sustainable development on Earth.

3. Challenges to Space Sustainability

Most of the commercial space activities of the New Space Economy are taking place or planned to take place in various Earth orbits, cislunar orbit, or on the lunar surface. The largest concentration of satellites is to be found in low Earth orbit, which ranges from about 300 km to 2,000 km in altitude. Although Earth orbits circumscribe a vast volume of space, it is nevertheless finite, and constitutes a limited natural resource that must be used rationally and equitably. In this section, we will describe how the Earth’s orbital domain is becoming increasingly *congested* with active satellites, increasingly *contaminated* with space debris, and increasingly *contested* by state and non-state actors alike. These three key trends constitute major challenges to space sustainability. We will examine each of these three challenges in more detail in the following subsections.

3.1 Congestion by Active Satellites

As of this writing (June 2024), there are over 10,000 active satellites in orbit around the Earth. This number has been increasing exponentially in recent years, driven mostly by the deployment of very large satellite constellations by commercial operators. Just one such constellation, Starlink, will have more satellites when it is completed than all the satellites that were launched by all nations during the first 60 years of the Space Age, which began with the launch of *Sputnik* on October 4, 1957.

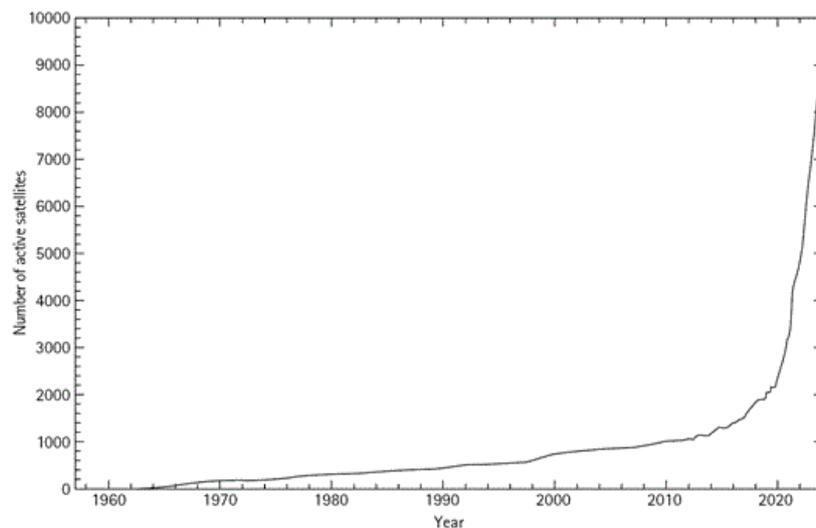


Figure 23.1 Evolution of the Number of Active Satellites in Earth Orbit (October 1957–December 2023)

Source: Data from the General Catalog of Artificial Space Objects (J. McDowell, planet4589.org/space/gcat).

The current rate of increase in the number of satellites shows no signs of abating (Figure 23.1). Taking into consideration all the other large constellations currently being planned or under development, not to mention all the other individual satellites under development by a growing number of space actors, we are likely to see tens of thousands of new satellites in space by the end of the decade. Clearly, this rate of growth in the number of satellites cannot be sustained indefinitely, because at some point we will start to run up against the limitations of orbital carrying capacity.³ Long before that happens, we will need to develop some form of space traffic management to avoid collisions among active satellites.

However, active satellites represent only the tip of the iceberg of collision hazards in space, and in fact, this is the comparatively “easy” challenge to solve, because active satellites have known trajectories and many have the capability to maneuver to avoid collisions. Space debris poses a far greater challenge.

p. 465 **3.2 Contamination by Orbital Debris**

Since the early days of the Space Age, space systems have delivered, and continue to deliver, countless societal benefits to people on Earth. However, these benefits have come at the cost of the degradation of the Earth’s orbital environment through the introduction of a large quantity of anthropogenic orbital debris.

The space environmental legacy of the first 60 years of the Space Age is a vast number of defunct satellites, mission-related debris, rocket bodies, and fragments of these classes of objects in orbit. According to the Space Debris Office of the European Space Agency (ESA), there were 36,500 of these debris objects large enough to track as of September 2023 (ESA 2023a). The active satellites therefore represent around 20% of the total number of tracked space objects.

However, this population of tracked debris represents only the part of the orbital debris iceberg that is visible just above the water. It corresponds to objects with at least one dimension greater than 10 cm in size that can be consistently detected and tracked using optical and radar sensors. In other words, this is the visible debris that is known and tracked, and can therefore be monitored for potential collisions with active satellites or other debris. In addition to this known debris population, there is a much, much larger population of objects that are too small to track, whose existence is known only statistically. The ESA Space Debris Office estimates that there may be as many as one million space debris objects ranging in size from 1 cm to 10 cm, and perhaps as many as 130 million ranging in size from 1 mm to 1 cm (ESA 2023a). All of these objects pose collision hazards for active

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satellites and human spaceflight. Active satellites capable of maneuvering can avoid collisions with the larger trackable objects, but they cannot evade the smaller untracked debris objects because there are no orbital data for those objects, so there is no way to predict when and where a hit from one of those objects will occur. Yet, even small debris objects can pose a significant risk \hookrightarrow of a catastrophic collision to operational satellites and crewed spacecraft. Figure 23.2 shows examples of such impacts by orbital debris on an operational satellite and the International Space Station (ISS).

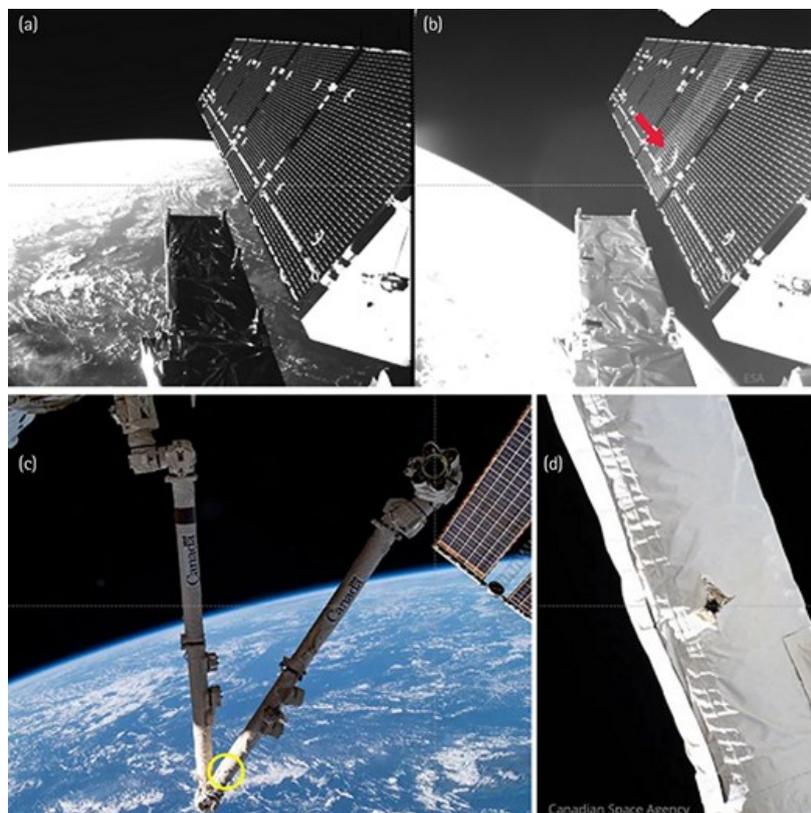


Figure 23.2 Examples of Debris Impacts on Satellites and Crewed Spacecraft in Orbit

Note: Examples of Debris Impacts on Satellites and Crewed Spacecraft in Orbit. Panels (a) and (b) show one of the solar arrays of the European Space Agency's *Sentinel 1A* satellite before (a) and after (b) a piece of debris hit it in space. The depression in bottom one-third of the second solar panel (white arrow) in (b) indicates the location of the strike. Panel (c) shows the Canadarm on the International Space Station (ISS), with a white circle indicating the impact point of a debris fragment. Panel (d) is a close-up of the area in the white circle from Panel (c), showing the damage to the thermal insulation on Canadarm, which was pierced by the debris object.

Source: Panels (a) and (b), ESA; Panels (c) and (d), NASA.

Collision avoidance and collision resilience both impose additional costs and operational risks. In the case of collision avoidance, an operator has to use the operating fuel on the spacecraft meant for orbit maintenance to perform collision avoidance maneuvers. Often the quantity of available maneuvering fuel is a limiting factor for the operating lifetime of a spacecraft, so consuming station-retaining fuel to avoid collisions reduces the operating lifetime of the spacecraft and hence its profitability.

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If a spacecraft is designed to be refueled in orbit, then one could replenish the fuel used for collision avoidance maneuvers, but this comes at additional cost and risk to the operator. In \hookrightarrow the case of the smaller untrackable debris, the only option is to make the spacecraft more resilient to small debris impacts. This may be achieved through the use of shielding and greater redundancy to eliminate single-point failures, but that drives up the cost of the satellites. Another option would be to focus on resilience at the system level and forego resilience at

the individual spacecraft level by accepting that one will have to replace a number of spacecraft damaged by debris. This strategy has the downside of compounding the debris problem, unless the satellites rendered non-functional by debris impacts are somehow removed from orbit. Here we start to see the sorts of considerations that come into play when making responsible investments in space systems.

3.3 Contestation over Orbital and Other Space Resources

Fans of *The Hitchhiker's Guide to the Galaxy* will be familiar with the oft-repeated Douglas Adams quote "Space is big," and while this may be true in the interplanetary or cosmic sense of the word, the part of space that matters most to us is the space around planet Earth. This orbital space is a limited natural resource that is becoming increasingly congested by a steadily increasing number of space actors, all of whom have equal rights to access the space domain.⁴ Likewise, since all satellites use the electromagnetic spectrum to communicate and transfer data, the spectrum, too, is becoming increasingly contested, as is evidenced by the growing number of satellite filings lodged with the International Telecommunication Union (ITU) (Figure 23.3) and the battle over frequency bands vital to all manner of wireless communications at the quadrennial World Radiocommunication Conferences (WRCs) convened by the ITU.

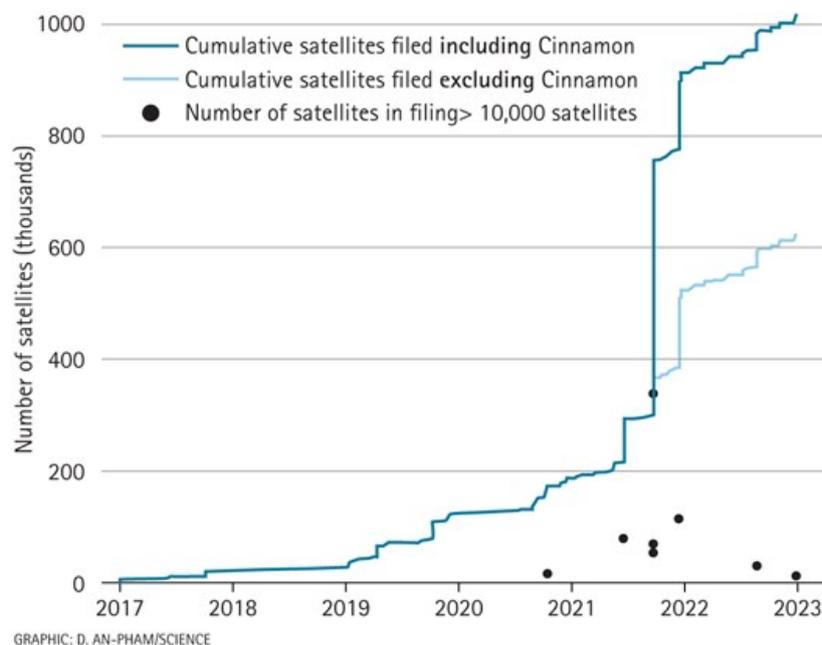


Figure 23.3 Number of Satellite Filings Lodged with the International Telecommunication Union (ITU) from January 1, 2017 to December 31, 2023

Notes: Rwanda's 337,320-satellite constellation, Cinnamon-937, is currently the single largest satellite constellation on the ITU's books (Falle et al. 2023).

Source: doi: 10.1126/science.adi4639, used with permission.

The Earth's orbital space and the frequencies of the electromagnetic spectrum constitute finite natural resources that must be used rationally and equitably. In the early days of the Space Age, these limitations were not as evident as they are today, and space operators could essentially ignore other operators, most of the time. However, with the rapidly accelerating pace of space activities and the growing congestion in orbit, there are mounting concerns that humanity may eventually run up against these natural limits to growth of space activities. Developing countries that do not yet have their own national space programs are also concerned about their ability to access these spectrum and orbital resources in the future.

Although it is the case that more countries are becoming space nations (as of this writing, 94 countries have operated at least one satellite in space), most of the new space actors are non-state actors. Many of them come from other industrial domains (e.g., software and communications) and may not be aware that, when they become part of the global space arena, they are entering a fragile and strategic domain. Some of the behaviors that these actors are accustomed to practicing in their customary terrestrial industrial domains may not be appropriate for the space domain.

Space is also becoming increasingly contested by military actors. Once seen as a means of enhancing military capabilities on the ground, space is now also being seen as an operational domain by the militaries of the leading space powers as they jostle for control of the new “high ground” of space. As more militaries increase their reliance on space systems, they are taking steps to protect their space systems from attack while also developing offensive capabilities to disrupt, degrade, deny use of, or destroy the space capabilities of an adversary. These counterspace capabilities use kinetic as well as non-kinetic means of engagement. Some of these capabilities cause temporary and reversible disruptions to space systems, but others, such as direct ascent anti-satellite missile intercepts, are particularly worrying because they create large amounts of orbital debris that pose a collision risk to the space systems of many other space actors, not only the actor originally targeted by such an intercept.⁵

Commercial operators of large constellations are having to perform thousands of collision avoidance maneuvers every year to dodge space debris, a significant fraction of which is debris linked to these destructive anti-satellite tests (Oltrogge et al. 2022). Such is the concern about this source of debris that, in December 2022, the United Nations General Assembly passed resolution 77/41 calling upon states to commit not to conduct such tests in orbit. As of December 2023, 37 States had made the commitment called for in that resolution. A number of industry space operators have also added their voice in support of the call to end such debris-producing anti-satellite tests (Berger 2023).

In this section, we have identified and described the three main challenges to space sustainability, namely: orbital congestion with active satellites, the proliferation of orbital debris, and the contestation among a growing number of actors for access to limited orbital resources. Next, we will examine how space sustainability relates to broader discussions of sustainability in general and discuss the connection between space sustainability and sustainable development on Earth.

4. The Emergence of Space Sustainability as a Concept

The term “space sustainability” has become a part of the vocabulary of the space community only within the last ten years or so. Initially understood in rather limited terms to be about the dangers posed by space debris, a much richer understanding of the concept has evolved in recent years. In this section, we will trace the emergence and evolution of the concept of space sustainability and locate it within the broader narrative of sustainable development. Our discussion will be largely framed in the context of the sustainable development dialogues in the United Nations system because sustainability is a global challenge and the UN is the leading global forum shaping a common understanding of the challenges of sustainability and the collective actions needed to address those challenges.

There are some interesting parallels between the genesis and evolution of the concept of sustainable development on Earth and the concept of space sustainability. The concept of sustainable development, as we now understand it, had its origins in the environmental movement of the 1960s and 1970s, which arose out of concerns over environmental degradation due to overpopulation and pollution. Gradually over the course of the ensuing decades it gave rise to the much broader concept of sustainable development now encapsulated in the 17 Sustainable Development Goals adopted by the United Nations in September 2015 (see also Chapter 30 in this handbook).

In a similar manner, what is now broadly understood to encompass space sustainability began with a concern about the degradation of the Earth's orbital space environment through the proliferation of orbital debris and the steadily increasing number of satellites and space actors. Deeper reflection has revealed that space debris is symptomatic of the underlying unsustainable way in which humanity has been conducting space operations during the past 60 years. In the first few decades of the Space Age, there were only a handful of nations conducting space activities and the number of satellites was sufficiently low that each actor could operate largely without concern that their activities might affect other actors or degrade the space environment through the introduction of orbital debris. This situation prevailed up until the late 1990s. Beginning in the early 2000s, the increased availability of commercially available off-the-shelf space-qualified components for small satellites made space accessible to a much broader range of actors from the academic and entrepreneurial worlds. This in turn increased the demand for more affordable access to space. During the mid-2010s, the advent of more plentiful and less costly opportunities for access to space provided yet another boost to the burgeoning commercial space sector. This dramatic lowering of both the financial and technological barriers to space activities has enabled many more actors to enter the space arena, thus resulting in a much more congested orbital domain and a proliferation of orbital debris.

p. 470 Already in the late 1980s, there were concerns among the leading space agencies about the unmitigated proliferation of orbital debris and the possibility of debris-on-debris collisions resulting in a runaway cascade of debris creation, dubbed the "Kessler Syndrome" [↳] after the seminal paper by Kessler and Cour-Palais (1978). Following the explosion of an upper stage in low Earth orbit in 1986, NASA and ESA convened a conference on the topic in 1987 and subsequently established a working group to start addressing debris mitigation from the technical, policy, and operational perspectives. This working group was later expanded to include other space agencies as well, and became the Inter-Agency Debris Coordination Committee (IADC), which established the first international standards for debris mitigation.

By the late 1990s, it was clear that the debris situation in orbit was getting worse and more concerted action at the global level would be required to address the issue. The last global UN conference of the second millennium was the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), held in Vienna in 1999, and space debris was among the items discussed. The outcome document of this UN summit, *The Vienna Declaration on Space and Human Development*, called for action "to improve the protection of the near-Earth space and outer space environments through further research in and implementation of mitigation measures for space debris". This was the first time that a UN summit outcomes document made reference to the protection of the space environment. It would be almost another two decades before the connection between protecting the space environment and protecting the Earth's environment would be made.

The call for protecting the space environment was picked up by the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS), which addressed aspects of this issue through various action teams and working groups. Gradually, the space community came to realize that space debris was the symptom of a more complex set of underlying challenges that stemmed from the way in which space activities were being conducted and which had technical, scientific, policy, and regulatory dimensions as well. In 2010, COPUOS established a Working Group on the Long-Term Sustainability of Outer Space Activities to address the issue in a more holistic manner (Martinez 2023).

This working group discussed the topic in depth over the next eight years, and in 2019, UN COPUOS adopted a set of 21 Guidelines for the Long-Term Sustainability of Outer Space Activities (United Nations 2019) that comprise a collection of internationally recognized measures for ensuring the long-term sustainability of outer space activities and for enhancing the safety of space operations. The guidelines address the policy, regulatory, operational, safety, scientific, technical, international cooperation and capacity-building aspects of space activities that are now collectively referred to as "space sustainability." Strictly speaking, the term "space sustainability" is a misnomer, because what we are really referring to is the long-term sustainability of *space activities*, not the sustainability of the space environment itself, but the term is now firmly entrenched in the

vocabulary of the English-speaking space community. However, the UN has six official working languages and COPUOS adopted a more precise definition:

The long-term sustainability of outer space activities is defined as the ability to maintain the conduct of 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, in order to meet the needs of the present generations while preserving the outer space environment for future generations. (United Nations 2019)

In September 2015, the United Nations adopted the 2030 Agenda for Sustainable Development to address global challenges in the form of 17 Sustainable Development Goals (SDGs), which have 169 associated targets. The Agenda 2030 document has numerous references to the importance of preserving the planet that is our home, but not a single reference to the indispensable role of space activities in supporting the achievement of Sustainable Development Goals, nor of the importance of preserving the Earth's space environment, if only to support the achievement of the SDGs. At the time Agenda 2030 was adopted, this connection had not yet been made in the multilateral fora. However, once adopted, Agenda 2030 was assimilated into the priorities and work of all UN bodies, including COPUOS, which then set about demonstrating how space activities could support Agenda 2030.

When the space sustainability guidelines were adopted in 2019, there was a conscious effort to link space sustainability to the wider sustainable development narrative in the UN, and this was done through the definition of space sustainability adopted by UN COPUOS. Readers familiar with the "Brundtland report" titled *Our Common Future* by the World Commission on Environment and Development (United Nations 1987) will notice a parallel between the definition of sustainable development on Earth given in that report as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" and the UN COPUOS definition of space sustainability quoted above.⁶

With this broader understanding of the concept of space sustainability and its intimate connection to sustainable development on Earth, we now turn to the role of the investor vis-à-vis sustainability in the space context. When investment decisions are made with regard to commercial space activities, one of the criteria used is that of financial sustainability. It is important to understand that, while a given commercial space activity may be financially sustainable and profitable in the short to medium term, it may be carried out in a manner that is ultimately unsustainable in the long term, especially if multiple actors behave in the same unsustainable way. In other words, space sustainability is a precondition for a sustainable space economy.

5. The Role of Investors in Developing a Sustainable Space Economy

Having established the importance of conducting space activities in a sustainable fashion, in this section, we will discuss the role of the investment community in developing a space economy built on sustainability principles. We note that, when we refer to a "sustainable space economy," we are referring to sustainability from both the environmental perspective as well as the business perspective. We will begin by noting that the investment community plays a significant role in building and maintaining a sustainable space economy through its influence in shaping the interactions among the various actors. These groups of actors comprise:

- (1) *Companies* (of various sizes, maturity, and type of service/application);
- (2) *Various types of investors* (e.g., angel, venture capital, institutional, family offices);
- (3) *Government* (acting as both customer and regulator); and
- (4) *Nongovernmental customers* (e.g., business-to-business (B2B) and direct business-to-consumer (B2C))

markets).

p. 472 In a growing and diversifying space economy, investors have an important role to play in addressing the unique sustainability challenges associated with operating in the space domain. This begins with considering the impact of a planned activity on the space environment. Return on investment (ROI) and growing the benefits from space activities depends upon maintaining a stable and safe operating environment in orbit. Therefore, an investment strategy that considers the importance of responsible operations practices and seeks to promote a stable and safe operating environment can also contribute to growing the potential returns from space activities.

While investment decisions are often driven by near-term ROI considerations, space ventures are generally long-term endeavors, with potentially even longer-term environmental implications. Some of the traditional short-term approaches and thinking of venture capital investment practices on Earth exacerbate space sustainability risks. If investments in a space activity are made without considering the impact of that activity on the space environment or the space activities of other actors, this could contribute to the emergence of a “tragedy of the commons”⁷ situation where space operations could become unsafe and unsustainable, eventually leading to the loss of investments and the degradation of future investment opportunities.

Broadly speaking, sustainability is increasingly a desired outcome of investment decisions in many sectors and is underpinned by the triple bottom line philosophy that encourages investors to seek out projects that have a positive social impact while not contributing to the net degradation of the environment. This means that impact and sustainability are increasingly at the top of everyone’s minds: in family offices, institutional investors, angel investors, and venture capital firms.

As an example, we can point to the response of industry to the growing societal acceptance of the need for urgent collective action to combat the anthropogenic causes of climate change and its impacts. A growing number of companies wish to be seen as responsible corporate citizens and are taking steps to reduce their carbon footprint. This has led to a number of “net zero” initiatives around the world aiming to slow down significantly (and ultimately arrest) global warming by reducing industrial and other anthropogenic greenhouse gas emissions. This same “net zero” philosophy is now extending to the space domain, as exemplified by the Net Zero Space initiative of the Paris Peace Forum (PPF 2023) and the Zero Debris Charter of the European Space Agency (ESA 2023b), which both aim to achieve sustainable use of the Earth’s orbital environment by 2030 by taking concrete steps to mitigate the production of new orbital debris and remediate existing debris. Both initiatives have attracted interest from a considerable number of commercial entities.

The rationale for including environmental sustainability considerations in investment decisions and seeking out companies that exhibit responsible behaviors and encourage others to follow suit is that, quite apart from the ethical argument that “it’s the right thing to do,” it is also a way to make investment decisions now that will sustain and even increase investment opportunities in the future. This is the basic premise of responsible space investing. In the next section, we will discuss what responsible investment means in the space context.

6. Responsible Investment in the Space Context

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In Section 2, we discussed the notion of responsible investment in general terms and suggested that the triple bottom line thinking of people-planet-profit (Elkington 1994) should be extended to the orbital economy. In this section, we will discuss what responsible investment means in the context of the space sector, the benefits of responsible investment, and the potential consequences of not making responsible investment decisions.

Responsible investment in the space sector can be defined to be an investment philosophy and approach that explicitly considers the role that the investor and portfolio companies play in promoting the long-term health

and stability of the market through the manner in which the funded entities operate in the orbital environment. This philosophy and approach manifests through selecting or disqualifying investments based on specific ethical or environmental impact criteria, in addition to the traditional financial analysis and portfolio construction techniques, and by influencing portfolio companies to adhere to stated responsible investment principles and goals through active ownership.

This investment approach is premised on the belief that the long-term profitability of space investments is dependent on maintaining a safe and stable operating environment in space. Responsible space investing entails developing and maintaining a sustainable space investment ecosystem in which the various actors operate symbiotically to create, launch, and operate assets in space that maximize investment returns and benefits to society over the long term without contributing to the degradation of the space environment, interfering harmfully with the operation of other space assets, or reducing the ability of end users to benefit from space activities.

Responsible space investment recognizes that the consideration of potential value created by an investment opportunity should extend beyond the immediate financial return. The shared operating environment of the orbital space domain means that the actions of one actor can affect the ability of other actors to operate safely and sustainably in that domain. A safe and stable operating domain is essential for positive investment outcomes for those investing in companies that operate in the space domain (e.g., satellite remote sensing or communications operators) or those investing in companies that rely upon use of the space domain (e.g., companies involved in the downstream applications of satellite remote sensing or communications). Sustainability of the domain is an integral part of managing risk to return on investment. For the long-term success of commercial ventures in the space sector, it is important that investors consider sustainable use of the domain as part of their overall risk management process.

6.1 Benefits of Responsible Investment in Space Activities

Responsible use of the space domain drives stability and predictability, reduces risk in a number of ways, and increases safety and operational consistency in the domain (Maclay et al. 2021). Instilling responsible design and operations practices early in the life cycle of a space investment can contribute to reduced costs of operations. It can help to drive regulatory stability and consistency while contributing to common business norms across jurisdictions in support of fair market competition.

p. 474 Encouraging the development of responsible space activities can itself create new investment and market opportunities. These include direct investment potential in new and novel ↴ commercial services that may be created in support of space sustainability, such as space situational awareness services, orbital debris removal, satellite refueling and servicing, etc. It can also help create sustained downstream investment in the markets and services that are partially or fully enabled by space applications and technology. Space-enabled, communications, data, and other services are being used by a growing number of terrestrial industries to enhance the efficiency of their operations, as well as to expand their product and service offerings. Building sustainability and social impact (SSI) practices for the space domain might both enhance current space business opportunities (through contributing to SSI performance in terrestrial sectors) and help draw into the space sector institutional investors motivated by sustainability and impact considerations.

As more B2B and B2C space markets emerge, consumers and end users may prefer to support companies with a demonstrated commitment to responsible use of the space environment. In this regard, the development of metrics and standards for sustainable practices and operations in the space domain will contribute to both sustainability of the domain and growth of the space economy. As standards and/or sustainability rating initiatives specific to the space sector are developed, investors should remain engaged to support their

adoption and implementation by space industry and operators. Mature SSI-related metrics for space may also help draw in both public markets and further sources of capital not currently involved in the space sector.

6.2 Consequences of Not Making Responsible Space Investment Decisions

There are consequences to not encouraging responsible behavior in space activities; decisions that we make now might limit future investment opportunities and returns. In an increasingly complex and congested domain, failure to operate responsibly can increase instability and uncertainty, and ultimately negatively affect or limit society's ability to use the space domain in economically viable ways.

Failure to limit debris creation and to develop effective practices for coordination of space traffic will lead to increased collision risk and increased potential for harmful interference, which would in turn impose increased costs on operations, making business cases and financial returns more difficult to achieve. Failure to operate in responsible ways may lead to regulatory reactions that might limit business growth or impose additional costs.

Overall, developing operations practices and approaches that are not responsible may dampen demand from governments and end-user customers for certain space services. For example, if certain operators are perceived to behave in an irresponsible and unsafe manner, customers may have concerns about service or data continuity and may seek non-space alternatives. Lack of sustainable space operations practices could ultimately pose a risk to other investable markets as well—markets that in some cases provide the capital that supports space investment. Commercial satellite operators rely on the stability of the orbital environment. If that environment becomes increasingly unstable, unsafe, and costly to operate in, the overall availability of capital for new space investments might decrease.

With this understanding of what constitutes responsible investment in space activities, and the reasons why investors should invest responsibly in space activities, Section 7 presents some considerations they should bear in mind when evaluating space ventures from a responsible investing perspective.

7. The Elements of Responsible Investment Practices in Space

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Responsible investment in space activities is foundational to the establishment of a flourishing, sustainable space economy. Thus far, we have demonstrated the importance of responsible investment in the space sector and we have described what, in general terms, constitutes responsible investment in space. In this section, we take a deeper look at some of the specific characteristics of space activities and then frame these into a set of considerations that investors can use to guide them in making responsible investment decisions. Consistent application of these considerations provides the basis for a set of responsible practices for investment in commercial space activities.

First, investors should begin with an understanding that space is a uniquely challenging investment environment, due to a variety of factors:

- *The nature of space as a shared domain* beyond national jurisdiction in which the actions of one party can affect the ability of others to operate safely and/or economically, both directly and indirectly.
- *The outdated governance framework* that is not keeping up with the rapid pace of commercial space activities, which gives rise to regulatory uncertainty and the possibility of fragmented or divergent regulation and regulation shopping.
- *The harsh physical environment of space*, which is exacerbated by the very limited to nonexistent ability to engage in maintenance, recovery, repair, and/or recycling of most assets currently deployed in space.

- *Operational risks* due to increasing orbital congestion, space debris, counterspace activities, and other behaviors that are perceived as irresponsible or threatening.
- *The dual-use nature of space technologies*, which means that national security considerations and technology transfer safeguards are ever-present realities that must be contended with by entrepreneurs and investors alike.
- *The use of space as a political and diplomatic tool*, which means that space investments are subject to national political and geopolitical uncertainties.

These factors combine in complex ways to impact on the financing and operations of commercial space activities.

When it comes to making informed space investment decisions, investors need to be mindful of the long time horizons for many space activities vis-à-vis traditional investment cycles. Not only are the markets emerging or immature, but investors also have to contend with a complex milieu of startups at the nexus between science fiction, technical feasibility, and business, and must have an ability to discern what distinguishes a viable space investment opportunity from very early stage companies with no proof of concept for their technology, no proven market, limited teams with little to no business experience, and little to no financing.⁸

p. 476 As with all investments, there is always the risk of failure. However, space investors need to be mindful that the negative consequences of failure in orbit could potentially extend far beyond the balance sheet and affect many more actors than just those directly involved in the investment. These consequences could be long-lasting as well if the failed investment results in debris that will remain in orbit for decades or even centuries.

In summary, investing responsibly in space requires an understanding of the uniquely challenging investment environment in space and the importance of developing specialized skills, approaches, and attitudes that support a responsible investment philosophy. As part of a responsible approach to space investing, space investors should:

- recognize that responsible investment in space activities requires a certain amount of domain-specific knowledge and an awareness of domain-specific risks, beyond what may be required in other sectors, to be able to make deep and balanced assessments of the viability and risks of the proposed investment, and of the full spectrum of consequences of failure;
- inform themselves of current gaps in space governance concerning issues such as jurisdiction and control over space objects and space activities;
- be aware of the actual and potential dual-use capabilities of space systems and the importance of maintaining as much transparency on intentions and activities as is practicable to allay concerns about the intent of space activities;
- strive toward the highest possible technical, market, and operational due diligence standards to make informed and responsible investment decisions;
- recognize the need to plan for the entire life-cycle of a space project and to make operational and financial provisions for the timely and safe disposal of orbiting assets when they reach the end of their operational life;
- link investment decisions to state-of-the-art best practices for the safety and sustainability of space activities;
- recognize that short-term investment decisions can have unpredictable, long-term consequences for the space environment;

- recognize that the operational and economic consequences of environmental disruption might be more significant in space than in other terrestrial industries;
- recognize that mistakes made, failed companies, and assets abandoned in space result not only in financial losses to the investor(s) concerned, but also in additional impacts on the domain, which could reduce the ability of others to have equitable access to a safe and stable space environment, diminish future space investment opportunities, and reduce the success of other space-based endeavors.
- recognize that investing responsibly in a space company means making operational and financial provisions for the safe and timely transfer or disposal of all orbiting assets should that company fail;
- promote the principles of responsible investing among other space investors.

Sustainability will play an important role in shaping the future of the space economy. Over the past few years, space sustainability has become a salient topic in space conferences as the larger established commercial space actors have started to recognize that profitability and sustainability of commercial space activities are intimately linked. The same recognition needs to extend to the investment community that is fueling the rapid expansion of the global space economy, much of it through financing startups. Once investors become aware of the importance of responsible and sustainable space investments, the focus will shift from whether to do sustainable and responsible investing to which sustainable and responsible space activities are available for investment. To avoid the appearance (or the fact) of “greenwashing” or hollow “virtue signaling,” sustainable and responsible space investment mandates must have clear goals, standards, and accountability. In this regard, the development and application of widely used space sustainability ratings or indexes would be helpful as investment allocations could be made based on the components of such a sustainability rating or index.⁹

8. Conclusion

We are at a historic tipping point in the industrial development of space, with new companies, products, and services being announced almost daily. From serving existing space markets to creating entirely new ones, the new space economy offers significant opportunities for investment and wealth creation. The staggering array of options for investment is both exciting and intimidating, because space investment lies at the nexus between what was not long ago deemed science fiction, and what is today technologically feasible, to create emerging markets and business opportunities. To paraphrase a famous line from the title sequence of the original *Star Trek* television series, it could be said that “space investors boldly go where no other investors have gone before.” This has given rise to much excitement about the potential of space to become the world’s next central economic driver for centuries to come. However, this excitement must be tempered by the realization that space is both a fragile and a strategic shared domain, and that humanity should not tread too heavily on the Earth’s orbital space environment. Doing so would endanger our current ability, and that of future generations, to use that environment as the driver of societal benefit and economic prosperity envisaged by many proponents of investment in the new space economy.

In this chapter, we have demonstrated the challenges to space sustainability that arise from the growing congestion in space, the proliferation of orbital debris, and the contestation of orbital resources by a growing number of space actors. We have also discussed the emergence of the concept of space sustainability and demonstrated the link between space sustainability and sustainable development on Earth. We have made the arguments that the long-term financial sustainability and profitability of commercial ventures in space depends on all space actors behaving in a responsible and sustainable fashion that does not harm the space environment, and that investors have an important role to play in shaping the behaviors of commercial space actors through responsible investment practices. We have described what constitutes such practices and provided the elements of a framework for making responsible investment decisions.

To date, most analyses of the potential growth of the new space economy (e.g., Crane et al. 2020) have addressed the financial sustainability of commercial space activities while overlooking the importance of responsible behaviors in space to ensure the sustainability of those activities from an environmental perspective. Space sustainability cannot be achieved through regulation alone because of the diversity of regulatory regimes across multiple jurisdictions and the proliferation of opportunities for access to capital. Investors have as much of a role to play as regulators in shaping responsible behavior through promoting and adhering to responsible investment practices.

p. 478 9. Epilogue—Toward a Circular Space Economy?

Our discussion in this chapter has been premised on the notion of the space economy being developed using resources sourced on Earth and launched into outer space. These resources are used to accomplish their task and are then abandoned in orbit, or they re-enter the atmosphere where they are vaporized. This, after all, is how space activities have been conducted since the beginning of the Space Age. But it stands to reason that we cannot continue such practices indefinitely, for two reasons.

First, the Earth's resources are finite, so if we are launching non-renewable mineral resources into space, we are diminishing access to those resources for future generations. The total mass of anthropogenic objects in Earth orbit as of June 2024 was around 12,400 metric tons. We are already seeing the emergence of commercial services to extend the operational life of satellites through on-orbit refueling and servicing. In the future, we can foresee the emergence of commercial services to reuse, repurpose, and ultimately recycle these resources in space that have already been lifted out of the Earth's gravity well.

The second reason why abandoning Earth's mineral resources in space and allowing them to re-enter the atmosphere may be unsustainable is that, with the deployment of very large satellite constellations, if atmospheric disposal to clear orbits becomes a norm, then we will soon be introducing into the Earth's atmosphere much higher quantities of certain minerals used in spacecraft construction than the natural flux from meteoric material over billions of years (Ferreira et al. 2022). The implications of this for upper atmosphere chemistry and phenomena such as climate change are not clear at this stage, but if research shows that the much greater rate of reentries expected in future may be harmful to the atmosphere, there will be societal, regulatory, and political pressure on the space community to develop alternatives to atmospheric disposal.

Together, these two factors could provide the impetus for the development of a circular space economy built on the basic principle of *Reduce–Reuse–Repurpose–Recycle*, which would provide plenty of additional responsible space investment opportunities.

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Notes

- 1 The notion of responsible investing has been around for centuries. Early manifestations were often driven by religious convictions, such as the Quakers forbidding their members from profiting from the slave trade and Muslims avoiding investment in companies with activities that are not permitted under Shariah law. However, with growing mass activism beginning in the 1960s, responsible investing has come of age, combining people power with the positive stewardship potential of capital. Sherwood and Pollard (2023) provide a brief overview of the historical evolution of responsible investing.
- 2 The confusion caused by the interchangeable use of these terms is exacerbated when responsible investing is referred to as “ESG investing.” The problem is that the acronym “ESG” means different things to different people, which has caused confusion among observers and has resulted in ESG supporters and skeptics often talking past each other. There are investors that focus exclusively on financial returns and only consider ESG issues that could impact those returns negatively. Other investors aim to generate profits and achieve positive outcomes for people and the planet, while avoiding negative impacts. These differences translate into a wide divergence in ESG ratings that makes progress measurement and peer-to-peer comparisons difficult (Berg et al. 2022). This confusion has led to a growing negative sentiment around the whole concept of ESG, especially among US investors. For this reason, in this discussion, we avoid the ESG framing and refer to responsible investment instead, taking the view that sustainability and prosperity are intimately linked.
- 3 On the face of it, orbital carrying capacity is about how many satellites can be placed in orbit to operate safely. But deeper analysis indicates that a much more nuanced approach is necessary. The physical number of objects that can be placed in space is so vast that it is not a binding constraint. The real limiting factor therefore isn’t what the space environment can physically sustain, but rather at what point the expected benefits from launching satellites no longer exceed the costs. The

- orbital dynamics aspects of the issue are discussed by Letizia et al. (2023) and the economic aspects by Rao and Rondina (2024).
- 4 Although our discussion focuses on near-Earth orbital regions, namely low Earth orbit, medium Earth orbit, and the geostationary orbit, the problem of orbital congestion will also apply to cislunar space as more countries and companies develop and send spacecraft to the Moon and beyond. Orbital regions of special significance in deep space and cislunar space, such as the Earth–Moon and Earth–Sun Lagrange points, as well as the few stable lunar orbits, will in time also become congested and contested.
 - 5 Indeed, space debris is completely indiscriminate and will follow the laws of orbital dynamics to impact any actor that crosses its path, whether friend or foe, including the actor that produced this debris in the first place. Moreover, in an era of proliferating satellite constellations, destroying one satellite in a network would confer a very limited advantage to one actor, but could potentially have long-term negative consequences for many other space actors. For this reason, debris-producing destructive anti-satellite weapons have limited military utility in an increasingly congested space domain.
 - 6 Ironically, the Brundtland Report, which preceded the Vienna Declaration by more than a decade and Agenda 2030 by 28 years, was prescient in its observation of the tie between sustainable development on Earth and the importance of preserving the space environment, but this connection does not seem to have been picked up in the later sustainable development discussions leading to Agenda 2030.
 - 7 The “tragedy of the commons” is a situation where numerous independent actors enjoy unfettered access to a finite, valuable resource (e.g., a pasture). If each user acts only in their own self-interest and takes as much of the resource as they can, they will tend to overuse it, and may end up destroying its value altogether. The basic idea was conceptualized by William Foster Lloyd in 1832 and named the “tragedy of the commons” by the biologist Garrett Hardin (1968).
 - 8 SpaceFund, an investment firm that invests in space startups, maintains the SpaceFund Reality Rating databases that rank startups in various types of space activities on a scale of 0–9. At the bottom end of the scale, a 0 represents very early-stage companies with little to no financing, limited teams, and no proof of concept for their technology, while the top end of the scale at 9 represents well-financed companies with proven technology, established product-market fit, and a well-rounded management team. The SpaceFund Reality Rating is accessible online at <https://spacefund.com/reality-rating/>.
 - 9 An example of such an index is the Space Sustainability Rating, developed under the aegis of the World Economic Forum by a consortium of partner entities. See <https://www.weforum.org/projects/space-sustainability-rating/>.